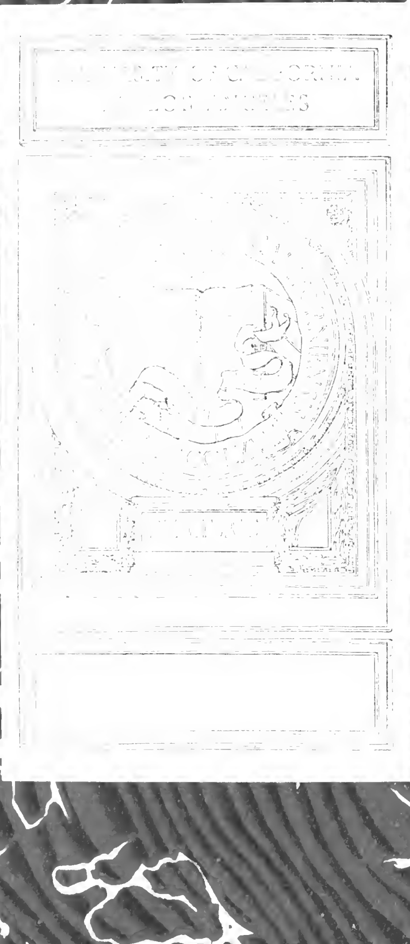

PRINCIPLE OF HOT WATER HEATING ILLUSTRATED BY TRANSVERSE SECTIONAL VIEW SHOWING BOILER, RADIATOR AND EXPANSION TANK.

American Radiator Company.

Cyclopedia

of

Engineering

A General Reference Work on

STEAM BOILERS, PUMPS, ENGINES, AND TURBINES, GAS AND OIL ENGINES, AUTOMOBILES, MARINE AND LOCOMOTIVE WORK, HEATING AND VENTILATING, COMPRESSED AIR, REFRIGERATION, DYNAMOS, MOTORS, ELECTRIC WIRING, ELECTRIC LIGHTING, ELEVATORS, ETC.

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Foreword

THE rapid advances made in recent years in all lines of engineering, as seen in the evolution of improved types of machinery, new mechanical processes and methods, and even new materials of workmanship, have created a distinct necessity for an authoritative work of general reference embodying the accumulated results of modern experience and the latest approved practice. The Cyclopedia of Engineering is designed to fill this acknowledged need.

¶ The aim of the publishers has been to create a work which, while adequate to meet all demands of the technically trained expert, will appeal equally to the self-taught practical man, who may have been denied the advantages of training at a resident technical school. The Cyclopedia not only covers the fundamentals that underlie all engineering, but places the reader in direct contact with the experience of teachers fresh from practical work, thus putting him abreast of the latest progress and furnishing him that adjustment to advanced modern needs and conditions which is a necessity even to the technical graduate.

¶ The Cyclopedia of Engineering is based upon the method which the American School of Correspondence has developed and successfully used for many years in teaching the principles and practice of Engineering in its different branches.

¶ The success which the American School of Correspondence has attained as a factor in the machinery of modern technical and scientific education is in itself the best possible guarantee for the present work. Therefore, while these volumes are a marked innovation in technical literature—representing, as they do, the best ideas and methods of a large number of different authors, each an acknowledged authority in his work—they are by no means an experiment, but are, in fact, based on what has proved itself to be the most successful method yet devised for the education of the busy man. The formulæ of the higher mathematics have been avoided as far as possible, and every care exercised to elucidate the text by abundant and appropriate illustrations.

¶ Numerous examples for practice are inserted at intervals; these, with the text questions, help the reader to fix in mind the essential points, thus combining the advantages of a text-book with those of a reference work.

¶ The Cyclopedia has been compiled with the idea of making it a work thoroughly technical yet easily comprehended by the man who has but little time in which to acquaint himself with the fundamental branches of practical engineering. If, therefore, it should benefit any of the large number of workers who need, yet lack, technical training, the publishers will feel that its mission has been accomplished.

¶ Grateful acknowledgment is due the corps of authors and collaborators—engineers and designers of wide practical experience, and teachers of well-recognized ability—without whose co-operation this work would have been impossible.

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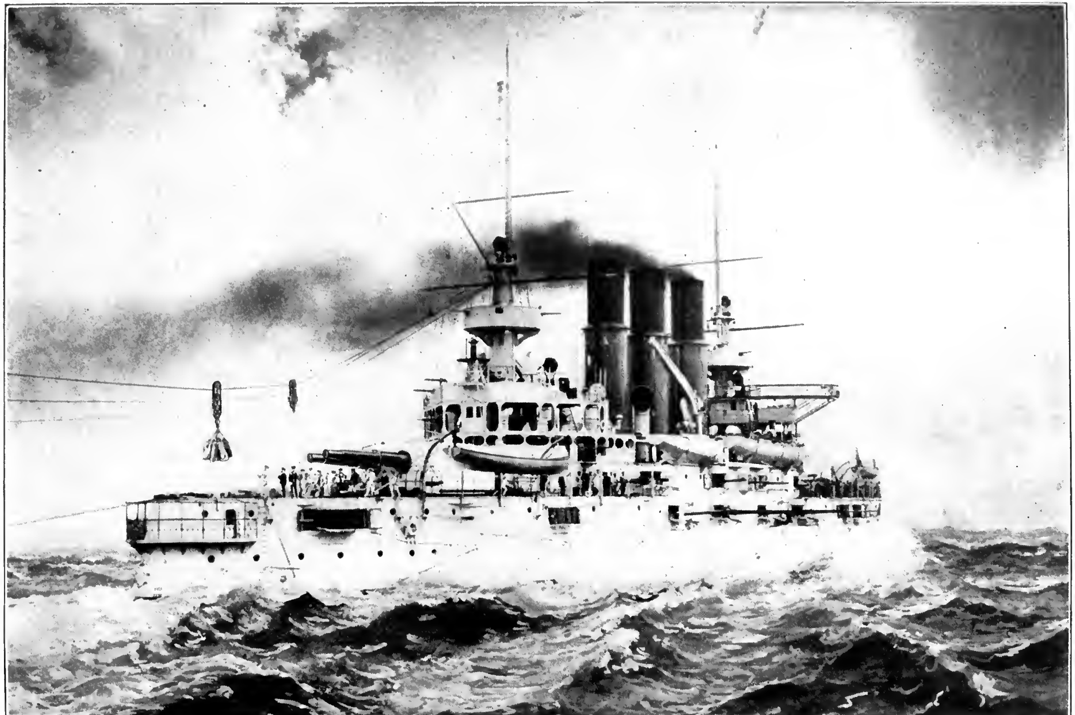


RUSSIAN BATTLESHIP RETVIZAN.

Sunk by Japanese Torpedo in first attack on Port Arthur, Feb., 1904, at outbreak of Russo-Japanese W

MARINE BOILERS.

The marine boilers now used may be divided into three distinct classes which in turn may be subdivided. These general classes are,

1. The rectangular or box boiler.
2. The cylindrical, or drum boiler.
3. The water-tube boiler.

THE RECTANGULAR BOILER.

The Rectangular Boiler shown in Fig. 1 is made square or box-shaped; hence the sides are flat. This form was one of the earliest used; at present, however, its use is restricted to low pressure, that is, under 30 pounds per square inch. The reason why this boiler cannot be used for high pressure is that the flat plates tend to bulge outward when under high pressure. In order to prevent the plates from bulging they must be stayed with numerous longitudinal and vertical stay rods.

Box boilers were generally made with an internal uptake as shown in Fig. 1. This construction permits of a larger steam space and reduces loss of heat by radiation. It is, however, expensive in first cost and repairs; also the plates of the uptake waste rapidly, especially near the water line, because the heat is not transmitted as readily by steam as by water. In case the uptake is made separate and does not form a part of the boiler, this objection is avoided.

The tubes of the rectangular boiler are usually horizontal or nearly so. When set inclined or with a "rake," as it is called, there is more room for manholes at the smoke-box end.

The extremities of the tubes at the combustion chamber end are near the furnace but are higher at the smoke-box end. The water level is about the same as with the horizontal tubes; the ends nearest the combustion chamber having the greater depth of water over them. The inclination is about one inch to the foot

Rectangular boilers were made in two ways, and from the form of construction were known as **wet bottom** and **dry bottom.** The wet bottom boilers were made with the furnace wholly inside and independent of the shell; the furnaces being surrounded by water on all sides. In the dry bottom boiler, the furnaces terminated in the boiler shell at the bottom, having a water space called

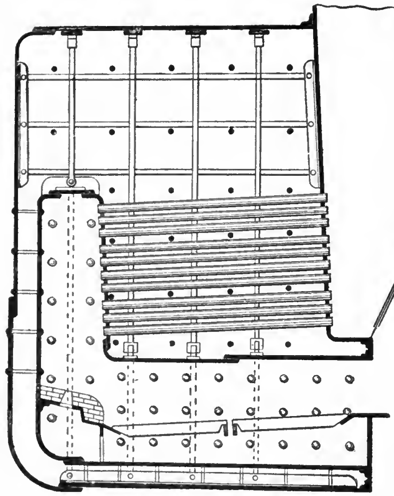


Fig. 1.

the water leg between them. This water leg causes trouble by getting filled up with sediment. A furnace had water around the sides but like the locomotive and most vertical boilers, there was no water underneath.

The dry bottom boiler is lighter, (as the bottom plates are omitted), cheaper, has greater durability and is easier to examine. On the other hand it is more dangerous to the ship, as the heat is likely to cause corrosion of the frames if of iron, or burn the frames if of wood. The wet bottom boiler is very difficult to inspect and repair.

In order to avoid the large number of stays in the steam space, for pressures over 30 pounds per square inch, the oval boiler was introduced. It has semi-cylindrical top and bottom and flat sides. This form was soon abandoned because it would stand only about 45 pounds pressure.

THE CYLINDRICAL BOILER.

Next after the oval boiler came the cylindrical. This boiler is made with the shell a complete cylinder. It is lighter, cheaper and more easily made than the rectangular. It occupies more space and for a given heating and grate surface has a smaller steam space. Cylindrical or Scotch boilers may be divided into three classes as follows:

1. Single ended boilers.
2. Double ended boilers.
3. Gunboat or through tube boilers.

THE SINGLE ENDED BOILER.

The single ended, return tube boiler, has furnaces and tubes only at one end. The arrangement of furnaces and flues is similar to that of the Lancashire boiler. The single ended marine boiler, shown in section in Figs. 2 and 3, is often made very large; sometimes 17 feet in diameter and 12 feet long.

The **shell** is made up of belts of wrought iron or mild steel. They are fastened together by being riveted where the edges overlap.

The **front** and **back** are made up of flat circular plates. The edges are flanged and riveted to the shell plates.

The **furnaces** are cylindrical, 3 feet to 4 feet in diameter and about 7 feet long. The front ends of the furnace flues are riveted to flanged holes in the front plate; the back ends are riveted to the combustion chamber. These flues are not made plain cylinders because a plain cylinder, unless small, cannot stand high pressure. Furnace flues are usually made with ribs or corrugations.

The **combustion chamber** is formed of flat and curved plates flanged at the edges and riveted together. The form is shown in Fig. 2. The flat sides are fastened to the back and shell plates by short stay bolts. The back tube sheet forms one side of this chamber. Since the space in the flues is small the combustion chamber is made sufficiently large to allow complete combustion of the hydro-carbons driven out of the fuel by the heat of the fire.

Grate Surface. The two lengths of grate bars, which form the grate surface, divide the furnace flues into two parts. The coal is burned on the bars, the fire occupying the portion above them. The space below the grate is called the **ash pit.** Air enters the ash pits and then passes up through the spaces of the grate bars to the coal.

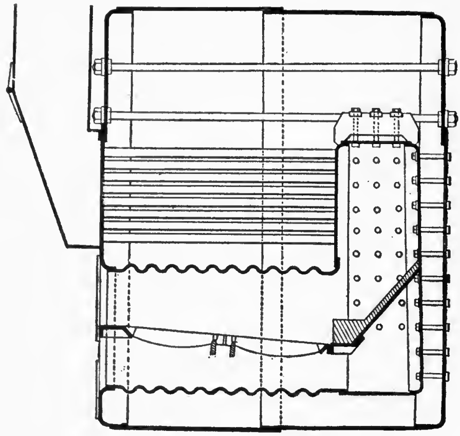


Fig. 2.

The furnace doors. The furnaces are fitted with doors through which fuel is supplied to the fire. The doors are usually provided with gratings which allow air to pass to the top of the fuel. The ash pit also has doors which are called **ash pit doors** or **draft plates.** These draft plates serve to regulate the supply of air to the ash pit. The furnaces, if corrugated, must be fitted with **ash pans** to enable the ashes to be drawn out readily. These ash pans protect the grates from wear caused by the constant use of the hoe.

Bridge. The back of the furnace is formed by the bridge, which is usually built of fire brick.

Tubes and Heating Surface. The tubes of the marine boiler are similar to those of the horizontal multitubular boiler. They are expanded into the front plate and the rear tube plate. The tubes form a large heating surface in a small space. The heating surface of the boiler is made up of the tubes, tops of furnaces, and top and sides of the combustion chamber. The tubes, however, furnish the greatest amount.

The **water level** is about 6 to 8 inches above the top row of tubes; the space above the water level is called the steam space and the part below, the water space.

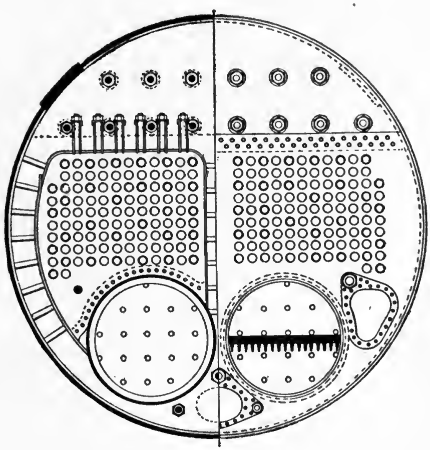


Fig. 3.

Stays. All the flat or nearly flat plates of the boiler and combustion chamber must be stayed to prevent bulging and collapsing. The flat ends above the water line are stayed by means of long stay rods, similar to those of a multitubular boiler. The ends are provided with large washers to distribute the pressure over a large area. The combustion chamber plates are supported by short stay bolts secured by nuts. The top plate of the combustion chamber is supported by girders or crown bars; sometimes called "dogs." The tubes act as stays for the tube sheets, but it is usual to put in a few tubes thicker than the rest, so that they may be screwed into the tube sheets and secured by thin nuts on both sides of the plate. The stay tubes of Fig. 3 are indicated by the heavier circles. Sometimes solid bars or blind tubes are used in place of stay tubes.

Manholes. For examining and repairing the interior of a boiler, manholes and handholes are provided where necessary. These manholes are similar to those of the multitubular boiler.

The **size and number of furnaces** depend upon the size and heating surface of the boiler. The large boilers usually have three or four furnaces and the smaller ones have two. Large furnaces are more efficient than small ones because the grate area increases directly as the diameter, while the air spaces above and below the grate increase as the square of the diameter. This greater space together with the greater inclination of the grate bars aids combustion. The length of the grate bars is nearly constant for all sizes of flue. It has been found by practice that furnace flues should be between 36 and 54 inches in diameter. Then boilers of one furnace may be made up to 9 feet in diameter, and those over 15 feet diameter should have four furnaces. The great difficulty in designing such large boilers is to provide sufficient grate area for the large heating surface; hence for large diameters four furnaces are used to avoid excessive length of grate.

The furnace flue leads to a combustion chamber from which the products of combustion return to the front of the boiler through the tubes to the uptake.

A single furnace boiler has one combustion chamber. A two furnace boiler may have a combustion chamber for each furnace or a common combustion chamber. In case there is but one boiler in the ship it is better to have two combustion chambers, so that in case a tube bursts the boiler will not be disabled. If, however, there are several boilers, it is better to have a common combustion chamber for the two furnaces, because the alternate stoking keeps up a more steady supply of steam and also consumes the smoke. Three furnace boilers usually have three combustion chambers and four furnace boilers generally have two. If three combustion chambers are used with four furnaces, the two more central furnaces lead to one only, while each of the outside furnaces has one. In designing a marine boiler the number and size of the flues is important. Large flues are likely to collapse under external pressure, but they allow a large grate. In using a greater number of smaller furnace flues instead of larger ones, the necessary grate area can be obtained.

THE DOUBLE ENDED BOILER.

This type of boiler has furnaces in both ends with return tubes over them similar to the single ended boiler. It is practically equal to two single ended boilers placed back to back but having the rear plates removed. By thus saving the extra weight of

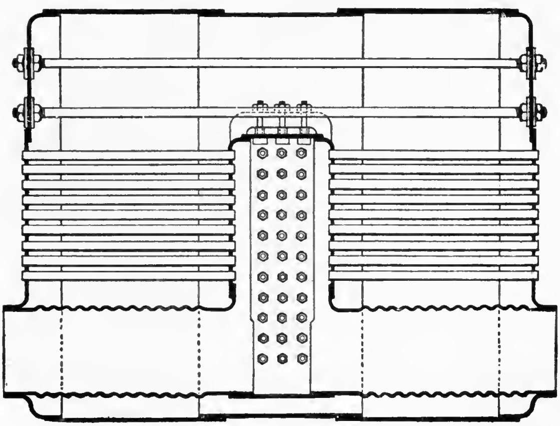


Fig. 4.

the back plates and reducing the radiating surface a double ended boiler is lighter and cheaper in proportion to the total heating surface than a single ended boiler. The double ended boiler is often made 18 feet in diameter and about 16 feet long. There are two distinct classes of double ended marine boilers; those having all the furnaces open into one combustion chamber and those having several combustion chambers.

The boiler with one common combustion chamber is not very common at present. If one furnace is being cleaned the whole boiler is cooled by the rush of cold air. This is the chief objection to its more general use.

A better form is that shown in Figs. 4 and 5. The opposite furnaces have a combustion chamber in common; that is, the combustion chambers, as in Fig. 5, are separated longitudinally by water spaces. Thus the boiler in Fig. 5 has three combustion chambers since it has three furnaces. This kind of boiler is considerably used because it avoids the faults of the single combustion

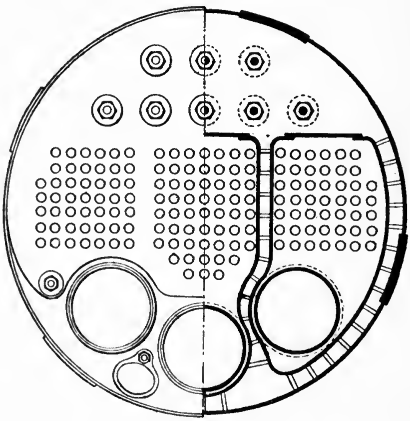


Fig. 5.

chamber but retains the good features of the double ended boiler. Considerable care is necessary when raising steam because the tubes are likely to leak on account of the unequal expansion of the tube sheet. A brick bridge wall called the arch or deflector built in the middle of the combustion chamber prevents the cold air from rushing against the opposite tube plate.

Another common form of double ended boiler has two combustion chambers. The furnaces at either end have a common combustion chamber; these latter being separated by a water space. The backs of the combustion chambers thus formed are large and flat, and on account of the large number of stays are difficult to clean. In vessels of the navy the boilers are generally made with a combustion chamber for each furnace. This form is shown in Figs. 6 and 7, which are sections of one of the boilers of the U. S. S. "Texas." This type is the heaviest and most expensive.

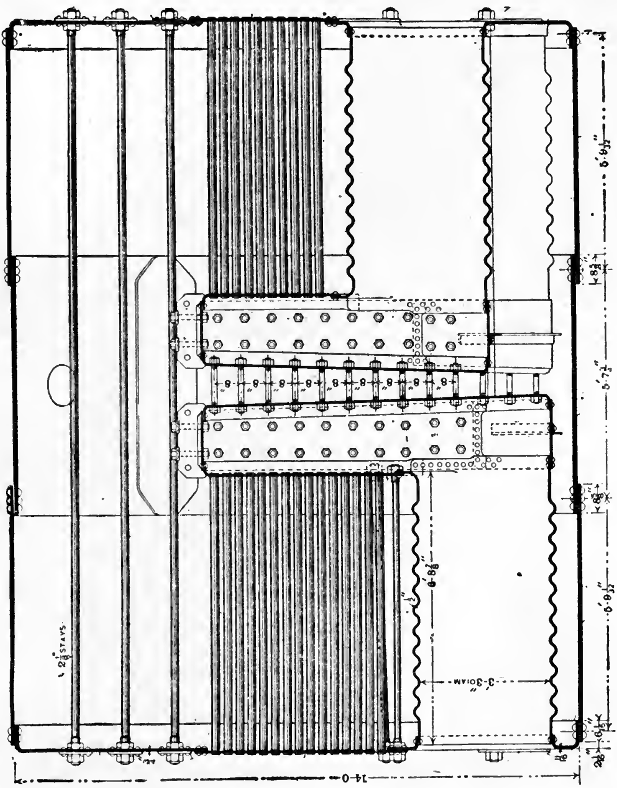


Fig. 6.

It is similar to two single ended boilers, as it has separate combustion chambers for each furnace.

GUNBOAT BOILERS.

In gunboats and other vessels of slight draft there is not sufficient room for a return tube boiler. The boilers used in these vessels are of a particular type and suited to the requirements. The boiler shown in Fig. 8 resembles both the cylindrical boiler and the locomotive boiler. It is cylindrical and in external appearance like the return tube boiler, except that it is longer

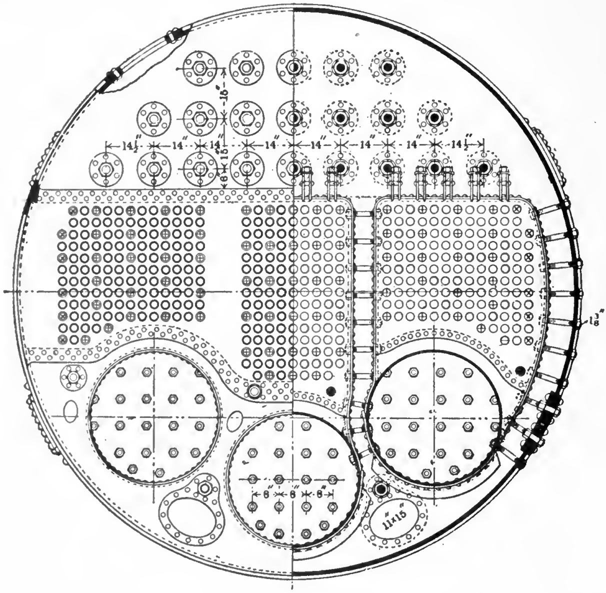


Fig. 7.

and of less diameter. The fire is in a flue which leads to a combustion chamber. The hot gases pass from the combustion chamber through a nest of small tubes to the uptake at the front. Sometimes a hanging bridge in the combustion chamber deflects and retards the hot gases. This boiler burns coal freely and evaporates water quickly and efficiently. The chief objections are the small heating surface for the space occupied and the great length.

Locomotive Boilers. This boiler was used for launches and torpedo boats. It was a convenient form and a very light boiler for the heating surface. With it forced draft was almost invariably used on account of the small grate area. The furnace crown, being flat, requires careful staying.

Let us leave the consideration of the water-tube boilers until we have finished the cylindrical.

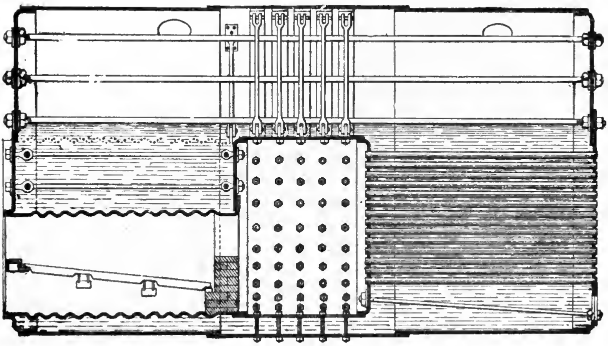


Fig. 8.

MATERIALS.

In marine work, the weight of boilers and engines is important. In the navy especially, the machinery must be as light as is consistent with strength. By using material that is very strong and durable the marine engineer is able to reduce the weight of the machinery. The great advance made within the last few years is largely due to the use of superior materials. Steel, which was formerly very scarce and expensive, is now made at such a slight cost that it is rapidly taking the place of iron for most engineering purposes.

The materials used for boilers are briefly described in "Construction of Boilers." The method of converting cast iron into wrought iron and steel and the various properties of these metals are discussed in "Metallurgy."

The *steel* used for boiler construction is made by the Bessemer and Siemen's processes. Experiment shows that the higher the tensile strength, the lower the elasticity. Steel for boiler shells usually has an elongation of about 15 to 25 per cent. and a tensile strength of 45,000 to 60,000 pounds per square inch. For the internal portions of the boiler, the material should be somewhat softer in order that it may be flanged and stand the wear and tear of manufacture.

In order to know that the materials have the proper qualities,

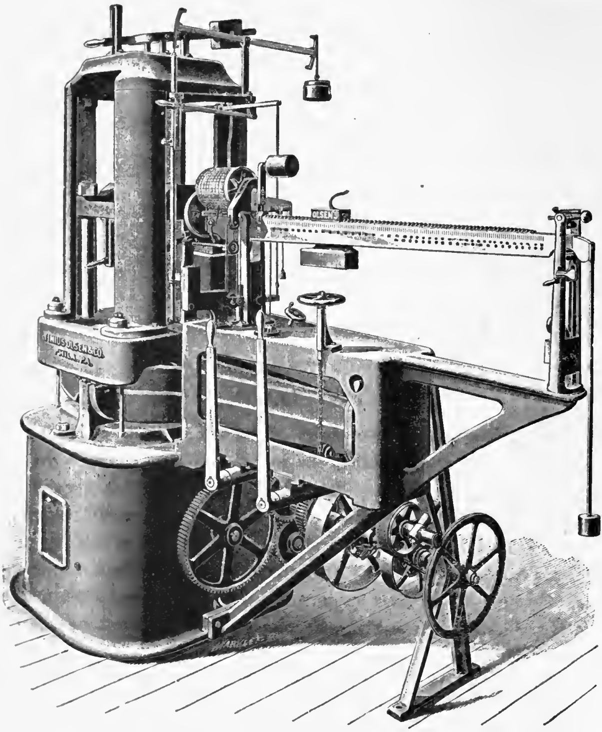


Fig. 9.

specimens are tested. The results of these tests show the ultimate tensile strength, elastic limit, contraction of area and elongation.

The simplest way to test a piece of iron bar or plate would be to fix it firmly at the upper end and hang weights on the other end, adding other weights until the bar is broken. This is but a crude method, and in order that the elastic limit and elongation may be determined with the tensile strength, testing machines are used. There are a large number of testing machines in use but the general principles are the same.

Testing Machines. The frame of a testing machine has two heads, to which the ends of the test piece are fastened by wedges or other devices. One head is drawn away from the other for tensile tests. The pull is transmitted to some weighing device, usually levers and knife edges like the beam of ordinary platform scales. The power causing the pull may be applied by a lever, by hydraulic power, or by steam.

Testing machines are made for all varieties of testing; tensile, compressive and shearing stresses. Also for deflection of beams and for strength of wood, cement, brick and stone. Fig. 9 shows an Olsen testing machine designed for tensile and compressive tests of iron and steel.

In order to test materials test pieces or specimens are made.

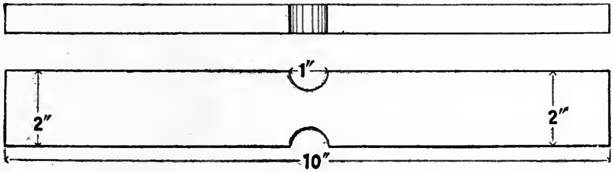


Fig. 10.

For testing **iron plate** the test piece should be at least one inch wide, about two feet long and planed on both edges. Many engineers recommend these dimensions; but, according to the Board of Supervising Inspectors of Steam Vessels, the test piece should be 10 inches long, 2 inches wide and cut out at the center, as shown in Fig. 10. According to their rules, the width of plate at this reduced section shall be 1 inch if the plate is $\frac{5}{16}$ inch or under; if any other thickness, the area of cross-section shall approximate $\frac{4}{10}$ of one square inch. It shall not exceed .45 square inch nor be less than .35 square inch. The force necessary to break the piece is taken as the proportionate part of the tensile strength per square inch. Thus if the test piece having a reduced section of .4 square inch is broken at 19,200 pounds, the tensile strength of the plate is $\frac{19,200}{.4} = 48,000$. If the tensile strength so determined equals the tensile strength as stamped on the plate, the plate can be used in the construction of marine boilers.

To ascertain the tensile strength and other qualities of **steel,** a test piece should be taken from each plate. These test pieces are made in the form as shown in Fig. 11. The straight part in the center is 9 inches long and 1 inch wide; and, to determine elongation it is marked with light prick punch marks at distances 1 inch apart; the marked space being 8 inches in length. The ends are from $1\frac{1}{2}$ to 2 inches broad and 3 inches to 6 inches long.

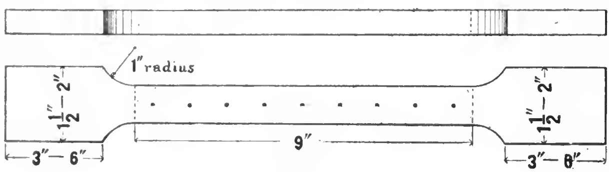


Fig. 11.

According to the Rules of the Board of Inspectors, the sample must show, when tested, an elongation of at least 25 per cent. in a length of two inches for a thickness up to and including $\frac{1}{4}$ inch. It must have the same per cent. of elongation in 4 inches if the plate is over $\frac{1}{4}$ inch to $\frac{7}{16}$ inch thick inclusive. For all plates over $\frac{7}{16}$ inch up to $1\frac{3}{4}$ inches thick the sample must show an elongation of 25 per cent. in 6 inches.

No iron or steel plate having a tensile strength of less than 45,000 pounds is allowed in the construction of any part of a marine boiler. Among other rules of the same Board are found the following:

"Iron of 45,000 pounds tensile strength shall show a contraction of area of 15 per cent. and each additional 1,000 pounds tensile strength shall show 1 per cent. additional contraction of area up to and including 55,000 pounds. Iron of 55,000 T. S. and upwards showing 25 per cent. reduction of area shall be deemed to have the lawful ductility. All steel plate of $\frac{1}{2}$ inch thickness and under shall show a contraction of area of not less than 50 per cent.

Steel plate over $\frac{1}{2}$ inch in thickness, up to $\frac{3}{4}$ inch in thickness shall show a reduction of not less than 45 per cent. All steel plate over $\frac{3}{4}$ inch thickness and less than $1\frac{3}{4}$ inches in thickness shall show a reduction of not less than 32.5 per cent."

"No plate shall contain more than .06 per cent. of phosphorous and .04 per cent. of sulphur, to be determined by analysis by the manufacturers."

"The samples shall also be capable of being bent to a curve of which the inner radius is not greater than $1\frac{1}{2}$ times the thickness of the plates after having been heated uniformly to a low cherry red and quenched in water of 82° F."

In testing material of other forms than plate, a stay rod for instance, it is better to test a sample of the whole forging if the testing machine is of sufficient capacity. If, however, the machine is too small the test specimen may be made in the form of a bar about 1 inch in diameter and 18 inches long having the central portion turned down to a diameter of about $\frac{5}{8}$ to $\frac{3}{4}$ of an inch. The turned portion should be about 9 inches long in order that the prick punch marks for determining elongation may be made as described with Fig. 11.

For testing the compressive strength of iron and steel it is usual to take a short cylinder of the material usually about an inch in diameter and a length equal to three diameters or less. If the specimens are long they will give way by bending rather than by crushing. In most commercial tests the elongation is taken as the indication of ductility, as the reduction of area can not be found as accurately without considerable difficulty.

In testing for tensile strength, the results calculated from the data are,

1. *Tensile strength* in pounds per square inch of original area.

2. *Elongation*, per cent. of a stated length (usually 8 inches), between gage marks.

3. *Elastic limit* in pounds per square inch of original area.

Stress. The number of pounds of force applied per square inch is called the stress. If the piece is under direct tension or compression the stress is considered uniform and is equal to the load divided by the area of the transverse section. Thus, if the section of the plate is 1″ by $\frac{7}{16}$″ and the actual stress is 17,750 pounds the stress per square inch is $\frac{17,750}{.4375} = 40,570$ (about) pounds.

Ultimate Strength. The maximum stress that a test piece will stand is called the ultimate strength. For ductile materials the breaking stress is considerably less than the ultimate stress. That is, when the loads are gradually applied the total load will reach a maximum and then the metal stretches so that at the moment of rupture the load is much less than the maximum. The strength of iron and steel depends somewhat upon the rate of testing; the more rapid the application the higher the stress as recorded by the scale beam.

Strain is the stretch per unit of length of the test piece when in tension. If the original length is L, and the stretch or elongation is B, the strain becomes $\frac{B}{L} = b$.

Elastic Limit. When testing a piece, at first the stress and strain are proportional. The point at which the strain or stretch begins to increase more rapidly than the stress is called the elastic limit. This limit is not definite; it can be determined approximately only. A load greater than the elastic limit will produce a permanent elongation.

Stretch Limit is the stress at which the scale beam of the testing machine will fall while the straining head is at rest.

Reduction of Area. When a test piece ruptures the area at that point is much less than the plate or bar before testing. This reduction shows the ductility of the material; it also shows the property of changing shape without actual rupture. This is important in boiler construction.

Elongation. Ductile materials stretch before breaking. To measure the ultimate elongation the two broken pieces are placed in a straight line with the broken ends in contact. The length between points can be measured. It is usual to use 8 inches as this distance. As the prick punch marks are made before testing, the elongation is easily determined. The ratio of the elongation to the original length is called the ultimate elongation. Suppose the distance between the extreme prick punch

U. S. BATTLESHIP ALABAMA.

Displacement, 11,525 tons; 11,366 horse-power; twin screws; 18 guns.

marks is 8 inches before testing and $9\frac{7}{8}$ inches after. Then the bar or plate has stretched $1\frac{7}{8}$ inches. The ultimate elongation is $1\frac{7}{8} \div 8 = .234$ or 23.4 per cent.

These various properties of materials may be shown by **diagrams.** Fig. 12 shows the diagram for wrought iron and steel when under tension. The unit stresses are taken as ordinates and the unit elongations as abscissas. For each stress the corresponding elongation, as found by the testing machine, is laid off. The curve is drawn through these points. Each specimen has its own curve, those shown in Fig. 12 being plotted from average values. Since stress and elongation are proportional up to the elastic limit, the curve from the origin to the elastic limit is a straight line.

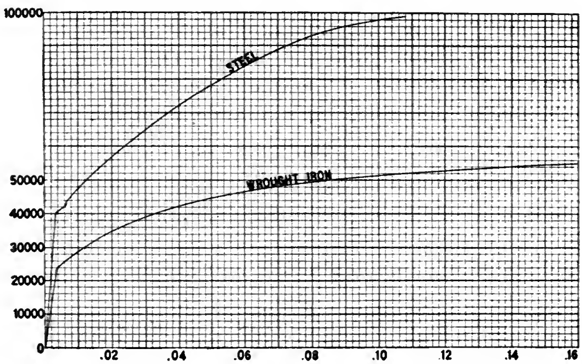


Fig. 12.

At the elastic limit the curve changes suddenly and the elongation increases rapidly. From the elastic limit to the point at which the piece breaks the stress is not proportional to elongation. The end of the curve indicates the point of rupture. Curves show the properties of various materials. It is seen that the elastic limit is not well defined but can be estimated very nearly. These curves may be plotted from results of tests or they may be drawn automatically by the testing machine.

Steel for boiler construction should have the following properties.

Tensile strength	50,000 to 60,000 lbs.
Elastic limit	30,000 to 35,000 lbs.
Reduction of area	50 per cent. or more.
Elongation in 8 inches	25 per cent. or more.

The mechanical tests are given in "Construction of Boilers."

BOILER CONSTRUCTION.

Shell. As the cylindrical boiler is the strongest form to resist internal pressure, it is most extensively used. For this reason we will consider the construction of the cylindrical Scotch boiler.

Boiler shells are composed of plates with riveted seams. If steel is used the plates may be placed either lengthwise or crosswise with the circumference; if of iron, the plates should be arranged so that the fibre will extend around the circumference as iron is stronger in the direction in which it is rolled.

RIVETING.

Rivets are made from bars of tough ductile iron or mild steel. These bars are cut to the proper length and each piece is placed in dies which form the tail. The tails of rivets are of various shapes depending upon the kind of riveting, the pan-shaped shown

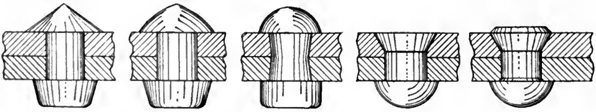


Fig. 13. Fig. 14. Fig. 15. Fig. 16. Fig. 17.

in Fig. 13, and the cup-shaped shown in Fig. 14 being the most common. The cylindrical portion called the shank is tapered for about one-half the length in order to enter the holes easily. The proportions of rivets vary and there are no standard sizes.

The heads of rivets are formed by knocking down the point of the shank with a hammer or by means of a riveting machine. Heads made by hand are usually conical or cup shaped, as shown in Figs. 13 and 15. Fig. 14 shows a conoidal headed rivet. Countersunk rivets are shown in Figs. 16 and 17. Rivets are tested mechanically as briefly described in "Construction of Boilers."

Circumferential or ring seams are usually **lap joints** since the tendency to rupture at these seams is only one-half as great as at the longitudinal seams.

These latter are usually double riveted and for high pressures treble riveted. Lap joints are constructed by making one plate overlap the other and riveting them together. Fig. 18 shows the most simple form of this joint and is called a single riveted lap joint. Double riveted lap joints may have the rivets arranged as shown in Figs. 19 and 20. The former joint is called a double riveted lap joint with chain riveting, and the latter a double riveted lap joint with zigzag riveting. The zigzag riveting is a little weaker than the chain, but the joint is usually tighter and less lap is required.

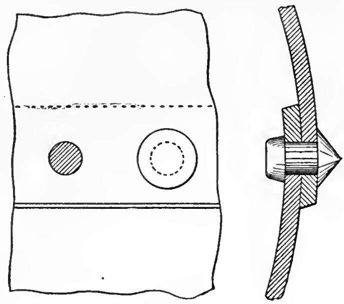


Fig. 18.

The *efficiency* of lap joints depends upon the pitch of the rivets, the diameter of the rivets, the thickness of plates and the number

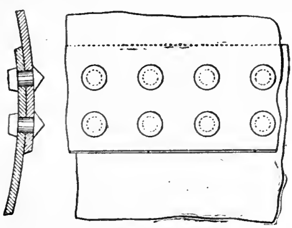


Fig. 19.

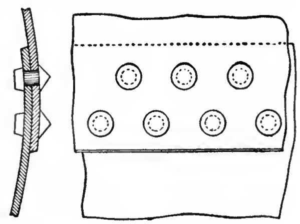


Fig. 20.

of rows. The efficiency is also somewhat altered if the plates are drilled instead of punched. As there are so many conditions we can give only rough average efficiencies.

Lap joint, single riveted, efficiency about 56%.
Lap joint, double riveted, efficiency about 70%.
Lap joint, treble riveted, efficiency about 72%.

The probable efficiency of joints may be calculated by mathematics, but the actual efficiency can be obtained only by means of the testing machine. In testing, a piece of uncut plate (the size of which depends upon the capacity of the machine) is first tested. Then a portion of the joint of approximately the same size is then tested. The ratio of the breaking strength of the joint to that of the uncut plate is the efficiency.

Longitudinal seams are almost always made with the **butt joint.** These joints are seldom single riveted because they

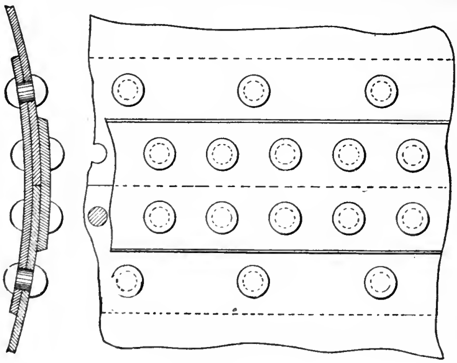


Fig. 21.

are no stronger than a double riveted lap joint and are more expensive. If, however, they are made with double butt straps and double or treble riveted, the joint shows a high efficiency. The two butt straps may be of the same width or the inner may be wider than the outer. Fig. 21 shows a double riveted butt joint with two butt straps. A treble riveted butt joint is shown in Fig. 22. The following are approximate efficiences:

Butt joints, single riveted, efficiency about 65%.
Butt joints, double riveted, efficiency about 75%.
Butt joints, treble riveted, efficiency about 85%.

Butt straps are usually about the thickness of the shell plates.

FLANGING.

End plates and nearly all the internal plates of a marine boiler are flanged. This operation is likely to weaken the plates, if not crack them. Ductile iron and steel can, with proper care and good machinery, be flanged with little danger of spoiling the plates. In flanging, the plates are heated locally which causes internal stresses to be set up; these stresses can be almost entirely removed by annealing. When flanging the holes for the furnaces in the end plate, care must be taken to prevent distortion of those flanged while the others are being operated upon. The danger is prevented if all the holes are flanged at once but this

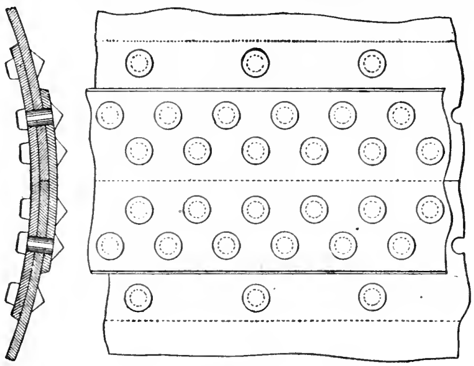


Fig. 22.

process requires heavy machinery. When flanging end plates the material is likely to become thin at the curved portions; to prevent this suitable moulds should be used and the heat regulated carefully.

STRENGTH OF SHELL.

The rules for the construction of the various parts of the marine boiler as given by engineers, writers and legislation do not agree. If a boiler is made in England it must conform to the rules of the Board of Trade or Lloyd's Registry. For boilers built in the United States the rules given by the Board of Supervising Inspectors of Steam Vessels must be followed. In the Navy, boilers are constructed from rules by the Naval Department or from a special act of Congress. The above rules differ somewhat, but all boilers must have parts which do not vary much from the requisite size.

As stated in "Construction of Boilers," the shell tends to rupture longitudinally; the resistance being the two sections of metal at the sides.

In "Construction of Boilers" we stated the following formulas for the strength of shell,

$$p = \frac{2\,t\,S\,E}{f\,D},$$

$$t = \frac{f\,D\,p}{2\,S\,E}.$$

p = working pressure in pounds per square inch.
t = thickness of shell in fractions of an inch.
S = tensile strength of material.
f = factor of safety.
D = diameter of boiler in inches.

This formula is the same as that given by the English Board of Trade.

Suppose a single ended Scotch marine boiler is 13 feet 6 inches in diameter. The shell plates are $1\frac{1}{32}$ inches thick and the joints have an efficiency of .81. If the tensile strength is 60,000 pounds and a factor of 4.5 is used what is the working pressure?

$$p = \frac{2\,t\,S\,E}{f\,D}$$

$$= \frac{2 \times \frac{33}{32} \times 60{,}000 \times .81}{4.5 \times 162}$$

$$= 137.5 \text{ pounds.}$$

The formula given by the Board of Supervising Inspectors of Steam Vessels is, using the notation above,

$$p = \frac{t \times 2 \times S}{6 \times D}.$$

Add 20 per cent. if the longitudinal seams are double riveted.

Then for the boiler whose dimensions are given above, the working pressure is,

$$p = \frac{\frac{33}{32} \times 2 \times 60{,}000}{6 \times 162}$$

= 127.3 and 20 per cent. additional gives $p = 152.76$.

This formula does not allow for the kind of joint, the only distinction being single and double riveting.

Factor of Safety. A steam boiler should be very strong in order to provide for defects in material and workmanship, wear and tear of manufacture, and when under steam, wasting by corrosion. For these reasons there should be considerable difference between the working pressure and the bursting pressure. This difference, or the ratio in which the bursting pressure exceeds the working pressure is called the factor of safety. When the material and workmanship is moderately good the factor may be about 6. In case the material is good, the boilers well made and cared for but not often inspected the factor should be about 5. If material and workmanship is high class, the boilers well made and regularly inspected the factor may be about $4\frac{1}{2}$. The factor should never be less than 4.

End Plates. There are several methods of connecting the end plates to the shell. Those methods which use a flanged end plate are by far the best. The flange is usually placed inward as

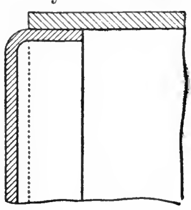


Fig. 23.

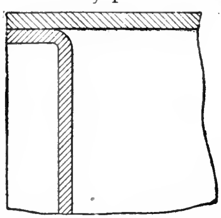


Fig. 24.

shown in Fig. 23; but for small boilers it is sometimes placed outside, shown in Fig. 24, to facilitate riveting. In some cases the shell plates are flanged. This has some bad features among which may be mentioned; the difficulty of flanging the thick plate, the tendency of the pressure to straighten out the flange and the low strength necessary for the desired ductility.

The quality of iron or steel for end plates depends upon the amount of flanging to be done. If the circular edges and the holes for the furnaces are to be flanged the material should be very ductile to prevent injury. The thickness of the end plates is less than that of the shell plates. It is dependent upon the pitch of the stays; the end is usually made up of two or three plates. As the pitch of the stays in the steam space is greater than that of the tubes the end plate of the steam space should be thicker than the tube sheet. However, they are often made the same thickness and the top plates stiffened by large washers. End plates are from $\frac{9}{16}$ to $\frac{3}{4}$ inch thick. Sometimes they are made thicker in order to avoid fitting nuts and washers to screw stay bolts, and the heavy reinforcing about manholes.

FURNACES.

In the rectangular boilers the furnaces were made square or rectangular having the corners rounded. This form is not suitable for high pressures so the furnaces of Scotch boilers are always made cylindrical as it is the best form to resist uniform external pressure. The furnace flues should be as thin as the external pressure will permit. Thick plates are more likely to blister and become injured by heat than thin ones. A mild quality of steel is perhaps the best material to use. It is important that the furnaces

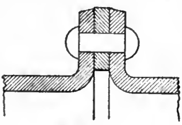


Fig. 25.

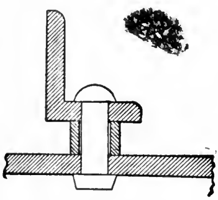


Fig. 26.

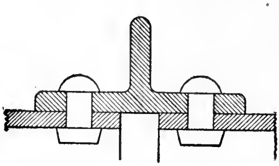


Fig. 27.

should be as nearly a true circle as possible, as any deviation causes a great increase of deformity through external pressure.

In "Construction of Boilers," Fairbain's formula for the strength of flues is given. The formula for long furnaces given by the Board of Supervising Inspectors of Steam Vessels is,

$$P = \frac{89{,}600 \times t^2}{L \times D},$$

in which P = working pressure in pounds per square inch, t =

thickness of flue in inches, L = length in feet and D = outside diameter in inches. In this formula L is not to exceed 8 feet.

In case the flue is made with rings riveted to the flue, L is taken as the distance between rings.

What is the allowable pressure on a furnace flue 6 feet long, 42 inches in diameter and $\frac{1}{2}$ inch thick?

$$P = \frac{89{,}600\ t^2}{L \times D} = \frac{89{,}600 \times .25}{6 \times 42} = 88.9 \text{ pounds.}$$

Furnace plates are made from $\frac{3}{8}$ inch to $\frac{3}{4}$ inch in thickness, $\frac{7}{16}$ to $\frac{9}{16}$ being common.

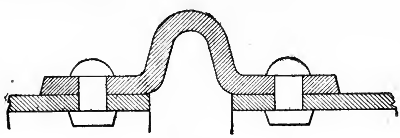


Fig. 28.

If $\frac{9}{16}$ inch is not sufficiently thick for the length some means of strengthening is employed.

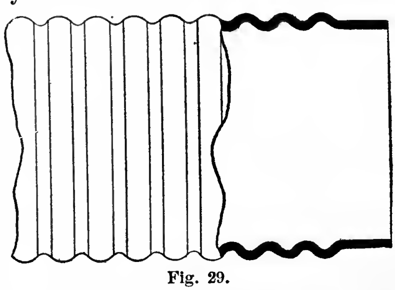


Fig. 29.

A section of Adamson's flanged seam is shown in Fig. 25. On the end of each belt external flanges are formed which are riveted together with a wrought iron ring between them. The radius of the flanges should not be less than $\frac{3}{4}$ inch and a greater radius is better. This form of joint makes the flue rigid circumferentially and elastic longitudinally. Fig. 26 shows the section of a ring made of angle iron. This ring is about 3″ × 3″ × $\frac{1}{2}$″. The ring is riveted to the flue at intervals; ferrules being placed between so that the water space is about 1 inch. Sometimes the ring is made in two parts and bolted together. Another method is to make them in one piece and weld the ends. The section of a welded ring of T iron is shown in Fig. 27. The ring is riveted to the ends of the flue sections which are not flanged. This method provides for calking on both inside and outside. Such a form of joint does not require flanging; but as flanging is easily done with modern machinery and all good boiler plate will stand it, these forms do not offer that advantage. The best form for longitudinal expansion is that shown in Fig. 28, called the bowling hoop ring.

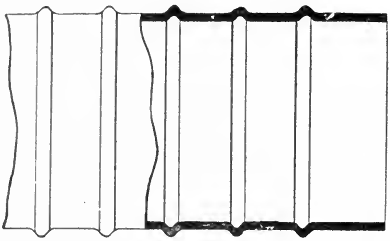


Fig. 30.

All these forms except the Adamson's ring have joints so arranged that the rivet heads are exposed to the fire. They have also the disadvantage of the projecting rings which prevent the flues from being placed near the shell plates.

To overcome the above disadvantage, the furnace flues are forged with **corrugations** or ridges. Perhaps the most used form is that called the Fox furnace shown in Fig. 29. These corrugations are about 6 inches center to center and $1\frac{1}{2}$ inches deep. Another form of furnace is the Purves, shown in Fig. 30. The

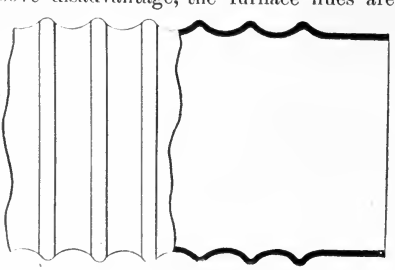


Fig. 31.

The Morison furnace is shown in Fig. 31, and the Holmes in Fig. 32. These furnace flues are made on the principle of the bowling hoop but with the hoop not separate from the plates. The Holmes has few corrugations and is rigid longitudinally but is not as strong to resist pressure as the Fox; consequently the latter may be made thinner than the former. A corrugated furnace has about 25 per cent. more heating surface than the plain flue. On account of the expansion and contraction, scale is loosened from the corrugations of the Fox furnace; hence it is called a "self-cleaner" of scale.

The formula for the working pressure for these furnaces is,

$$P = \frac{C \times t}{D},$$

in which P = the working pressure, t = the thickness in inches, D = the outside diameter measured to the bottom of the corrugations and C = a constant.

C = 14,000 for Fox corrugations.
C = 14,000 for Purves corrugations.
C = 13,500 for Morison.
C = 8,800 for Adamson's rings.
C = 5,677 for plain flues three feet in length and between 16 and 40 inches diameter.

What is the necessary thickness of a Fox furnace 8 feet long, 40 inches in diameter, with a working pressure of 165 pounds?

$$P = \frac{C \times t}{D}, \qquad t = \frac{P\,D}{C}$$

$$t = \frac{165 \times 40}{14{,}000} = .47 \text{ inch.}$$

If the thickness is made $\frac{1}{2}$ inch the allowable pressure is 175 pounds, because,

$$P = \frac{C \times t}{D} = \frac{14{,}000 \times .5}{40} = 175.$$

According to the Board of Supervising Inspectors this formula applies only to those furnaces whose corrugations do not exceed 8 inches from center to center and the plain parts at ends is not more than 9 inches.

Methods of Connecting Furnaces to End Plates. Three forms of furnace connection are shown in Figs. 33 to 35. In Fig. 33 the furnace is flanged to meet the front. This is better than any form of angle iron but it has the defect that the pressure tends to open the joint. If this form is used the radius of flange should not be less than $1\frac{1}{2}$ inches. In Fig. 34 is shown the method of flanging the end plate inward to meet the furnace. This method gives a good appearance to the front of the boiler and allows space for manholes. Flanging the plate outward as shown in Fig. 35 is used more for small boilers. For this flanging the plates must be of good quality. Mild steel is the best material, as it can be flanged readily.

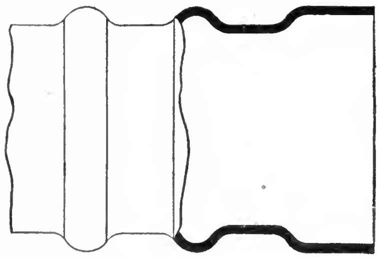


Fig. 32.

The longitudinal joints of furnaces are usually welded. In case the joints are riveted, the butt joint with double straps and single riveting should be used. Steel furnaces are almost always welded.

COMBUSTION CHAMBERS.

The Combustion Chamber is the space into which the hot gases from the furnace pass and where the hydrocarbons are burned. Its volume depends upon the size of the furnace flues.

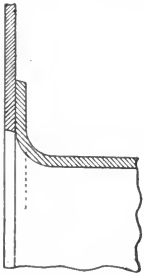


Fig. 33.

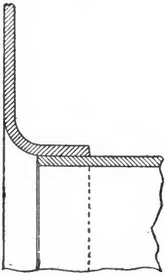


Fig. 34.

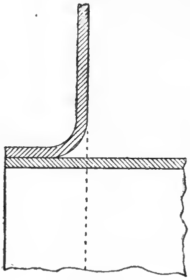


Fig. 35.

The capacity of this chamber above the grate bars is usually made about equal to the capacity of the furnace for a single ended boiler. For a double ended boiler having a combustion chamber common to opposite furnaces, the volume of the combustion chamber should equal three-fourths of the combined volumes of the two furnaces. In the single ended boiler the length of the combustion chamber is made about two-thirds of the furnace diameter.

The top plates of combustion chambers are generally flat in double ended boilers and either flat or curved in single ended. The flat tops require more staying than the curved, but they increase the volume slightly.

The side plates curve with the boiler shell as shown in Fig. 7. The front plate of the combustion chamber is the rear tube sheet; the back plate is flat and is nearly parallel to the back plate (if single ended) or arranged as shown in Fig. 6.

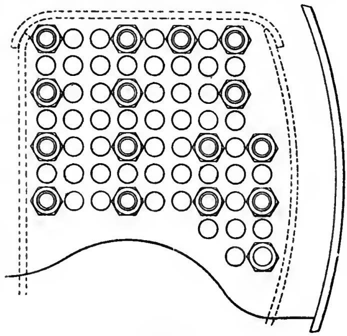


Fig. 36.

The plates of combustion chambers are from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch thick. The top and bottom plates are often made a little thicker to reduce the staying and to allow for wear. All joints of combustion chambers are made by riveting the flanged edges. The joints should be so arranged that no rivets or edges of plates are exposed to the direct action of flame, and also, so that there will not be a ledge formed upon which sediment may collect and cause corrosion.

TUBES.

The tubes for marine boilers are made of wrought iron or steel and are from $2\frac{1}{4}$ to 4 inches in external diameter. The length varies from 25 diameters for natural draft to about 40 diameters for forced draft. In boilers of the U. S. Navy the tubes are about $2\frac{1}{2}$ inches in diameter and $6\frac{1}{2}$ to 7 feet long. The thickness of the tubes depends upon the material and the diameter. The table on page 32 gives the principal dimensions of lap-welded wrought iron boiler tubes. Steel tubes can be obtained "solid drawn," that is, without any joint. The tubes are often made

LAP WELDED BOILER TUBES.

External Diameter. Inches.	Internal Diameter. Inches.	Thickness. Inches.	Internal Circumference. Inches.	External Circumference. Inches.	Internal Area. Square Inches.	External Area. Square Inches.	Length of tube per sq. ft. inside. Feet.	Length of tube per sq. ft. outside. Feet.	Weight per foot. Lbs.
1	.856	.072	2.689	3.142	.575	.785	4.460	3.819	.708
1¼	1.106	.072	3.474	3.927	.960	1.227	3.455	3.056	.900
1½	1.334	.083	4.191	4.712	1.396	1.767	2.863	2.547	1.25
1¾	1.560	.095	4.901	5.498	1.911	2.405	2.448	2.183	1.665
2	1.804	.098	5.667	6.283	2.556	3.142	2.118	1.909	1.981
2¼	2.054	.098	6.484	7.069	3.314	3.976	1.850	1.698	2.238
2½	2.283	.109	7.172	7.854	4.094	4.909	1.673	1.528	2.755
2¾	2.533	.109	7.957	8.639	5.039	5.940	1.508	1.390	3.045
3	2.783	.109	8.743	9.425	6.083	7.069	1.373	1.273	3.333
3¼	3.012	.119	9.462	10.210	7.125	8.296	1.268	1.175	3.958
3½	3.262	.119	10.248	10.995	8.357	9.621	1.171	1.091	4.272
3¾	3.512	.119	11.033	11.781	9.687	11.045	1.088	1.018	4.590
4	3.741	.130	11.753	12.566	10.992	12.566	1.023	.955	5.32
4½	4.241	.130	13.323	14.137	14.126	15.904	.901	.849	6.01
5	4.720	.140	14.818	15.708	17.497	19.635	.809	.764	7.226
6	5.699	.151	17.904	18.849	25.509	28.274	.670	.637	9.346
8	7.636	.182	23.989	25.132	45.795	50.265	.500	.478	15.109
10	9.573	.214	30.074	31.416	71.975	78.540	.399	.382	22.190
12	11.542	.229	36.260	37.699	103.749	113.097	.330	.318	28.516
16	15.458	.271	48.562	50.265	187.667	201.062	.247	.238	45.200
20	19.360	.320	60.821	62.832	294.373	314.159	.197	.190	66.765

slightly larger at the front end in order that they may be easily removed; about $\frac{1}{16}$ inch greater diameter is sufficient.

Tubes are usually expanded in the tube sheets as explained in "Construction of Boilers." The tubes are usually arranged in horizontal and vertical rows and not staggered. In the same boiler it is well to have about the same number of tubes for each furnace.

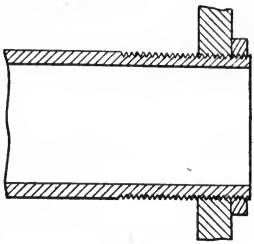


Fig. 37.

The tube sheets are usually from $\frac{9}{16}$ inch to $\frac{3}{4}$ inch thick. In large boilers with high pressure the tube sheet may be $\frac{7}{8}$ inch thick.

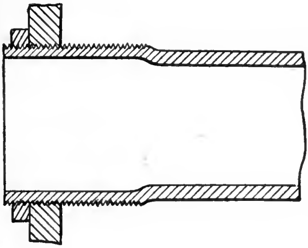


Fig. 38.

Stay Tubes. In order to prevent the tube sheets from bulging, thereby causing leaks at the tube ends, a few of the tubes (Fig. 36), are fitted as stay tubes. These tubes are made of the same external diameter as the ordinary tubes but of greater thickness. This extra thickness allows threads to be cut on the ends and rivets fitted. There are usually 14 threads per inch. Stay tubes are usually about $\frac{1}{5}$ inch thick; the threads may be formed on the tube as shown in Fig. 37, or the end may be made larger as shown in Fig. 38. Frequently the threads are cut at both ends; both tube plates are tapped and the tubes screwed in. When both ends are threaded one end must be smaller than the other so that it may be slipped through the hole. The back end is beaded over or nutted and the front end fastened with shallow nuts. Sometimes two nuts are placed on the front end; one inside and one outside of the boiler plate.

STAYS.

All plates of a boiler that are not cylindrical or hemispherical must be stayed. This is done by means of rods called stays. There are many methods of staying; the same flat surfaces of one boiler even may be stayed in different ways. The stays for each boiler are designed especially for that boiler according to the experience and judgment of the engineer.

Stay bolts. The back and side plates of the combustion chamber of the cylindrical return tube marine boiler are flat or

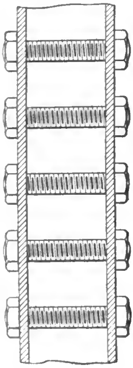


Fig. 39.

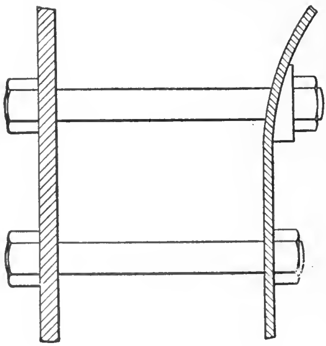


Fig. 40.

nearly so. These plates are stayed to the sides and back of the boiler by means of short screw stay bolts which are turned down in the center. These bolts are screwed in place, calked, and then fastened by shallow nuts as shown in Fig. 39. The nuts should be of about the same thickness as the plates ; also they should be set up tight without any washers, lead, or cement. In some cases, however, a beveled washer is necessary ; this is shown in Fig. 40. Whenever these washers are used the taper should be slight.

The number of stays depends upon the working pressure, thickness of plate and the pitch of the stays. They are usually arranged in horizontal and vertical rows. The short screw stays are from $1\frac{1}{8}$ to $1\frac{1}{2}$ inches in diameter and are supplied with a fine thread. The pitch of the screw threads varies a little; a fine thread gives a large effective diameter but if the plates bulge between the stays only a few threads remain in contact with the plate. This difficulty is largely overcome by nuts.

An equation for determining the distance between the stays is,

$$a^2 = \frac{9\,t^2\,S}{2\,p}$$

AFTER-DECK OF H. B. M. S. *ROYAL SOVEREIGN*.

Showing 17-inch armor barbette.

in which a = distance between stays, t = thickness of the plate, S = stress in the plate, and p = working pressure.

Suppose the plates are $\frac{5}{8}$ inch thick, the working pressure is 160 pounds and the stress is 5,500 pounds, then,

$$a^2 = \frac{9 \times (\frac{5}{8})^2 \times 5{,}500}{2 \times 160}$$
$$= 60.42 \text{ sq. in.}$$
$$a = 7.77 \text{ inches.}$$

The Rules of the Board of Supervising Inspectors of Steam Vessels give the following. For plates $\frac{7}{16}$ inch and under to find the working pressure, multiply 112 by the square of the thickness in sixteenths and divide the product by square of the pitch of the stays.

Example. Plates $\frac{7}{16}$ inch thick and the stays 6 inches apart; what is the working pressure?

$$\frac{112 \times 49}{36} = 152.44 \text{ pounds.}$$

For plates over $\frac{7}{16}$ inch thick the constant is 120 instead of 112.

Example. Plates $\frac{5}{8}$ or $\frac{10}{16}$ inch thick and the stays 8 inches apart; what is the working pressure?

$$\frac{120 \times 100}{64} = 187.5 \text{ pounds.}$$

If the stays have nuts on both the inside and outside of the plates, the constant is 140.

Example. Plates $\frac{9}{16}$ inch thick and the bolts 10 inches apart; what is the working pressure?

$$\frac{140 \times 81}{100} = 113.4 \text{ pounds.}$$

Through Stays. The flat ends of cylindrical boilers are stayed in many different ways. We have seen how the back plates are stayed to the combustion chamber by short screw stays; also that the tube sheets are held together by the tubes, a few of which are fastened with nuts. In the steam space are placed through stays or diagonal stays. Most marine boilers are short; therefore, the through stays are generally used. These stays are usually plain rods $1\frac{1}{4}$ to $2\frac{1}{2}$ inches in diameter. The ends are fastened to the plates by nuts and washers as shown in Figs. 41 and 42. The large washers are used to secure a greater bearing surface; they are usually riveted to the end plates.

These stays being in the steam space should be at least 14 inches apart so that a man can pass between them. The threads at the ends may be cut on the plain rod or the ends may be forged larger and the threads cut on the enlarged part. In order to reduce the number of stays the heads of the boiler may be curved as shown in Fig. 43. This form reduces the volume of the steam

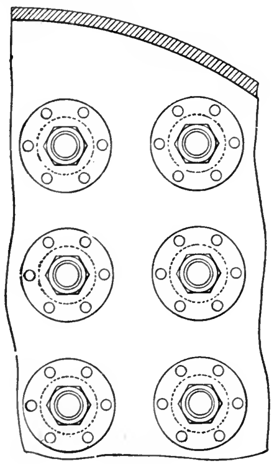


Fig. 41.

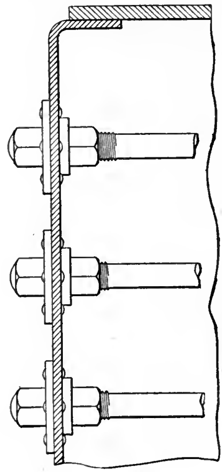


Fig. 42.

space but gives a stronger boiler. This construction is used in the U. S. Navy to some extent.

The size and number of through stays depends upon the pressure and the thickness of the plates. The spacing of the stays depends upon the size and form of the particular boiler. The diameter of the stays should be calculated to give a section sufficient to bear the load. Stays should not have a load of more than 6000 pounds per square inch if of wrought iron, and 9000 if of steel.

For long boilers the flat ends may be stayed to the shell plates by means of diagonal or gusset stays as described in "Construction of Boilers."

Girders. The tops of the combustion chambers are generally flat. To support this flat surface the girder or crown bar is used. The usual forms have been discussed in "Construction of Boilers."

The English Board of Trade give the following formula for calculating the working pressure,

$$\frac{C \times d^2 \times T}{(W - P)\, D \times L} = \text{working pressure}$$

W = width of combustion chamber in inches.
P = pitch of bolts in girder.
D = distance between girders from center to center in inches.
L = length of girder in feet.
T = thickness of girder in inches.
N = number of supporting bolts.
d = depth of girder in inches.

$$C = \frac{N \times 1000}{N + 1}, \text{ if the number of bolts is odd.}$$

$$C = \frac{(N + 1)\, 1000}{N + 2}, \text{ if the number of bolts is even.}$$

DIMENSIONS OF A BOILER.

The **diameter** of a return tube cylindrical boiler is largely dependent upon the necessary grate area. The diameter of a furnace is limited on account of the danger of collapsing; the length of the grate is also limited. Hence to increase the grate area there must be more furnaces. If another furnace is added the diameter of the boiler must be increased.

In order to fix the **area of the grate** the amount of steam required per hour should be known, at least approximately. One pound of good coal will evaporate 10 pounds of water in an ordinary marine boiler. If the coal is of ordinary quality only about 8 pounds of water can be evaporated per pound per hour. The amount of coal burned per square foot of grate (natural draft) is about 20 pounds; with good stoking 25 pounds.

Hence, for good conditions (natural draft) the amount of water evaporated per square foot of grate is $10 \times 25 = 250$ pounds. From this the size of the grate can be calculated. Thus, if the engine uses 15,000 pounds of steam per hour and the evaporation is 250 pounds per square foot, the total grate area must be $\frac{15,000}{250} = 60$ square feet. Then if the furnaces are 40 inches in diameter and the grate bars are 6 feet long, the number of furnaces would be, $\frac{60}{6 \times 3\frac{1}{3}} = 3.$

If forced draft is used the number of pounds of coal burned per square foot per hour may be greatly increased; the amount being from 25 to 75 pounds. This increases the evaporation per square foot and consequently the grate area can be reduced.

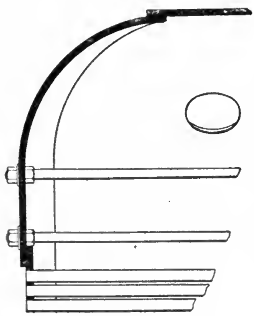


Fig. 43.

Heating Surface. All surfaces of the boiler, which transmit heat to the water, are heating surfaces. In calculating the total heating surface of a marine boiler, the sum of the following parts is taken.

Furnace. The surface of the upper half of the furnace; or the part above the level of the grate bars.

Combustion Chamber. The part above the level of the bridges, including the actual area of the back tube plate.

Tubes. The external surface of the tubes measured between the tube sheets.

The front tube sheet is not considered heating surface.

The total heating surface of marine boilers is from 25 to 38 times the grate area. For U. S. battleships and cruisers it is from 30 to 35.

The area of the tubes is about .85 of the total heating surface.

Area through Tubes. The combined internal area of the tubes, or the area through which the hot gases and smoke pass to the uptake, is generally from $\frac{1}{7}$ to $\frac{1}{5}$ the area of the grate. Too small an area checks the draft, especially if the tubes have become choked with soot and ashes. Too large an area permits a slow velocity of the gases, which, although it gives time for heat to pass to the water, also allows soot and dust to form in the tubes and reduce evaporative efficiency.

Steam Space. The distance from the top row of tubes to the top of the shell is generally from .25 to .30 of the boiler diameter. If the tubes are too high the steam space will be contracted and the water surface reduced. Priming may be caused by too small a water surface as well as by a contracted steam space.

The necessary volume of the steam space depends upon the amount of steam used in a given time. If the steam space is small the admission of steam to the cylinders is likely to cause a drop of pressure in the boiler, which in turn causes a rapid evaporation at the time. Excessive ebullition causes priming. A slow speed engine, which takes steam at intervals, requires a larger steam space in the boiler than does a high speed screw engine which uses steam at such frequent intervals that the flow is nearly constant.

The volume of the steam space varies with different conditions. For fast running screw engines there should be about $\frac{1}{2}$ cubic foot per I. H. P. of the engine. This space may be made much less if forced draft is used. Volume of steam per stroke and not weight determines the size of the steam space, hence the higher the pressure the less the steam space.

Water Spaces. The spaces between the various parts of the boiler should be sufficiently large to allow good circulation. The spaces between nests of tubes should be 10 or 12 inches in order that a man may enter and clean the tubes. Between the furnaces and between the furnaces and shell the space should not be less than 6 inches. The space between the back plates of the combustion chamber and the shell, or the back plates of the combustion chambers if double ended, should taper from about 6 inches at the bottom to about 9 or 12 inches at the top. The larger space at the top is for the greater volume of the heated water and steam. If spaces are less than 6 inches they are hard to clean and the circulation is likely to be poor.

Size of Boiler. Now that the area of tubes, size of grate, area of heating surface, volume of combustion chamber and steam space are known, the size of the boiler can be determined.

In general, the boiler should have $1\frac{3}{4}$ to 2 cubic feet of volume per I. H. P. for natural draft and $1\frac{1}{4}$ to $1\frac{1}{2}$ for forced draft. However, no fixed rules can be given, as each boiler is designed for the given conditions and these may vary considerably. Low pressure demands a larger boiler than high pressure. Boilers for ships in merchant marine and those designed for long voyages have large boilers.

Area of Uptake and Funnel. In determining the size of the funnel many conditions are considered. The funnel is often designed to suit the appearance of the ship. Some engineers prefer a small high funnel while others have a tendency to use a short funnel of large diameter. The best diameter is fixed by rules based on successful practice.

The area of the funnel is from $\frac{1}{8}$ to $\frac{1}{6}$ that of the grate. In the navy the funnels are made as small as possible for obvious reasons. The principal reasons for reducing the size of the funnel in the merchant marine are wind pressure, cooling action of wind and appearance. A funnel $\frac{1}{5}$ to $\frac{1}{6}$ the area of the grate and whose top is about 40 feet above the grate will generally give good results.

When forced draft is used the funnel may be made shorter and smaller. In the navy the top of the funnel is about 75 feet above the grate. Funnels are usually circular in section but sometimes are made oval. They are made of plate iron with lap or single butt joints, the butt strap being on the inside. The plates should be thicker at the bottom than at the top. For naval vessels the funnel plates are usually of steel and are made as light as possible.

Manholes. Manholes and handholes are very similar; the chief difference being that of size. The uses and general construction has been described in "Construction of Boilers." There should be one or more manholes of a size at least 12 × 15 inches in every marine boiler. There is usually one in the shell, in the steam space; two or more are usually placed in the end of a single ended boiler and in each end if the boiler is double ended. The hole cut in the plate should be strengthened by a plate or ring to compensate for the metal cut out. Another way is to flange the plate inward; the flange stiffening the plate and forming a good face for the door joints. The doors are placed inside the boiler and are held in place by crossbars called "dogs." Sometimes a large manhole cover is fitted externally and held in place by bolts.

The Rules of the Board of Supervising Inspectors state that all manholes for the shells of boilers over 40 inches in diameter shall have an opening of at least 11×15 inches in the clear. Also: Manhole openings, flanged, invariably should have a depth and thickness of flange to furnish as many cubic inches of material as was removed from the plate to form the opening.

In order to show the principal dimensions of a boiler, and the proportions of the various parts, the following description and table is given. It states in detail the dimensions of one of the main boilers of the U. S. battleship "Massachusetts," which is one of the most recent and most powerful battleships of the Navy.

There are four double ended main boilers and two single ended auxiliary boilers. All the boilers are of steel and of the horizontal fire-tube type. Each main boiler has eight furnaces; four in each end. The auxiliary boilers have four furnaces in each. The shell of the main boiler is made of three courses of three plates each; the rivets being $1\frac{1}{4}$ inches in diameter. The longitudinal joints are treble riveted with double butt straps. The circumferential seams are double riveted lap joints. The joints of the combustion chambers are single riveted. The heads of the main boilers are flat but those of the auxiliary boilers have curved end plates. The radius of the curve is 2 feet $2\frac{1}{2}$ inches at the front end and 2 feet $1\frac{39}{64}$ inches at the back end. The furnaces are fitted with Cone's patent shaking grate bars.

The circulation, while starting the fires, is obtained by means of Weir's hydrokineters. Each boiler has 4 safety valves, $3\frac{1}{2}$ inches in diameter, on one base.

All the tubes are of steel. There are two main smoke pipes and two auxiliary smoke pipes, the latter within the former. The mechanical draft is obtained by means of Sturtevant blowers and the closed fire-room system.

BOILERS OF THE U. S. S. "MASSACHUSETTS."

FOUR DOUBLE ENDED CYLINDRICAL BOILERS.

DETAILS OF ONE BOILER.

Working pressure	160 pounds
Length	18 feet
Diameter	15 feet
Thickness of shell	$1\frac{19}{64}$ inches
Thickness of heads, top	1 inch
Thickness of heads, bottom	$\frac{3}{4}$ inch
Thickness of tube sheets	$\frac{5}{8}$ inch

FURNACES.

Number in each boiler	8
Thickness	$\frac{1}{2}$ inch
Greatest external diameter	3 feet 4 inches
Least internal diameter	3 feet
Length of grate	5 feet 9 inches

COMBUSTION CHAMBERS.

Number	4
Thickness of plate	$\frac{9}{16}$ inch
Width at top	2 feet $5\frac{3}{8}$ inches
Depth	7 feet $2\frac{5}{8}$ inches

TUBES.

Outside diameter	$2\frac{1}{2}$ inches
Length between tube sheets	6 feet $1\frac{1}{4}$ inches
Number, ordinary	676
Number, stay	248
Thickness, ordinary 12 B. W. G.	.109 inch
Thickness, stay 6 B. W. G.	.203 inch
Spaced vertically	$3\frac{1}{2}$ inches
Spaced horizontally	$3\frac{3}{4}$ inches

STAYS.

Diameter of screw stays	$1\frac{17}{64}$ inches
Number of through braces (upper)	24 of $2\frac{1}{4}$ inches diameter 3 of $2\frac{1}{2}$ inches diameter
Number of through braces (lower)	3 of $1\frac{3}{4}$ inches diameter
Number of braces around lower manhole	12 of $1\frac{3}{4}$ inches diameter
Number of braces from head to back tube sheets	20 of 2 inches diameter

HEATING SURFACE.

Tube	3647.5 square feet
Furnace	245 square feet
Combustion chambers	418 square feet
Total	4,310.5 square feet
Grate surface	138 square feet
Area through tubes	25.13 square feet
Area over bridge walls	15.56 square feet
Volume of furnace and combustion chamber above grates	559.93 cubic feet
Volume of steam space, water level 6 inches above top tubes	737.41 cubic feet
Water surface, water level 6 inches above top tubes	239.22 square feet

SMOKE PIPES. (TWO)

Diameter	7 feet
Total area	68.42 square feet
Height above lowest grate	70 feet

STOP VALVES.

Diameter of main stop valve	9 inches
Diameter of auxiliary stop valve	5 inches

TOTALS, FOUR BOILERS.

HEATING SURFACE.

Tubes	14,590 square feet
Furnaces	980 square feet
Combustion chambers	1,672 square feet
Total	17,242 square feet
Grate surface	552 square feet
Area through tubes	100.52 square feet
Area over bridge walls	62.24 square feet
Volume of furnaces and combustion chambers	2,239.72 cubic feet

RATIOS.

Tube H. S. to G. S.	26.43 : 1
Furnace H. S. to G. S.	1.78 : 1
Combustion chamber H. S. to G. S.	3.01 : 1
Total H. S. to total G. S.	31.24 : 1
Area through tubes to G. S.	.18 : 1
Steam room per square foot of grate	5.34 cubic feet

FURNACE DOORS.

The furnace doors for a marine boiler must be as simple as possible. They are often made of cast iron but wrought iron is better on account of the rough usage to which they are subjected.

Because of the rolling of the ship, there should be some device for holding the door open while stoking. Doors should be as small as possible so that the amount of cold air admitted while stoking and cleaning will be small. However, it must be large enough to stoke and clean the fires easily. When the furnaces are large two doors are advantageous because the amount of opening for stoking and cleaning is reduced and the sides of the grate more easily attended to. Doors should have a grid or damper for admitting air to the top of the fire.

A door made of a single plate is likely to get very hot, warp and even crack. In order to protect the door from the heat an inside plate or screen is bolted to the door. This plate is perforated with many small holes through which air passes. As the air circulates between the two plates, the door plate is kept comparatively cool; the screen may be replaced when burnt. All latches and contrivances for keeping the doors open should be very simple and strong and capable of being worked easily because the stoker's chief tool is the shovel.

Fire door frames are also injured by the intense heat and should be protected with a screen or fire brick.

GRATE BARS.

Although there are many patent grate bars and an almost innumerable number of rocking grates, most engineers have found by experience that the plain ordinary grate bars are the best. The breadth at the top is about 1 inch; the air spaces between the bars are $\frac{1}{2}$ to $\frac{3}{4}$ inch at the top; the bars taper about 1 to $1\frac{1}{2}$ inch per foot of depth. This makes the space at the bottom somewhat greater than at the top so that coal and clinkers will not be wedged into the space. When wrought iron or steel bars are used the spaces may be made less. The spaces are also less for forced draft.

The length of the grate is about $1\frac{1}{2}$ times the diameter of the furnace. Thus for a furnace 3 feet in diameter, the grate would be $4\frac{1}{2}$ feet long. This length is, however, often exceeded. The grate bars are usually $2\frac{1}{2}$ to 4 feet long. If cast iron bars are used, they may be made about 5 feet long.

The fire bars are usually made in two lengths; this facilitates making and handling and also provides for expansion. The grate, however, is more efficient when the bars are in one length as the cross bearer is avoided, which causes a better flow of air and also allows the fireman to "prick" the fire more effectively.

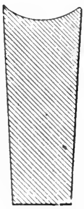


Fig. 44.

The grate should slope about 1 inch per foot. If the grates are very long the slope may be $1\frac{1}{2}$ inches per foot in order that the back end may be stoked more easily and the passage for the escape of the hot gases will be larger.

The bridge at the back end of the grate should be of such a height that the area of the passage is $\frac{1}{6}$ to $\frac{1}{8}$ of the grate surface.

Grate bars are likely to become very hot and burn at the tops. The burning is increased if the bars are irregular at the tops and the corners burned off. In case the air passages are blocked, either by warping or by clinker, air cools only one side of the bar. This will cause the other side to get hotter and hotter until the bar is burned. The slag formed from impurities in the coal melts and flows down the sides of the bars; as this slag solidifies on the sides it prevents the air from cooling the bars and as the slag at the top is thin, the heat burns the bars. To reduce burning the bars are often made concave at the top (as shown in Fig. 44), so that the ashes will accumulate there and protect the bar from the intense heat.

In order to allow for longitudinal expansion one end of the grate bars should be made slanting and the other notched to prevent sliding on the cross bar.

EFFICIENCY OF THE FURNACE.

The quantity of steam depends upon the amount of coal burned on the grate. This quantity of coal in turn depends upon the draft and the area of the grate. A furnace is said to be efficient if it burns the whole of the fuel upon it with little waste and without superfluous air. In order to produce perfect combustion there must be sufficient air to supply the necessary oxygen and the heat must be great enough to cause the chemical action.

Experiment shows that there is sufficient heat in a pound of coal to evaporate about 15 pounds of water, but in marine practice only about 10 pounds of water are evaporated per pound of coal. This shows the efficiency of the boiler to be about .7.

Among the causes of this low efficiency may be mentioned the following:

Bad stoking causes loss on account of the small pieces of coal which fall through the grate bars and are lost in the ashes. If anthracite coal is used it becomes brittle when heated and if disturbed breaks up. This loss may be as much the fault of the grate bar setting as the fireman.

If the grate bars are allowed to become uncovered or the fire become very thin an **excess of air** will enter the combustion chamber. As this superfluous air must be heated and does no good the heat is therefore wasted.

When the whole of the coal is not consumed there is of course loss. If **insufficient air** is admitted above the fire, a small portion of the fuel is not consumed but passes up the funnel as smoke. Also it may be deposited on the tubes as soot or burnt in the smoke box in the base of the furnace. The reasons for this loss are poor design and carelessness on the part of the fireman.

Perhaps the chief loss is due to radiation from the boiler shell and the various openings.

SMOKE BOX.

When the products of combustion emerge from the tubes they are conducted to the uptake by means of the smoke box. This box is constructed of iron or steel plate and is made smoke tight. It is made separate from the boiler and bolted in place by studs. The bottom of the smoke box should be at least 12 inches broad measured in the direction of the length of the boiler. If too narrow the bottom is soon filled with soot and dirt thus causing the lower rows of tubes to become inefficient if not useless. The bottom plate should be two or three inches below the lower row of tubes and the side plates about the same distance from the side rows of tubes. The smoke box front slopes outward making the top of much greater area than the bottom. The breadth at the top is about twice that at the bottom and the top pla s are fastened to the boiler above the top row of tubes. Above this the shape depends upon that of the uptake and funnel.

The uptake is the part between the smoke box and the funnel. It should lead to the funnel as directly as possible and with few bends or obstructions.

The thickness of the plates for uptake and smoke box is about $\frac{1}{8}$ to $\frac{3}{16}$ inch, depending upon the size of the boiler and the material used.

The doors and plates of the smoke box should be provided with screen plates to protect them from the heat; the distance between the plates is usually about 3 inches. Also the smoke box should have a back commencing just above the top row of tubes to protect the stay rod nuts.

When several boilers discharge into the same funnel, each smoke box should have a separate uptake so that the smoke from one smoke box will not enter another. In order to control the draft and even shut off one boiler or one nest of tubes a damper is placed in each uptake.

SAFETY VALVES.

The purpose of a safety valve is to automatically relieve the boiler from excessive pressure.

The principal requisites of a good safety valve for marine work are as follows :

When raised, the area for the escape of steam should be sufficient to allow steam to escape as fast as it is formed.

Its construction should be such that it will close as soon as the pressure has fallen below the load.

It should be so arranged that it can neither be tampered with nor get out of order.

Its parts should be so constructed that the valve will act efficiently and promptly.

It must be so designed and constructed that the motion of the ship will not affect it.

Weight loaded safety valves are not now used and the lever safety valves are in use in marine work only on old boilers. This type of valve does not fulfil the above conditions as well as properly constructed spring safety valves.

The necessary size of safety valves depends upon the volume of steam generated by the boiler in a given time. This volume depends upon the area of the grate, the draft, the kind of fuel, the working pressure and the heating surface. In calculating the necessary size, most of these conditions are not considered. The size also is taken as the area of the valve but the circumference should be used instead of area because for a given lift the amount of steam released is proportional to the circumference.

There are various rules for proportioning the safety valves. With given conditions the sizes obtained by using these different rules vary considerably.

The Rules of the United States Board of Supervising Inspectors state, that the lever safety valves attached to marine boilers shall have an area of not less than one square inch to two square feet of grate surface and the seats of all such safety valves shall have an angle of inclination of 45 degrees. Each boiler shall have a separate safety valve. Spring loaded safety valves of the "pop" type, there is, those constructed so as to give an increased lift by the operation of steam after being raised from their seats, shall have an area of not less than one square inch to three square feet of grate surface. Except for water-tube sectional boilers carrying a steam pressure of over 175 pounds per square inch, the area of the safety valve shall be not less than one square inch to six square feet of grate surface. Two safety valves may be used if the combined areas are equal to that of one of the required size. But no spring loaded safety valve can be used in place of a lever valve unless it has been approved by the Board of Supervising Inspectors.

The English Board of Trade gives the following rule. For boilers carrying a pressure of 60 pounds per square inch the area of the safety valve should be $\frac{1}{2}$ square inch to 1 square foot of grate.

For ordinary boilers,

$$\text{Diameter of safety valve} = \sqrt{\frac{\text{area of grate}}{452}}.$$

The area of grate is expressed in square inches.

Example. There are six furnaces in a double ended Scotch marine boiler. Each grate is 3 feet wide and 6 feet long. What should be the diameter of the safety valve?

Total grate area $= 6 \times 3 \times 6 = 108$ sq. ft. $= 15552$ sq. in.

$$\text{Diameter of safety valve} = \sqrt{\frac{15552}{452}}.$$

$$= 5.87 \text{ inches.}$$

In case two safety valves are used the combined area should be,

$$\frac{\pi d^2}{4} = \frac{3.1416 \times (5.87)^2}{4} = 27.06 \text{ sq. in.}$$

This gives $4\frac{1}{8}+$ inches as the diameter of each valve.

The French Government rule is based on the amount of heating surface and the pressure. This is evidently a much better rule than the preceding.

$$\text{Diameter of valve} = 1.23 \sqrt{\frac{\text{total heating surface}}{\text{pressure} + 9}}.$$

The heating surface is expressed in square feet. Then if in the above example the total heating surface is 30 times the grate area (which is 108 square feet), and the boiler pressure is 150 pounds, the diameter is,

$$1.23 \sqrt{\frac{3240}{159}} = 5.55 \text{ inches.}$$

The general arrangement of the common lever safety valve is shown in "Boiler Accessories."

In order to set the valve or in other words to find the pressure at which it will blow off, we must know the diameter of the valve, the weight of the valve and valve spindle, the length, weight and center of gravity of the lever and the weight of the ball at the end. The center of gravity of the lever may be found by balancing it on a knife edge.

Then to find the pressure at which the safety valve will blow off:

1. Multiply the weight of the ball in pounds by its distance in inches from the fulcrum.

2. Multiply the weight of the valve and spindle in pounds by their distance in inches from the fulcrum.

3 Multiply the weight of the lever arm in pounds by the distance of its center of gravity from the fulcrum in inches.

Then add together the three products, (1), (2), and (3).

Divide this sum by the area of the valve in square inches multiplied by its distance from the fulcrum. The result will be the pressure in pounds per square inch.

Example. Suppose a weight of 80 pounds is hung on the end of a lever which weighs 40 pounds. The center of gravity of the lever is 13 inches from the fulcrum and the ball is 38 inches from the fulcrum. The valve and spindle weigh 20 pounds and are 5 inches from the fulcrum. If the valve is 5 inches in diameter at what pressure will the safety valve blow?

$$\begin{array}{lr} (1)\quad 80 \times 38 = & 3040 \\ (2)\quad 20 \times 5 = & 100 \\ (3)\quad 40 \times 13 = & 520 \\ \hline \text{Sum} \quad = & 3660 \end{array}$$

The area of the valve is $\frac{3.1416 \times 5^2}{4} = 19.635$ sq. in. and is 5 inches from the fulcrum, hence

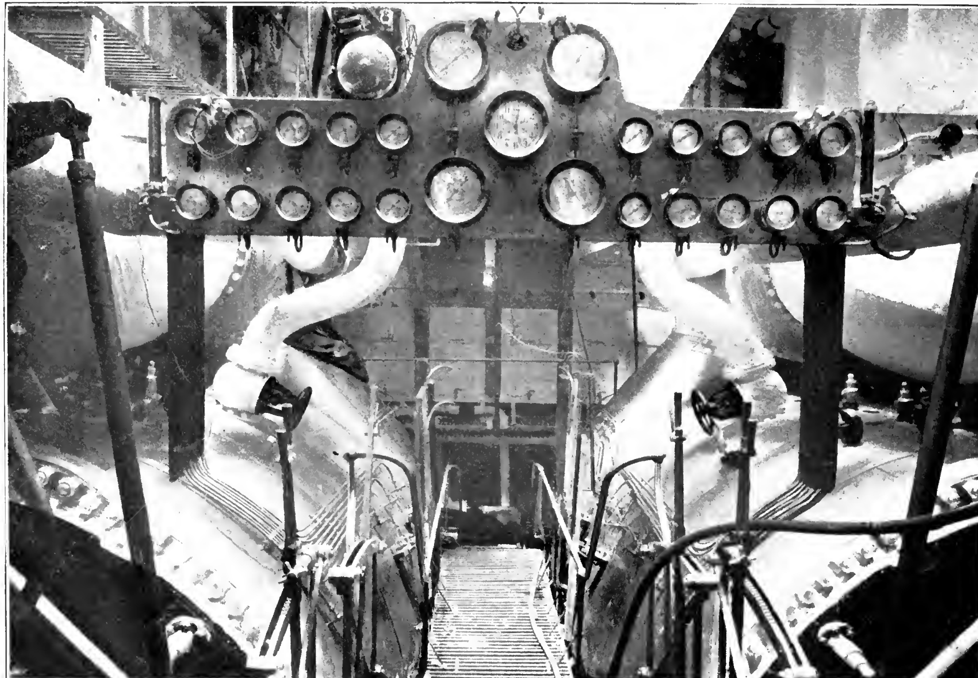
$$\frac{3660}{19.635 \times 5} = 37. + \text{ pounds.}$$

There are many spring safety valves used. The main principles of construction and operation are discussed in "Boiler Accessories."

STOP VALVE.

The main stop valve regulates the passage of steam from the boiler to the main steam pipe or engines. One is fitted to each boiler so that any boiler or all boilers may be in communication with or cut off from the engines.

This valve should be of sufficient size to pass out with little resistance all the steam the boiler is capable of making. One of the chief reasons for a drop in pressure between the boilers and engine is a small stop valve or one so constructed as to retard the flow of steam.



VIEW IN ENGINE ROOM OF CURTIS TURBINE STEAMER "CREOLE" LOOKING AFT
Fore River Ship Building Co.

The size of the valves depends upon the steam pipes. The size of the main steam pipe may be calculated as shown in "Boiler Accessories." This method takes into consideration the amount of steam used by the engine.

The diameter of the steam pipes from the boiler to the main steam pipe may be found from the following formula,

$$d = D\sqrt{\frac{4}{3n}}.$$

D = diameter of main steam pipe.
d = diameter of branch pipe.
n = number of boilers (two or more).

Example. The main steam pipe is 16 inches in diameter; what should be the diameter of the branch pipes to the three boilers?

$$d = D\sqrt{\frac{4}{3n}}$$

$$d = 16\sqrt{\frac{4}{3 \times 3}}$$

$$= \frac{16 \times 2}{3} = 11 \text{ inches (nearly).}$$

To determine the size of a pipe for any boiler, the following rule may be used.

Area $=(\frac{1}{4}$ square inch per square foot of grate $+$ .01 square inch per square foot of heating surface) $\times \sqrt{\frac{100}{\text{pressure}}}$.

Example. What is the diameter of the steam pipe of a boiler carrying a pressure of 120 pounds, and having a grate surface of 48 square feet and a heating surface of 1494 square feet?

$$\text{Area} = (\tfrac{1}{4} \times 48 + .01 \times 1494) \times \sqrt{\frac{100}{120}}.$$

$$= 24.6 \text{ square inches.}$$

The diameter would be $5\frac{5}{8}$ inches.

The valve and seat are usually made of bronze or gun-metal, and as full pressure is on them when shut, they should be strong enough to stand it.

Stop valves for warships and for some vessels in the merchant marine, are so constructed that whenever the pressure in the boiler becomes less than that in the steam pipe the valve immediately closes. Thus if a shot penetrates the boiler or if a tube or plate gives way, steam from the other boilers would not escape through the injured one.

Such a valve, the Foster Automatic Safety Stop Valve, is shown in Fig. 45. Steam enters at A and passes through the valve H and out at B. To start the flow of steam when the valve

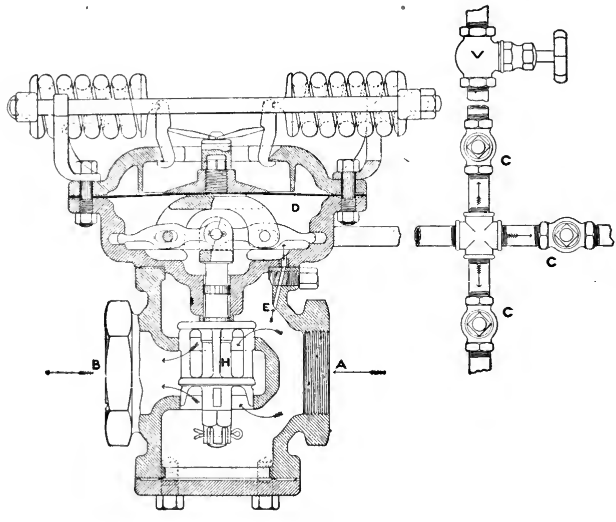


Fig. 45.

is closed and there is no steam passing through, open the passage E by turning the small set screw. As soon as the pressure in the diaphragm chamber accumulates to a point equal to the strength of the spring, it lifts the diaphragm, raises the valve from the seats and steam flows through.

Steam continues to flow until the pressure in the chamber D falls below the power of the spring. This happens in case of accident or when the valve V is opened. The pressure in D may also be relieved through the check valves C, which lead to the boiler and to the main steam pipe.

The steam port E is about $\frac{1}{16}$ inch in diameter. The springs are adjusted for a pressure of 20 to 30 pounds below the minimum pressure carried in the boiler.

In an older form of this valve, small hand valves take the place of the check valves. This makes the valve less automatic in starting, as first one valve is opened and when steam is flowing it is closed and another opened.

Auxiliary stop valves, also automatic, are fitted to each boiler so that steam may be supplied to auxiliary machinery, independent of the main stop valve and the main steam pipe.

FEED VALVES.

As water evaporates in the boiler fresh water must be fed to take its place. In the pipe conveying the feed water from the pumps to the boiler there should be a feed valve. There should be one in the main feed pipe and a similar one in the auxiliary feed pipe. These valves should be fitted with a screw spindle from which it can be detached. The spindle is used to shut the valve when no water is required and to regulate the height of the check valve to the amount of water required. As it is independent of the spindle it acts as a self-acting non-return valve. The valve, sometimes called a check valve, should be very strong and is often made of gun-metal or bronze.

The area in square inches through the feed valve may be found from the following rule.

$$\text{Area} = \frac{\text{total heating surface}}{240}.$$

For the auxiliary feed valve,

$$\text{Area} = \frac{\text{total heating surface}}{300}.$$

BLOW-OFF VALVE.

The blow-out valve or blow-off cock is fitted at or near the bottom of the boiler in order that some of the water may be blown off as required. A pipe connects this valve with another which is placed at the bottom of the ship. By opening these two valves the boiler may be emptied of its water if there is slight steam pressure, or if empty the boiler can be filled with salt water. As sea water is now seldom used for filling boilers, this connection with the sea is useful only to blow out the water. The boiler should not be blown out except when under slight pressure, 10 or 20 pounds. This valve or cock should be strong and well made because it is subject to hard usage and neglect.

The clear area through the blow-out valve should be about 1 square inch for each ton of water in the boiler.

SCUM COCK.

The scum cock, sometimes called the brine valve, is fitted to the boiler near the water level. Scum and other impurities collect near the water line and are blown out when necessary. Sometimes a perforated pipe is connected to it; this pipe should not be lower than the lowest working level. The object of the pipe is to collect scum and floating impurities. Formerly, when salt water was used as feed water, this valve came into frequent use, for the water became very dense and a part had to be blown out and replaced with sea water. However, at the present time it is used only when the surface of the water becomes dirty.

The principal impurity in marine boilers is oil. This oil, either in patches or pellets floats on or near the surface, and hinders the free rise of steam bubbles causing the boiler to overheat. It is blown out by the scum cocks. This valve should be placed below the water level and above the heating surface so that in case of leaks or accident the water will not fall below the latter.

It is better to remove the oil from the feed by means of filters than to wait and blow it out.

WATER GAGES.

Marine boilers should be supplied with water gages and gage glasses in the same manner as stationary boilers. These fittings are described in "Boiler Accessories." They should be placed on the front end where they are easily seen. As it is very important to know the true level at all times, these fittings must be kept very clean especially if the water in the boiler contains much salt;

the deposit of salt is likely to clog the connections. The drain cock at the lower end of the gage glass should be provided with a drain pipe so that the water will not corrode the front of the boiler.

The gage glass should be placed, not on the front plate but on a stand pipe which is connected to the steam space at a point where foaming and priming will not affect it and to the water space where there is little circulation. Gage glasses are likely to indicate a wrong water level if not often blown through. There are several reasons for this : Water cools in the gage glass and in the stand pipe, is therefore of greater density and shows lower water level. An accumulation in the gage glass of distilled water (condensed steam) is lighter than the water in the boiler and causes a higher level to be indicated.

Test cocks should be fitted to the end plate. This is important as it is essential that the water level be known even if the glass breaks. Low water in a stationary boiler is dangerous but as the furnace crowns of marine boilers are so far below the water level, there is not as much danger in having low water.

STEAM AND VACUUM GAGES.

Steam gages of the Bourdon type are used to indicate the pressure in marine boilers. Their method of working and general appearance are discussed in "Boiler Accessories." Pressure gages are used on the boilers and receivers and vacuum gages on the condensers. Usually the pressure gages, vacuum gages and a clock are placed on a gage board in the engine room so that the engineer can know at all times the working conditions of the various parts of the machinery.

SALINOMETER.

Formerly it was the custom to feed boilers directly from the sea. This water, however, contains considerable solid matter, called salt, which renders it undesirable for feed water. At present the amount of sea water thus used is small.

Saline matter in sea water is measured in ounces per gallon or as a proportion in 1000 parts. Sea water contains about $\frac{1}{32}$ of its weight in solid matter. Hence sea water if analyzed shows that for every 1000 pounds there are about 32 pounds of saline matter. This amount varies in different parts of the globe. The following gives an idea of the variation. The table shows the weight of solid matter per 1000 pounds and also the ratio of solid matter per pound.

Arctic Ocean	28.5 — $\frac{1}{35}$	Baltic Sea	6.6 — $\frac{1}{151}$
Atlantic Ocean (equator)	40.0 — $\frac{1}{25}$	British Channel	35.5 — $\frac{1}{28}$
North Atlantic	45.4 — $\frac{1}{22}$	Irish Sea	33.0 — $\frac{1}{30}$
South Atlantic	41.6 — $\frac{1}{24}$	Red Sea	43.0 — $\frac{1}{23}$
Black Sea	21.0 — $\frac{1}{47.6}$	Mediterranean Sea	38.0 — $\frac{1}{26}$
	Dead Sea 390.5 — $\frac{1}{2.6}$		

Suppose this salt water is fed to a boiler. The water is evaporated and the salt left behind. As the process continues the water within the boiler becomes more and more dense because the greater the amount of saline matter present the greater the density. This increase of concentration continues until the point of saturation is reached. The point of saturation is the point at which the water has dissolved all the salt that it can and any further evaporation causes salt to be deposited.

This increase of density raises the boiling point and the deposit of salt on the heating surface, if allowed to become thick, hinders the free transmission of heat and increases the liability of burning.

For these reasons it is necessary to have some means of knowing the proportion of salt in the water of the boiler. As the density increases directly as the amount of salt an hydrometer is used. This instrument is called a salinometer when used with salt water. It is a float having a constant weight and measures the densities of liquids by the depth to which it sinks when immersed in the liquids.

The instrument is a cylindrical tube small at the upper and enlarged at the lower end. The upper end called the stem is graduated; the lower end is enlarged to give buoyancy to the instrument. This enlarged end terminates in a small globe containing shot or some heavy substance to make it float in an upright position. When it is immersed in a liquid the weight of the liquid displaced is equal to the weight of the salinometer. For a dense liquid like salt water the stem will project farther above the surface than it will in fresh water.

To graduate this instrument it is placed in distilled water of a known temperature and the point to which it is immersed marked zero. Then sea salt is dissolved in water at the above temperature in the proportions of one, two, and three pounds of salt to thirty-two pounds of water. The points to which the instrument sinks in these solutions are marked $\frac{1}{32}$, $\frac{2}{32}$ and $\frac{3}{32}$. These divisions are subdivided into halves and quarters. The temperature at which these graduations are made is marked in the scale. Some salinometers are graduated for three temperatures, 190°, 200° and 210° F.

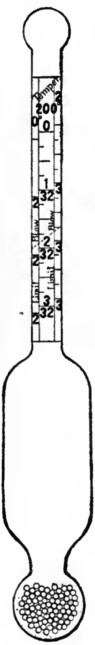


Fig. 46.

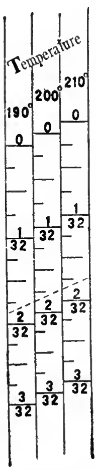


Fig. 47.

Fig. 46 shows an hydrometer with the scale graduated for salt water; the scale developed and enlarged is shown in Fig. 47.

It is necessary to know the temperature within a few degrees, because for every increase of 10 degrees the instrument indicates a density of $\frac{1}{8}$ of $\frac{1}{32}$ less. Or, if the temperature is 210° and the density reading is taken on the 200° scale, the reading will be in error $\frac{1}{8}$ of one of the $\frac{1}{32}$ divisions.

The salinometer is usually made of glass. If made of copper, it should be handled carefully as any indentation alters the relation existing between the volume and weight of the instrument. As a result the scale becomes incorrect.

Hydrometers are used in connection with a salinometer-pot.

All marine boilers should be provided with a permanently attached salinometer-pot. It should be so constructed that a constant flow of water from the boiler will be maintained while testing the density. Also, it should reduce the temperature of the water to a fixed temperature below the boiling point so that ebullition and the formation of vapor will be avoided. A common form of salinometer-pot is shown in Fig. 48. Water enters the central pipe in the tall compartment and when it has risen to the height of the small holes near the top, it flows out into the compartment. It then passes to the shorter larger chamber in which is placed the hydrometer and thermometer. The water level is kept constant by means of the overflow pipe. A small hole in the cover of the tall chamber allows air and vapor to escape.

The covers of the salinometer chambers are attached to chains which prevent their being lost when the vessel rolls.

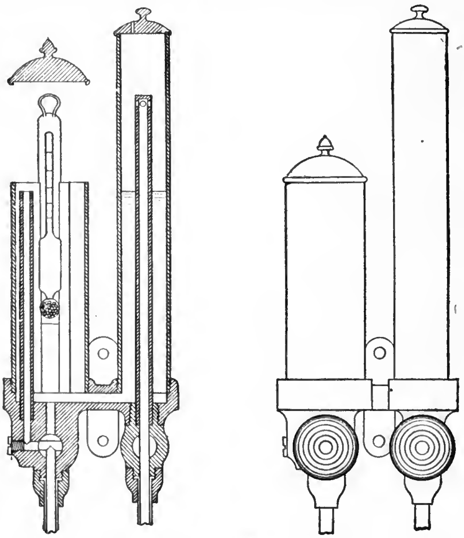


Fig. 48.

EVAPORATORS.

In all kinds of vessels, fresh water is a necessity. Those steaming on lakes and rivers can, of course, obtain fresh water with little trouble; but in the case of war ships and vessels sailing on the ocean this problem is not as easily solved. Of course a large quantity of fresh water can be carried in tanks and double bottoms but these methods are not altogether satisfactory. Water thus carried is dead weight and as it is likely to contain corrosive agents and scale forming salts it is injurious to the boiler.

The amount of make up water necessary in a large vessel is considerable. In most vessels of the present day this make up water is obtained from salt water by distillation. We know that when water is heated to form steam, the heat drives out the volatile gases and precipitates the solids. The steam thus formed is pure. Sea water is distilled in evaporators or distillers.

There are several evaporators having many ingenious devices but the principle upon which they all work is essentially the same.

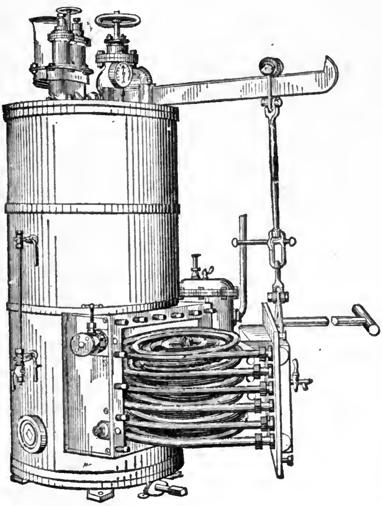


Fig. 49.

The evaporator, shown in Fig. 49, consists of a cylindrical shell similar to that of a vertical boiler and an arrangement of tubes within it. On the shell are placed such fittings as gage glass, pressure gage, salinometer, etc. Sea water is pumped into the evaporator by a donkey pump and it is then evaporated by admitting steam from the boilers or from one of the receivers to the coil of tubes. The steam thus formed from the salt water is either condensed in the auxiliary condenser or passes to the low pressure receiver. It then enters the boilers and makes up the loss from leakage, etc. The steam within the coils is partly condensed then trapped out and returned to the feed. The evaporator acts like a small boiler, the heat being supplied by steam instead of a furnace. The evaporation of sea water makes the water in the evaporator very dense and the tubes become coated with salt. When the salinometer shows the requisite density a part of the water may be blown out. The tubes are so arranged that they can easily be withdrawn from the evaporator (as shown in the figure) and cleaned. Evaporators are made both horizontal and vertical and in sizes to suit requirements.

HYDROKINETER.

We know that the water in a marine boiler below the level of the fire bars is at a much lower temperature than that above. Also we have seen that in all internally fired boilers the circulation is not good. Now, if a cylindrical marine boiler is filled with cold water and a fire is started, the water in the bottom of the boiler remains cold even after steam is formed. In order to raise the temperature of this cold water the circulation must be improved or the cold water drawn off and hot water substituted.

Some engineers adopt the above plan while others employ a small pump. Perhaps the best and most used method of improving the circulation is by means of a hydrokineter. This instrument consists of a series of nozzles one within the other. At the rear of each there is a grating through which the water passes. Steam from an auxiliary or donkey boiler is introduced into these nozzles and as it issues from the small one it causes the water to flow with the steam. With this instrument the circulation is greatly improved and the temperature of the water at the bottom of the boiler is very nearly the same as that of the water above. This plan allows steam to be raised in a much shorter time and causes the life of the boiler to be greatly prolonged while the cost of operating is practically nothing because the heat of the steam taken from another boiler enters the water in the main boiler.

FEED ARRANGEMENTS.

Marine boilers are fed with either fresh or salt water. When the water is salt it usually enters the boiler while cold; if fresh, it is taken from the hot well, and has a temperature of 100° to 140° or it may be fed cold as in the case of a lake or river steamer. The most common practice is to feed the boiler with hot fresh water heated by heaters, or from the hot well; the loss from leaks, blowing off of the safety valve, etc., is sometimes made up by taking salt water from the ocean and blowing off when the density in the boiler is about $\frac{3}{32}$. At the present time, however, this shortage is often made good by distilled water from evaporators or distillers.

The use of distilled water is advantageous because it contains no corrosive elements except a small amount of air. Sea water, however, not only deposits salt, which hinders the free transmission of heat, but contains compounds which corrode iron and steel.

One of the most harmful agents found in marine boilers is air. Pure water, if not in the presence of air, will not corrode iron. Air not only furnishes the oxygen necessary to promote corrosion by water but it also aids such chlorides as ammonium, sodium, potassium, barium, etc., in their corrosive action.

As it is almost impossible to feed water into a boiler without its containing some air, the feed should be introduced at some point where it may mix with the hot water and lose its air at a point where the corrosion will not be dangerous.

Water should never be admitted at or near the bottom of the boiler, because at that point the circulation is restricted and ashes and the inrush of cold air to the furnaces prevent heat from passing to the water. This causes the water to stay at the bottom of the boiler.

A better place to introduce the feed water is over the back ends of the tubes, so that it will be thoroughly mixed with hot water and the air readily flow to the steam space.

Many engineers prefer to inject the feed water in the form of spray at a point a little above or just below the surface of the water. This avoids all danger to the boiler plates. The feed is generally led through pipes which are fixed inside the boiler. By this plan the water is heated before it mixes with that in the boiler. This heating is of great importance if the feed is cold, as it tends to keep the boiler in good condition. The internal pipe should be so arranged that it always "runs full"; that is, it should never have any steam within it. If steam is present in the feed pipe, every stroke of the pump produces a concussion which damages the pipe and the boiler. This may be avoided by turning the end of the pipe upward when discharging above the water line, and downward with the end well below the water level, when discharging below the surface. The internal pipe is very likely to corrode rapidly but it is far more easily replaced than the plates or tubes of the boiler.

Marine boilers are fed by means of direct acting steam pumps;

injectors are seldom used. The pumps are usually vertical so that they will not take up too much floor space. There are many varieties of these pumps; the Worthington Admiralty pump shown in Fig. 50 may be taken as an example. It is of the vertical type and adapted to marine work either as a boiler feed pump or as a bilge or fire service pump. In construction and operation it is similar to the Worthington pump in general. It is usually duplex and capable of pumping against a pressure of 150 to 250 pounds per square inch.

LAGGING.

In addition to lagging the steam pipes, it is necessary to clothe the boiler to prevent loss by radiation which may amount to about 10 per cent. The material used should be incombustible and inorganic as well as a non-conductor of heat. Also, the clothing should be such that it will stand mechanical action; if it is brittle the dust formed by constant vibration is likely to get into the bearings of the engine.

In "Boiler Accessories" the various materials used for this purpose are described with a table showing their relative values. In addition to these there are several kinds of patent lagging which possess many advantages.

DRAFT.

The term draft is used in various ways. It usually refers to the difference in pressure between the gases when they leave the boiler and that of the external air. It is also used as meaning the difference between the air pressure under the grate and that on top of the coal. A third meaning is sometimes given to the word; it is the measure of the volume or weight of the gases passing over the fire in a given time.

The force of the draft is used in two ways. A portion of it is necessary to overcome the resistance of the grate and the fuel upon it, also the resistance of the combustion chamber, flues or tubes and uptake. It must also be sufficient to give the air the necessary velocity for direct combustion. Hence, if a thicker layer of coal is placed on the grate the intensity of the draft must be greater.

The draft must be sufficient to overcome the great resistance of the grate, fire, tubes, etc., as well as to supply the requisite *volume* of air for combustion.

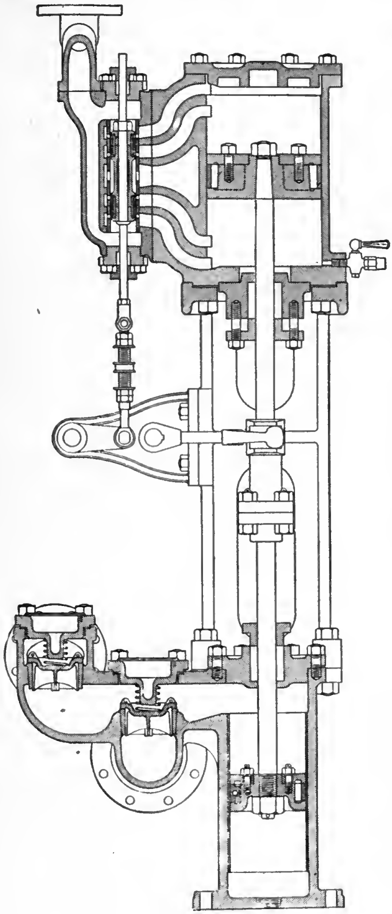


Fig. 50.

The velocity of the gases is due to a difference of pressure which, in the case of a chimney is dependent upon the temperature and the height of the chimney.

That chimneys do not always supply the necessary draft and that they must often be built very high is evident. Even changes of climate or wind often seriously impair the draft. For these reasons and on account of the impossibility of a high chimney on board a ship, some kind of artificial draft must be used.

In the locomotive, the intense draft is produced by a jet of exhaust steam. This method is not suited to marine work because the exhaust steam is condensed and used over and over again, thus reducing the amount of fresh water carried and increasing the power of the engines by the use of the condenser.

The most common method of producing mechanical draft is the fan blower. The fan for this work is what is known as the peripheral discharge type, that is, the fan consists of a number of blades extending radially from the axis. The air is drawn in axially at the center and discharged from the ends of the blades in a tangential direction. For forced draft the fan is enclosed in a case shaped so that the air will escape freely from the blades through a delivery pipe. Fig. 51 shows a Sturtevant fan used for forced draft in marine work

To design a fan of required size, the peripheral speed must be sufficient to create the desired *pressure* and the requisite *volume.*

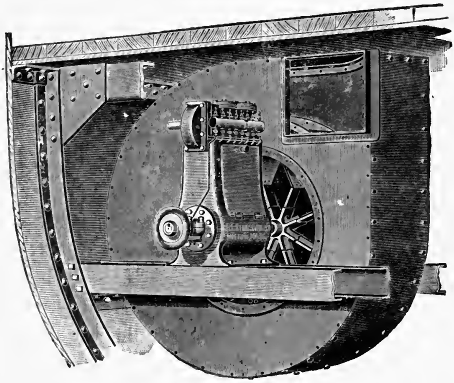


Fig. 51.

Thus, a large wheel running slowly or a small wheel running at high speed may give the desired volume and pressure. But if the wheel is too small the width may not be sufficient to permit the passage of the volume of air unless the fan is run at a speed that will make the pressure too great.

There are two methods of applying mechanical draft; increasing the *pressure under* the grate and creating a *vacuum above* the fire. As the first method was for a long time the only one used, mechanical draft was called *forced draft.*

The usual method of applying the *induced* or *suction* draft is to use a fan exhauster in place of a chimney, that is, the fan creates the partial vacuum of the chimney; a short stack conducts the gases to the atmosphere.

With the forced draft two methods may be used, the closed ashpit and the closed fire-room.

Closed Ashpit System. This method was first applied and is the best if it can be readily adopted. In marine boilers, the air is usually forced into the ashpit which is closed to the fire-room. The pressure in the ashpit causes all leakage to be outward. Therefore, if the pressure is considerable, there is tendency to blow the ashes out of the ashpit and the flames and fuel out of the doors. In order to avoid this danger, an arrangement of double doors and dampers is used. They are often so arranged that when the doors are opened, the draft is shut off.

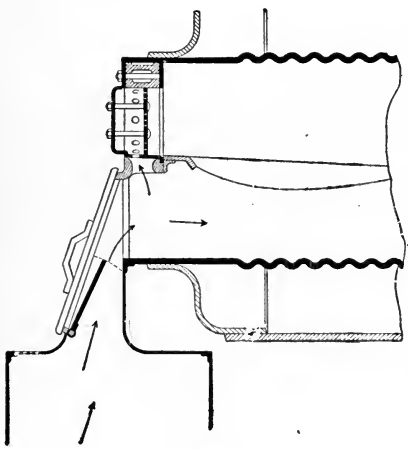


Fig. 52.

The great advantage of this system is that there is no leakage in the tubes at the combustion chamber end if proper care is taken.

In the navy, the protective deck and the water-tight subdivisions make it difficult to use the closed ashpit system. The chief disadvantage here is the absence of ventilation. Wherever it has been used and in the merchant marine it has been on the whole, very satisfactory.

This system has another advantage; it presents an opportunity for utilizing the heat of the waste gases.

There are several arrangements for applying forced draft by the closed ashpit system; that known as Kafer's method is one of the best.

Kafer's Method. This method of forced draft is illustrated in Fig. 52. The ashpits are closed by means of light iron doors made air-tight by asbestos gaskets. A hinged damper, shown in the figure as partly open, regulates the supply of air to each furnace.

The air from the blower passes through the duct to the closed ashpit and from there it may enter the space under the grate or it may pass through openings in the dead plate to the space between the inner and outer door plates. The inner plate is perforated with many small holes which allow the air to enter the space over the fire. As the air pressure in the space between the inner and outer plates of the door is greater than that in the furnace no gas can escape into the fire room, the leakage being pure air which improves the ventilation slightly and keeps the fire door cool.

Closed Stoke-hold. For ordinary work and for most vessels in the merchant marine, an air-tight fire-room is impracticable. In naval vessels, however, the numerous water-tight compartments and the constructions for protection from shot and shell make air-tight fire-rooms almost a necessity. During an engagement the boiler and engine rooms must be closed and air supplied artificially Thus mechanical draft is a necessity as well as an auxiliary.

In this method air is forced into the fire-room until the pressure exceeds that in the furnaces. Then the fires are stoked in the same manner as with natural draft.

Among the advantages of the closed fire-room system may be mentioned the following. It prevents the escape of flame and smoke into the fire-room ; all the leakage being inward to the furnaces. It aids ventilation since the great quantity of air for the furnaces must pass through the fire-room.

The great objection to this method is the chilling of the interior plates of the boiler whenever the fire-doors are opened. The inrush of comparatively cold air causes local contraction of tube sheets and combustion chamber plates which soon causes leaky tubes. This system is harder for the stokers than the closed ashpit system.

Induced System. In this system a partial vacuum is formed in the furnace by means of an exhauster which is similar to a blower. The effect is very similar to that of a chimney except that the draft is steadier, more intense and far more easily regulated. When used on board ship it gives good ventilation, and is easily regulated. The early difficulty of obtaining fans that would stand a temperature of 500° or more has been overcome.

JAPANESE BATTLESHIP MIKASA.

Flagship of Admiral Togo during the blockade of Port Arthur. Built in England. Destroyed by accidental explosion of magazine shortly after conclusion of hostilities, 1905.
Displacement, 15,200 tons; speed, 18.6 knots.

The relative efficiencies of the forced and induced systems have not been definitely determined because of the many circumstances which make the conditions unequal. However, tests seem to show that the induced system is more efficient. Probably this is due to the better distribution of air and the reduced tendency to blow holes in the bed of coal.

With this system the fan must be larger than with forced draft because the heated air occupies a much greater volume and also because the weight of air is increased by the portion of the coal which has entered into chemical combination with the air. This amount is about 5 per cent of the weight of air supplied.

Advantages of Mechanical Draft. Mechanical draft possesses many advantages for both stationary and marine work. For the navy it is a **necessity** because high funnels are undesirable if not impossible. Let us suppose the boilers are designed to furnish steam for the engines running at about 5,000 to 6,000 I. H. P. with chimney draft. If the enemy is sighted all possible speed is necessary and the I. H. P. must be increased to 10,000 or 16,000 in a very short time. If forced draft is not used the vessel would cruise under three or four boilers but would have in reserve four or five more. Now this extra weight is very seldom used and while unused is of course dead weight. Mechanical draft makes it possible for the fewer boilers to furnish the maximum amount of steam. This feature is especially noticeable in torpedo boats and destroyers.

In the merchant marine the forced draft system enables fewer and smaller boilers to furnish the required steam. Hence, either more passengers or a larger cargo may be carried.

With chimneys the conditions are practically fixed while with any of the three systems changes in conditions are possible.

One of the greatest advantages is the ease with which the draft may be controlled. The draft may be regulated by means of dampers in the chimney but chimney draft depends upon the state of the fire, that is, with a low fire the draft is slight. On the other hand, a fan controls the draft whether the fire is low or not. The maximum draft can be obtained almost instantly and at the time when it is most needed. Also, artificial draft may be so regulated that the steam pressure will be practically constant.

Forced draft is independent of climatic conditions; variation of wind and fog are not of any importance.

The efficiency depends upon the boiler. If with forced draft the boiler has a large ratio of heating surface to grate area, the efficiency will be greater than for a small heating surface. With chimney draft only about 20 to 25 pounds of coal can be burned per square foot of grate per hour; with forced draft 50 to 100 pounds may be burned. Thus the capacity, and perhaps the economy is increased.

Cheap fuels are much more easily employed with mechanical draft. Steamers may use a cheap inferior coal that could not possibly be burned with natural draft and ordinary grate bars.

With a chimney a high temperature is necessary to cause the requisite draft. If anything reduces this temperature the draft is impaired. With forced draft the heat in the waste gases may re-utilized in heating the feed water, or air for draft. Economizers, retarders and abstractors are successfully used with artificial draft.

The size of the boiler and hence the first cost is considerably lessened.

MECHANICAL STOKERS.

When small quantities of coal are fired at frequent intervals instead of large quantities at greater intervals an increased efficiency is the result. A mechanical stoker should then possess many advantages over hand firing. This economy, however, can be realized only when the mechanical stoker is suited to the work and properly operated.

Among the advantages may be mentioned the following: Absence of smoke, saving of labor, uniform fire, and the use of a cheaper fuel.

There are three principal types, the under feed, the inclined over feed and the chain.

In the **under feed** the coal is forced in and upward by means of a screw from beneath. The fuel is supplied along the center of the grate and as it is forced upward it falls over on the sides forming a mound. On account of the thickness of the fuel at the center the draft must be stronger there than at the sides. This is usually accomplished by means of a blower.

The **inclined over feed** stoker is a sloping grate with the highest portion at the front where the coal is fed. The grates are constructed so that they are moved at intervals so as to feed the fuel along and down the surface. This movement is usually caused by a small independent engine.

The **chain grate** is the third type. Fuel is fed at the front of the boiler to the chain grate which slowly moves toward the bridge. During this time the fuel burns undisturbed. When it reaches the bridge it is dumped as ashes. Air is supplied at various points, usually by means of some system of forced draft.

Mechanical stokers are likely to get out of order on account of the intense heat and the dirt. In order to get good results, constant attention is necessary; the rate of combustion must be regulated to suit the evaporation. Mechanical stokers are but little used at sea, although they are adapted for inferior fuels and bituminous coal.

FUELS.

The principal fuel used in marine boilers is **coal.** In some localities, however, *wood* or *petroleum* is more abundant and therefore more extensively used. The various kinds of coal are discussed in "Boiler Accessories." The kind used depends largely on the locality and choice of the owners. Bituminous coal is perhaps the most used on board ship chiefly on account of its cheapness. If the coal is in large lumps the thickness of the bed may be considerable. For very fine coal a thickness of three or four inches is most economical; a fire having such a thin bed of coal must be watched carefully and stoked almost continuously.

Patent fuels are made in blocks from small coal. This refuse from mines and coal yards cannot be easily transported unless mixed with tar, clay or some adhesive substance which holds the particles together. The heating value of these bricks depends upon the amount of coal in them.

The value of a fuel is determined by its chemical composition. All fuels contain carbon; almost all have some hydrogen, oxygen and small quantities of nitrogen and sulphur.

We know that heat is measured in British thermal units. The heat value of any given coal is equal to the sum of the heat units in the various elements.

If one pound of carbon is burned it gives out about 14,500 B. T. U., and requires about 12 pounds of air to consume it, that is, to convert it into carbon dioxide gas. If, however, the air supply is too small, there is considerable loss, the carbon forming carbon monoxide giving out only about 4,400 B. T. U.

One pound of hydrogen gas requires about 36 pounds of air to consume it. Its heat of combustion is about 62,000 B. T. U.

Sulphur is present in good coal only in very small quantities and has a heat value of about 4,000 units.

Knowing the amount of carbon and hydrogen in a pound of coal we can compute its heat value as explained in "Chemistry."

The heat value of any coal can be calculated if the chemical composition is known ; or it may be found by burning a little coal in a coal calorimeter.

Although about 12 pounds of air are theoretically necessary in burning a pound of coal, practically 18 to 24 pounds are supplied in order that the air may readily reach the fuel and that the carbon may be burned to carbon dioxide.

CARE OF BOILERS.

To manage a boiler successfully, the desired amount of work should be obtained from it and at the same time the expenses should be kept as low as possible. This requires a knowledge which can be obtained only by experience. Beside this skill in management, the boiler must be well designed, the feed water good and the fuel suited to the boiler. Still another condition is that the necessary repairs be made promptly and the causes for deterioration removed.

It is essential that the engineer should know the positions of all piping, valves, cocks, etc., so well that he can find them in the shortest possible time, even in the dark.

Before getting up steam, all the valves and cocks should be carefully examined to see that they are in good working order.

Getting up Steam. The method of getting up steam depends upon the type of boiler, the time allowed and the condition of the other boilers aboard. For instance, steam can be raised much more rapidly in a water-tube boiler than in a long double ended cylindrical boiler. If an engineer has plenty of time he has a fire built in one furnace and steam raised very slowly. If steam must be raised quickly, fires are started in all the furnaces at once and some means is employed to increase the circulation ; a hydrokineter or steam from another boiler. In case steam is up in an auxiliary boiler, the fires in the others are started from those in the auxiliary boiler, and the steam from the latter may be used to pump water into the empty boiler. Where there are no auxiliary boilers, steam should be raised slowly by building a fire in the lowest furnace.

Let us suppose we are to raise steam in a cylindrical boiler which is empty. First, it is necessary to inspect the interior. If the plates, tubes, joints, braces and stays are in good condition, all openings should be closed. Before closing manholes and hand-holes, all tools, materials and articles used in repairs or inspection should be removed. If soiled overalls, hand-lamps, etc., are left in the boiler, they are likely to cause trouble by stopping up the outlets.

It is important to have the safety valves in good working condition. They should be tried often so that they will not become rusted to the seats. The connections to the water column should receive particular attention as they are very likely to become clogged with salt, especially the lower ones.

The main stop valve should be closed but not tightly; it should be "cracked off the seat." If the valve is closed tightly it may become jammed to the seat when steam is formed. It is left slightly open for other reasons ; it gives the main steam pipe a chance to become warm as far as the bulkhead stop valves (if these are fitted) ; it allows condensation to be drained off and, with the atmospheric valve, it allows the air in the steam space to get out of the boiler when steam is formed. If there is no outlet, the air in the steam space becomes compressed while steam is forming. This imprisoned air when compressed prevents the free formation of steam and also causes the pressure gage to indicate a pressure greater than that due to steam.

Water gages and cocks may be left open until the water reaches their levels.

Let us now assume that the boiler has been thoroughly inspected and everything is in good working order. The boiler may be filled by opening the bottom blow-off valve and the sea valve. It may be filled through the top manhole by means of a hose from the shore or by pumping fresh or distilled water from the ship's tanks. Boilers should be filled with warm water if possible.

While the water is rising in the boiler, serious leaks may be detected by placing lamps in the combustion chamber and by opening the front connection doors.

The furnaces may be charged when the water has reached the proper height. On account of the expansion of water when heated, the filling is stopped with the level a little below steaming point.

Building the Fire. If there is a fire in an auxiliary or donkey boiler, the fires in the boiler under consideration may be started by throwing some burning coal from the auxiliary into the furnace or furnaces of the main boiler. If this cannot be done, a fire is kindled in one or more furnaces of the boiler. The back of the grate is covered evenly with a thin layer of small coal; on the front of the bars some pieces of split wood are laid side by side, the front end being supported by a couple of pieces of wood placed crosswise. If hard oal is used, the whole of the grate is covered. Some kindling, shavings or oily waste is then placed at the furnace mouth below the layer of wood.

When the fire is lighted, the furnace doors are kept slightly open and the ash pit doors opened. A few shovelfuls of coal are thrown on the wood as soon as it is well started. When the coal at the front of the furnace becomes incandescent it is gently pushed back and more coal added. This operation is repeated until there is sufficient incandescent coal on the grate.

The fire is usually built in the lowest furnace so that the water at that point will become heated and cause a circulation. Some engineers consider that a better circulation is obtained by starting the fire in one of the wing furnaces.

In case of emergency the fires may be lighted as soon as the water covers the heating surfaces; but this is not good practice and should be avoided if possible. This rapid raising of steam is injurious to boilers especially if they are long. Under most circumstances three hours should be allowed for raising steam and more if possible. For a long double ended cylindrical boiler six hours is the shortest time to be allowed.

When building the fire and while steaming the attention of a good fireman is essential.

Stoking. A complete knowledge of stoking can be obtained only from experience. It is easy to throw coal on a fire even if the doors are small ; but to place coal just where it ought to be placed when the doors are four feet above the floor and the ship is rolling is not an easy matter.

Certain varieties of coal, (anthracites) should not be disturbed after being placed on the fire, hence it is essential, with this coal, that the firemen should place it accurately; the fire should be sliced frequently. When the soft coal cakes, the fire must be broken up from time to time so that air can pass through the bed of coal.

The fires must be watched carefully; especially at the sides. Air has a great tendency to rush up between the plates of the furnace and the grate. Also air finds little resistance at thin places. All hollow places must be filled and the sides kept heavy or a damaging excess of air will rush with great violence into the combustion chamber. This rush of air is called back draft. To check this draft, open the furnace doors slightly and close the ash pit doors. To prevent the back draft the bed should be carried thicker and leveled frequently. If the hollows are more than filled the large amount of cold fuel will retard combustion at those places.

A good fire is slightly hollow in the center and has a nearly level appearance. Continual care is necessary. All fires connected with the same funnel must be kept equally thick or the thin ones will burn away fastest.

Coal should be placed on the fire frequently in small quantities. With forced draft, of the closed stokehold system, speed in firing is of the utmost importance; if the doors are kept open too long the inrush of cold air is both dangerous and uneconomical.

Thickness of Fire. The necessary thickness of the bed of fuel on the grate depends upon the kind, quality and size of the fuel, upon the draft and upon the frequency of firing. The thinner the fire the more rapid the rate of combustion. If the fires are kept thick, less cold air enters, as the doors are opened less frequently ; but large volumes of hydrocarbons are produced which are often at such a low temperature that they pass unconsumed up the chimney and are wasted.

With ordinary chimney draft, anthracite coal of egg size may be carried 5 to 8 inches thick. With smaller coal the bed may be thinner. If less than 4 inches thick it is difficult to keep the grates well covered especially if of large area. With free burning bituminous coal and natural draft, the thickness of the bed may be 6 to 8 inches. The thickness of the bed with mechanical draft should be much greater, the thickness depending upon the intensity of the draft. Bituminous coal should be fired more frequently than anthracite on account of the hydro-carbons.

When the fires throw a uniform bright light below the grate, it indicates a clear active fire. When the ash pits are dark, either uniformly or in spots, it indicates an accumulation of ashes or clinker on the grates. In such cases the hook bar or prick bar is run through the spaces between the grate bars from beneath and the ashes removed. If it is difficult to move the hook bar, it is an indication that the fire needs "slicing." That is, the clinker is to be removed by inserting the slice bar between the fuel and the grate. The edges and corners are likely to become clogged with ashes and cinders unless cleaned frequently. When the accumulation of ashes, cinders and clinker become so great that they cannot be removed by pricking and slicing, the grate must be cleaned.

Cleaning the fire is a necessary operation although it is injurious to the combustion chamber plates and tube sheets. This is due to the entrance of cold air while the door is open and the grate bare. It should be done at regular intervals and at least once in every twelve hours.

Cleaning the Fire. Before cleaning the fire, it should be allowed to burn low so that it will not be too heavy. It should not, however, be too light, or there will not be chaff enough left to start the fire again. The steam should be up to full pressure and there should be plenty of water in the boiler so that the feed can be partially shut off. The draft should be nearly closed during cleaning.

With soft coal the fire is more easily cleaned than with hard coal. To clean the fire, the fireman shoves back the incandescent coal leaving the clinker and ashes on the front of the grate bars. The clinker is hauled out and the fire brought to the front on the clean bars. The ashes are then worked through the grate bars at the back and the clinker hauled out over the fire to the floor plates. The clean incandescent coal is then quickly spread all over the grate and covered with a thin layer of green coal.

Cleaning the fire requires skill and care as it often happens that the fire goes out because there is not enough coal with which to start up again.

Some firemen prefer to clean one side at a time. One half is allowed to burn down and the ashes and clinker removed; the clean bars are then covered with green coal which ignites from the heat of the other half. After a time the other side is cleaned by the same method.

Another plan, used with coking coal, is to draw the clinker forward with the rake or hoe a little between each firing and throw green coal on the bare spots. Clinker should be removed before it gets cold or it will be difficult to detach it from the bars.

For hard coal the cleaning is more difficult and requires practice. Fire small quantities of coal frequently until the proper depth of fire is maintained. Then the slice bar may be run between the coal and the fuel to shake the ashes out. Never disturb a hard coal fire, that is, never break it up as with a soft coal fire. With hard coal keep the fire as level as possible and fire more heavily at the sides.

Smoke Consumption. In "Boiler Accessories" the various methods of firing to consume smoke were discussed. In the marine boiler, there are usually three or four furnaces; these are fired in turn, so that the smoke may be consumed if there is a common combustion chamber, and the formation of steam may be more constant. With hard coal there is little smoke.

When soft coal is heated great volumes of volatile gases are liberated which must be burned. Soft coal is usually fired at the front of the furnace where the heat drives off the hydrocarbons which are consumed while passing over the incandescent coal. The coke is then shoved back. A new supply of fresh coal is next placed at the front of the grate. This plan allows the use of very long grates, but it has the disadvantage that all the ashes and clinker collect at the back of the grates where it is hard to remove them.

Banking the Fire. It frequently happens that the steam supply is to be temporarily diminished or perhaps stopped entirely for a short time. In such cases the fires should be banked but not hauled. Before banking a fire it should be cleaned so that there will be a clean fire when it is started again.

Banking the fire means pulling the coal together in a heap at some portion of the grate; combustion being thus retarded.

There are two kinds of banked fires, "heavy" and "light." In case it is desired to keep the steam near working pressure and be ready to start in about a half hour the fires are banked heavy. The fire is cleaned, the coal gathered together in a pile and covered with green coal until the heap covers about one-half the grate bars. When this fire is started the heap is spread over the whole grate and as there is considerable coal in the pile there will be a normal steaming fire. In this case, the bare grate bars are usually covered with ashes to keep the cold air out of the combustion chamber.

With the front of the grate covered with ashes and the fire banked heavy everything may be closed and all cold air kept out. The steam made while the fire is banked can be used by running dynamos, distillers, etc., or it may be taken care of by the auxiliary condenser.

In case the fire is to remain banked for a considerable time and the pressure is allowed to drop the fires may be banked light. That is, the amount of coal used is much less, covering only about one-third the grate or just enough to start the fire.

There is a difference in opinion as to whether the fire should be banked in front or at the back. It is more generally banked at the back.

When the engines are stopped suddenly, but the boilers are kept ready to start again shortly, the excess of steam goes to the condenser by opening the bleeder valve in the main steam pipe.

Cleaning Boilers. Soon after the fires are hauled the boilers should be cleaned. The tubes should be swept, beginning with the top row. While doing this all doors except those of the front connection should be closed, so that the dust will go up the funnel and not into the fire-room. Tube brushes should be made of material stiff enough to detach the hard scale which sometimes adheres to the tubes. They should fit the tubes snugly. Tube scrapers are usually made of strips of steel arranged spirally.

After cleaning the tubes, the soot and ashes should be removed from the smoke box and combustion chamber. Scrape the scale from the plates and sweep them off with a stiff broom. The furnaces. ashpits and grate and bearing bars should then be cleaned of all soot, ashes, and scale.

All fittings, such as check valves, water glass, safety-valve, salinometer-pot, etc., should be kept clean and the connections clear.

The scale should be detached as soon as the boiler is cool enough to enter, because usually it can be detached more easily when damp. If the scale is very thin it should not be removed as it protects the iron or steel from corrosion. As it grows thicker, it prevents the transmission of heat, causes the boiler to have a lower efficiency, and is likely to cause overheating.

The methods of removing scale are numerous; those which are likely to damage the boiler should never be followed. It is much better to prevent the formation of scale than to be obliged to remove it after having become thick and hard.

After the scale has been removed, all the mud and rust should be scraped from the shell, the loose scale knocked from the stays and the boiler washed out. A strong stream of water from a force pump will often clean portions of the boiler which are inaccessible. After washing the boiler, the drying out may be hastened by placing trays of burning charcoal in the furnaces.

It is very important that the boiler be kept free from all fatty acids and oils. If the boiler is not cleaned frequently, oil will lodge on the stays, tubes, furnace crowns, tops of combustion chambers and on the shell. Oil is dangerous as it causes overheating.

Repairs. All boilers, no matter how well designed, constructed and managed need repairs from time to time. If the repairs are not made promptly and with the best materials and workmanship, the entire boiler will need to be replaced. The repairs needed are of great variety and the methods of procedure for similar cases differ greatly.

Replacing Fire Bars. In case the whole grate or a large number of fire bars drop into the ashpit or are badly burned the whole grate must be replaced after the furnace has been cleared out. But if only one or two bars have dropped out they may be replaced without drawing the fire. Some firemen are skillful enough to throw them in place, but a better plan, especially for those at the back of the grate, is to fasten the grate bar to the slicer with yarn and place it in position; the yarn soon burns away and the slicer can be withdrawn.

Seams and Rivets. All leaky seams and rivets should be calked while the boiler is empty; if a rivet continues to leak after calking, it should be cut out and a new rivet put in. The same applies to rivets which have, through corrosion or wear, become so small that their holding power is greatly impaired. Sometimes bolts are used in place of rivets when the boiler is so old that the jar caused by riveting is likely to cause new leaks. When bolts are used they may be made tight by washers or by means of lamp wicking mixed or coated with white or red lead.

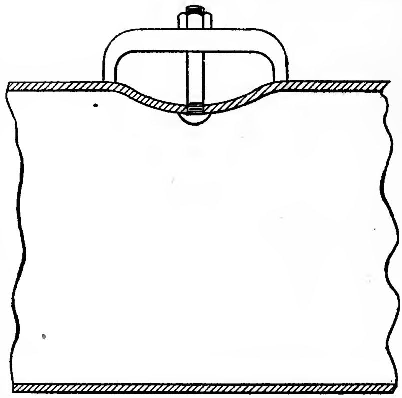


Fig. 53.

Furnaces that have come down slightly may be repaired by means of dogs that are similar to the crown bars on the tops of combustion chambers. The furnace plate is tapped at the center of the bulge and a dog placed lengthwise along the top as shown in Fig. 53. Sometimes it is necessary to place the dog circumferentially; but when so placed it has a greater tendency to slip. When the furnace comes down nearly the whole length it is held up by a series of dogs or by placing several hoops of **T** iron around it. Corrugated furnaces very seldom come down.

A furnace that has come down slightly may be restored to its original shape. The distorted portion is heated to a dull red and then forced to the original shape by means of blocks of wood, a screw jack and a piece of iron of the shape of the furnace. If this iron is heated it should be kept in place until both the furnace and the iron are cold; this process anneals the furnace plate. In case of collapse the entire furnace must be taken out and replaced. This is not a difficult job if the end plate and the combustion chamber plates are flanged to the furnace.

Circumferential Seams often need slight repairs on account of leaks. These repairs should be made as soon as possible as leaks rapidly increase. They are easily discovered because of the lumps of salt that collect at those places. If the boiler is lagged, soft spots in the lagging indicate leaks; if the leaks are not looked after promptly they will cause the shell to become weak. Usually these seams can be made tight by calking; but when the leak is too great for this method it is stopped by bolting a light iron cover plate over the seam as shown in Fig. 54. The space between the boiler and the cover is often filled with cement.

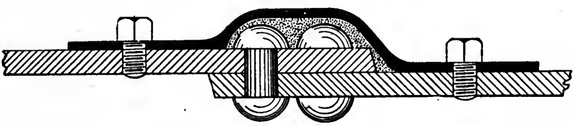


Fig. 54.

Shell Plates are patched by a **soft** patch or by a **hard** patch. A soft patch is made by securing a piece of plate over the defective portion of the boiler shell by means of patch bolts or studs. The joint is made tight by a mixture of white lead, oil, dry red lead and iron borings or filings. Soft patches must always be placed on the *inside* so that the action that caused the weakness in the original plate may come on the patch; also so that the pressure will not have a tendency to blow off the patch. A blistered plate in the furnace should be patched on the *outside*.

Soft patches are used when the boiler is old and weak; they should never be applied to a surface in contact with fire or hot gases except as a temporary expedient to stop a bad leak. A hard patch is one that is formed by riveting, or fastening by patch bolts, a piece of plate to the shell and making the joint tight by calking. The defective part of the plate should be cut away and the patch made large enough to rivet and calk. Hard patches should always be placed on the outside directly over the defective part and should be made of plate of about the same quality and thickness as the boiler shell.

When a patch is to cover a curved or uneven surface, a template should be made by hammering a piece of sheet lead into place. The piece for the patch can then be heated after drilling and made of the required shape.

A short crack can be stopped by drilling at each end and several intermediate points; these holes are countersunk and rivets placed in them. The rivet heads should be well spread by hammering. For a long crack, the plate should be cut away and a hard patch put on.

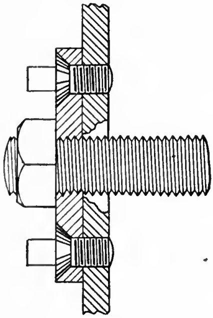


Fig. 55.

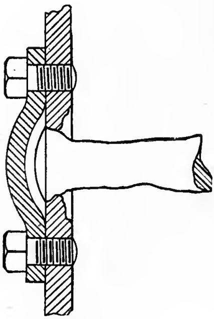


Fig. 56.

Screw Stays are often replaced both on account of the wasting of the stay and because of the wasting and bulging of the plates forming the water-leg. If the plates are thin the stays are likely to leak, especially if riveted over. Instead of renewing the stay bolt and placing a patch on the plate as shown in Fig. 55, the stay is sometimes left in place and a patch put on as shown in Fig. 56. The latter method should never be employed.

When the plates remain uninjured and the stay has wasted, a larger stay may be inserted.

Tubes often leak at the ends; if the leaks are due to the tubes they may be plugged temporarily by driving a pine wood plug into the end. These plugs should fit snugly and have a slight taper. When the leak is in the tube somewhere between the end plate and the back tube sheet it is stopped by driving a plug into the tube until the plug covers the crack. The plug will swell and salt up in a few minutes so that the leak will be tightly stopped. If the **tube plate** bulges, more of the ordinary tubes should be used as stay tubes or rods may be used in place of some of the tubes.

When the water-legs and bottoms of old boilers are badly worn out and cannot be made tight by calking and patching, they may be filled with cement. The cement is made thin and run in through the manholes. The surface of the cement filling should not be as high as the fire bars and the extremities of the feed and blow pipes must be kept clear.

WATER TUBE BOILERS.

For many years the cylindrical boiler has been almost the only type used in marine work. It has for that reason attained a high state of perfection. At various times engineers have tried to introduce water-tube boilers in place of the cylindrical, but on account of poor design, faulty construction or bad management, the experiments have not been entirely successful. At the present time, however, an increase of speed is demanded, and as a consequence higher pressures and lighter machinery are necessary. With this increase of pressure comes increase of weight, cost and damage in case of explosion. Engineers see that the cylindrical boiler must give way to a steam generator which is lighter, stronger and safer.

A water-tube boiler, if well designed and well constructed, seems to fulfill the requirements. Although the cylindrical boiler is serviceable, efficient, and can be made to stand any reasonable pressure, yet the water-tube boiler possesses many advantages over it. When the same care and skill have been used to perfect the water-tube boiler that have been used on the cylindrical, it ought to be as efficient and reliable.

The principal objections to the cylindrical boiler are the great weight, thick plates, difficulty of moving in and out of the vessel and the small furnace space. This last disadvantage has already been discussed. Also, when the boiler is under forced draft, the time allowed for the products of combustion to give up their heat is short.

Among the advantages of this boiler may be mentioned economy, and steadiness in supplying dry steam. It is also far better suited for salt water than is the water-tube boiler but this is not a great advantage at the present time.

Water-tube boilers are built in a great variety of designs. They may be divided into different classes, as straight tube and curved tube; or the drowned tube (that is, those having the upper ends submerged) and those having the upper ends opening into the steam space. Also, there is another division; those having a steam drum and those having none.

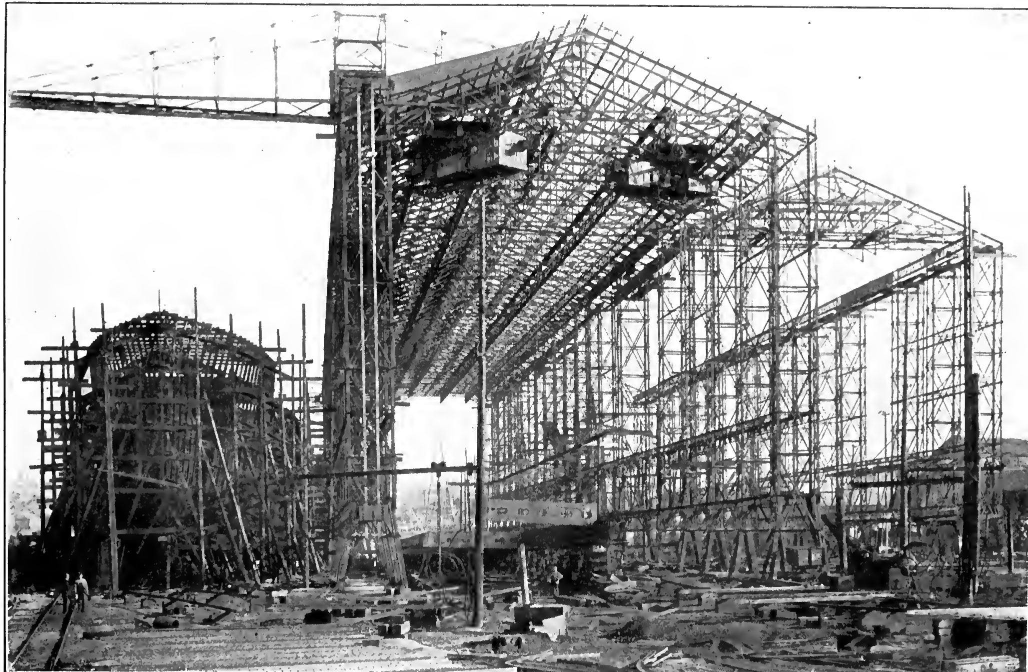
For convenience let us divide them into two classes, straight and curved tube. In the first class we may place among others, the Almy, Belleville, Babcock and Wilcox, Heine, Yarrow, D'Allest and Niclausse. A few of those having curved tubes are the Thornycroft, Normand, Mosher and Ward.

The straight tube boilers are easy to clean but are not as flexible and therefore steam cannot be raised in them as quickly.

The various water-tube boilers differ in detail but in the main they are similar. Of those used in marine work, the Almy, Belleville, Babcock and Wilcox, Yarrow, Thornycroft and Heine are described in "Types of Boilers." Some are better than others for certain conditions and as to what boiler is the best is a matter of opinion. Among the conditions which it is desirable to satisfy are the following:

1. Lightness of structure as compared with the cylindrical boiler.
2. Simplicity of form and construction.
3. Rapidity of raising steam.
4. Small quantity of water contained.
5. Great strength in proportion to the working pressure.
6. Capability of furnishing dry steam at high pressure.

The **grate area** is determined in a similar manner to that used in designing cylindrical boilers; but for most types the area must be greater so that the heat may be distributed evenly over the surface of the tubes. It is not well to have the heat too intense near any of the tubes. The construction of most



A Modern Shipyard.

water-tube boilers allows plenty of space above the fire both for complete combustion and for the distribution of heat.

The **tubes** should be made of solid drawn steel of the best quality. Copper is not a good material on account of its weakness at high temperatures. They are from $1\frac{1}{4}$ to 3 inches in diameter except in small light boilers where they are about 1 inch.

The **circulating tubes** or down comers are usually 3 to 6 inches in diameter. They should not be exposed to heat unless the flow is constant.

The **stays** in these boilers are not as numerous as in the cylindrical. The tubes, when in good condition, may be depended upon to hold the parts together, but in case the boiler is cooled suddenly they become unreliable. If the tubes are straight some of them may be fitted as stay tubes.

The size of the **steam drum** depends upon the amount of steam generated by the boiler. In order to make it as small and as light as possible, the boilers are sometimes worked at high pressure and the pressure maintained constant at the engine by means of a reducing valve.

The water-tube boilers having the upper ends of the tubes opening into the steam space have dash plates and internal steam pipes which separate the water and steam.

The various water-tube boilers have the following advantages over the cylindrical boiler:

1. Lighter (weight usually about $\frac{1}{2}$ that of the cylindrical).
2. First cost less on account of less material used.
3. Less danger of damage in case of explosion.
4. Large grate area and larger volume for combustion.
5. Greater rapidity in raising steam.
6. More easily placed aboard or removed.
7. Can be forced harder.

The last three conditions are of great importance in the navy. As to the relative economy there is much difference of opinion as the conditions vary considerably. In general the economy is about equal in both types.

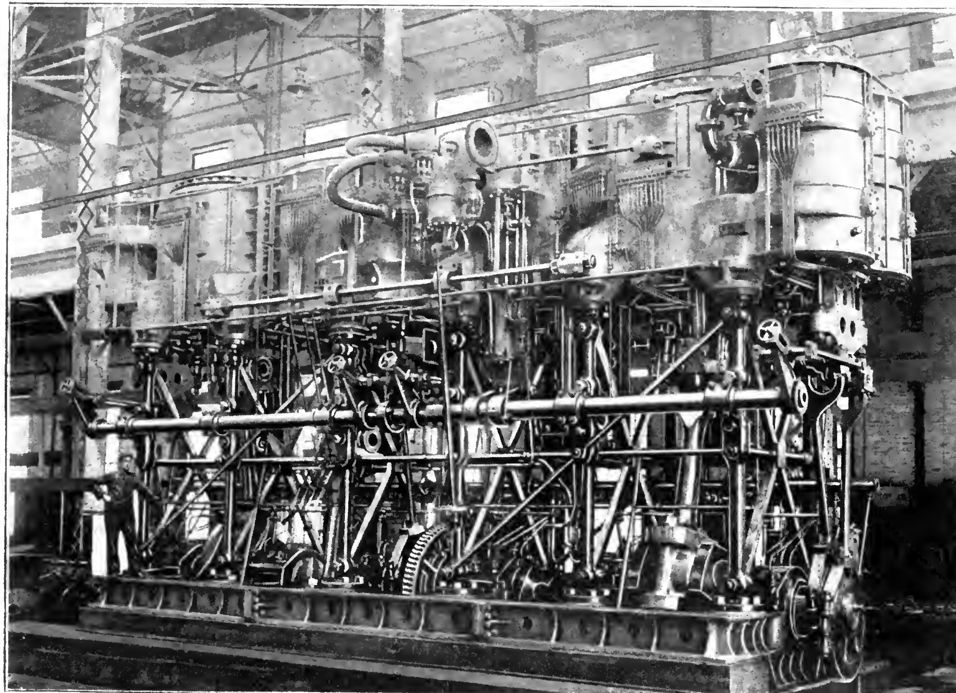
The ease of making repairs depends upon the type of boiler. The sectional type can usually be repaired more readily than others.

These boilers have several disadvantages among which may be mentioned the following:

1. Tendency to prime.
2. Difficulty of feeding.
3. Sensitiveness to corrosion and dirt.
4. Difficulty of repairing tubes.

These defects are reduced to a minimum if the boiler is of good design, well managed and constructed of best material.

Launch Boilers. The boilers used in torpedo boats, yachts and launches should be safe, light, compact and economical. Also they should be capable of supplying dry steam at high pressures. Small vertical fire-tube boilers are sometimes used but the water-tube boiler is better adapted to this work. The water-tube boilers already described are built in small sizes and generally give satisfaction. Perhaps the most used boilers for fast launches, yachts and small vessels are the Ward and Mosher. These boilers are similar in general principles to most marine water-tube boilers but are made small, light and compact.



ONE MAIN FOUR-CYLINDER TRIPLE-EXPANSION ENGINE ON U. S. S. "WEST VIRGINIA"

MARINE ENGINES.

The propulsion of ships by means of steam has been a subject of much interest and experiment during the last hundred years. The marine engine was at first a crude piece of machinery very bulky and wasteful of steam; but through the perseverance and skill of engineers, the marine engine of to-day is finely finished, compact, powerful and economical.

As in stationary and locomotive engines, the marine engine must fulfil certain requirements, and in order that it may do so the engineer must overcome certain obstacles and restrictions.

The first object of a marine engine is to propel the vessel through water at the required speed. It must also be so designed and constructed as to be readily reversed. In order to be commercially successful the engine and propelling apparatus must be suited both to the ship itself and to the required service.

Almost all vessels propelled by steam obtain their motion by the projection of a mass of water in the direction opposite to that of the vessel; the exceptions being so few and unimportant as to require no discussion. The water is usually projected in one of three ways:

1. By one or more wheels called **screw propellers** at the stern of the ship.

2. By one or more (usually two) **paddle wheels** outside of the boat.

3. By some device (usually a pump) which causes the water to issue in jets from orifices in the stern of the ship. This is called **hydraulic propulsion.**

The oldest of these three forms, is the paddle wheel and although the screw propeller is far better for sea-going ships, the paddle wheel is still used for certain kinds of service. Jet propulsion has not yet become common; the principal reason being the space used for the machinery and the large openings required in the sides of the ship.

The screw propeller is the most common means of propulsion and as it seems to be well adapted for the work, this type of machinery is worthy of the most attention.

About the beginning of the nineteenth century, many scientific men and mechanics turned their attention to the application of steam to navigation. They met with partial success but in almost every case the project was abandoned after the first unsuccessful trial.

Among these experimenters was an American named Robert Fulton. He was not the first to propel a boat by means of steam but he was the first to make steam navigation a success. Unlike those who abandoned their work after one or two unsuccessful trials he had perserverance enough to continue until his efforts were successful. In 1803, while in Paris, he constructed a small steamboat the trial trip being made on the Seine. The experiment was so successful that he had an engine built in England and then returned to America. In the spring of 1807 the "Clermont" was launched and the English engine put aboard in August. This boat was 133 feet long, 18 feet beam and 7 feet in breadth. The "Clermont" made a trip from New York to Albany (about 150 miles) in 32 hours and returned in 30 hours. The sails were not used on either occasion. This was the first successful long trip ever made by a steamboat.

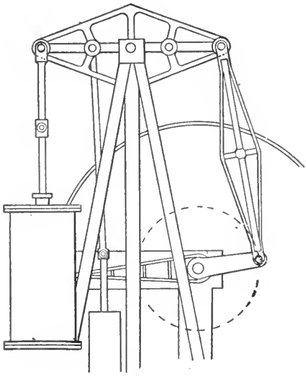


Fig. 1.

The engine of the "Clermont" was coupled to the crank shaft by a bell crank and the paddle wheels were connected to the crank shaft by gearing. The cylinders were 24 inches in diameter and of 4 feet stroke.

Fulton afterward built several steamers the largest one measuring 2,475 tons. This vessel was built for the United States Navy and was a very large steamer for that period.

While Robert Fulton was building steamers with success, Stevens of Hoboken built a steamboat which showed great merit. He used a horizontal sectional water-tube boiler with a working pressure of over 50 pounds per square inch. The usual pressures of the time were 5 to 7 pounds. His engine was direct-acting, high pressure and of the condensing type. The most remarkable feature was the use of a screw propeller of four blades.

In Stevens' second boat, the engines were of the same type as before, but twin screws were used instead of the single screw. Although the screw propeller was introduced as early as 1804, it was practically given up, and for about thirty years the paddle wheel was the principal means of propulsion.

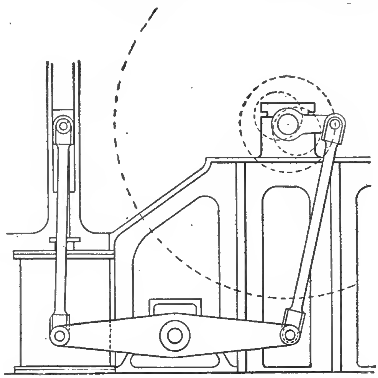


Fig. 2.

As the **beam engine** of Savery and Watt was the first to become successful, naturally some form of this type was the first to become common for paddle wheels. In the beam engine shown in Fig. 1, the motion passes from the piston-rod to a crosshead, and then is transmitted by a rod or link to one end of the beam; from the other end of the beam it is transmitted to the crank pin and shaft by means of the connecting-rod. These engines are well suited for side-wheel paddle steamers and have been used on river and harbor boats for many years. A modification of the beam engine is the **side-lever engine** shown in Fig. 2. This type was made in two forms, the true side-lever as shown in Fig. 2 and the "Grasshopper" engine. The latter differed from the former in that the lever was fulcrumed at the end instead of in the center. This engine possessed several advantages; a long stroke in a shallow ship, simplicity and consequently low first cost and little care. The main objections were its weight and bulk.

The **oscillating engine**, much used in England, was well adapted for paddle wheels. It is shown in Fig. 3. The cylinders are located below the shaft and are swung on trunnions. The piston-rod being connected directly to the crank shaft, makes fewer parts possible, as there are no guides, crosshead nor connecting-rod. Compactness and simplicity are among the advantages; the disadvantages being the difficulty in obtaining early cut-off and liability of the trunnions to leak. This type of engine could be used in an inclined position, but it worked best when vertical, that is, the piston-rod vertical when the piston is at the end of the stroke. These were the principal forms of early vertical engines.

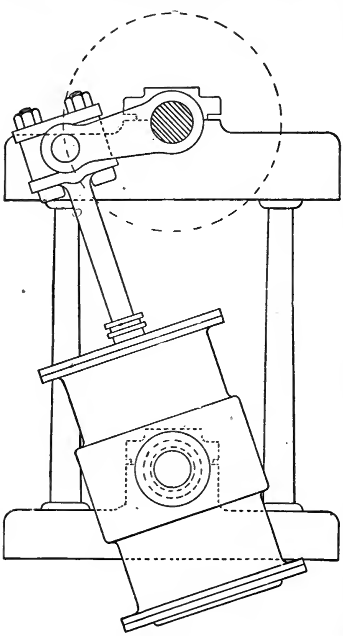


Fig. 3

Another type is the **diagonal or inclined engine.** This engine, shown in Fig. 4, is simply a horizontal engine set in an inclined position, to suit the height of the shaft at one end, and the frames of the ship at the other. It takes up a large amount of space in the fore and aft direction, but is very convenient when space is not one of the objects of design.

Of the other types of horizontal engines, **Penn's trunk engine,** shown in Fig. 5, has one striking peculiarity. It has no piston-rod; the connecting-rod hinges on a pin or gudgeon in the center of the piston. Inside of the cylinder and concentric with it is a cylindrical case or trunk which is attached to the piston and passes through stuffing boxes in both ends of the cylinder. This trunk serves as a support for the piston and makes an equal area on both sides of the piston exposed to steam. This engine is light and compact, and for low steam pressures, is economical. However, if the pressure is high, the friction of the large stuffing boxes is great; if the glands must be made very tight, the engine may be stopped. Again the loss of heat from the alternate heating and cooling of the large surface of the trunk is considerable.

The **return connecting-rod engine,** Fig. 6, is another form of the horizontal type. In this engine the connecting-rod is on the opposite side of the crank shaft from the cylinder. There are two piston-rods, one above the shaft on one side of the crank, and the other below on the other side. The piston-rods are fastened

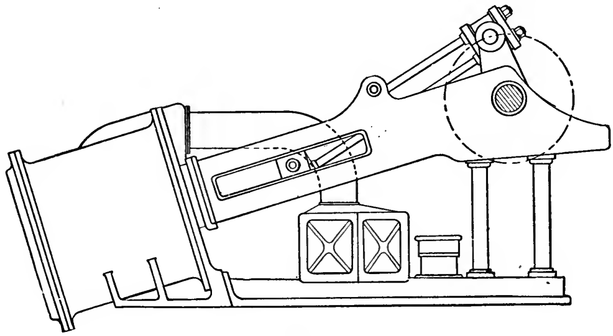


Fig. 4.

to a crosshead at the center of which is coupled the connecting-rod. This type of engine has some advantages and many disadvantages. It can have a long stroke since the cylinder may be near the shaft. It is not adapted for compounding as the cylinders cannot be made of the proper ratio without difficulty. The double number of stuffing boxes and other parts, together with the short eccentric-rod, make this engine undesirable.

The forms of engines already described were the results of early attempts to solve the problem of steam navigation. When, about the year 1840, the screw propeller began to gain favor, many experiments were made to determine the best type of engine. With the rapidly-revolving screw, in place of the slow paddle wheel, and the change in location of the shaft, a new type of engine was necessary. A change was made from the long stroke, heavy, low-speed engines to the small, light, high-speed type. This change was not made at once, but occurred slowly and with many blunders. During this time two other important changes took place. The increase of steam pressure from 10 or 15 pounds

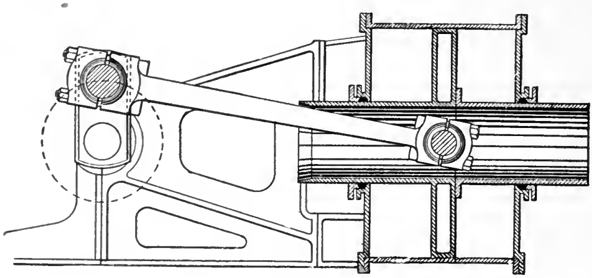


Fig. 5.

to 50 or 60, and the change from the jet condenser to the surface condenser. This latter change was of great advantage because it allowed the use of higher steam pressures which before were dangerous on account of scale.

With the higher steam pressure was produced still another

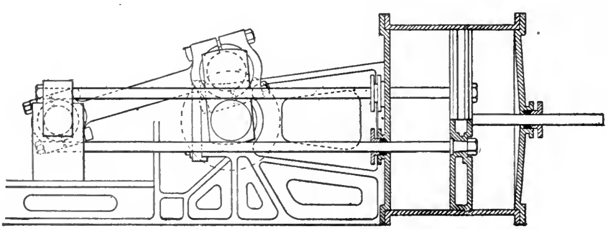


Fig. 6.

important advance. It became known among engineers that one of the greatest causes of loss in the engine cylinder was the initial condensation of steam necessary to raise the temperature of the cylinder walls. The great expansion desirable made the cylinder walls of low temperature at exhaust. This loss was prevented to a great extent by dividing the expansion among several cylinders.

These changes, higher steam pressures, surface condensers,

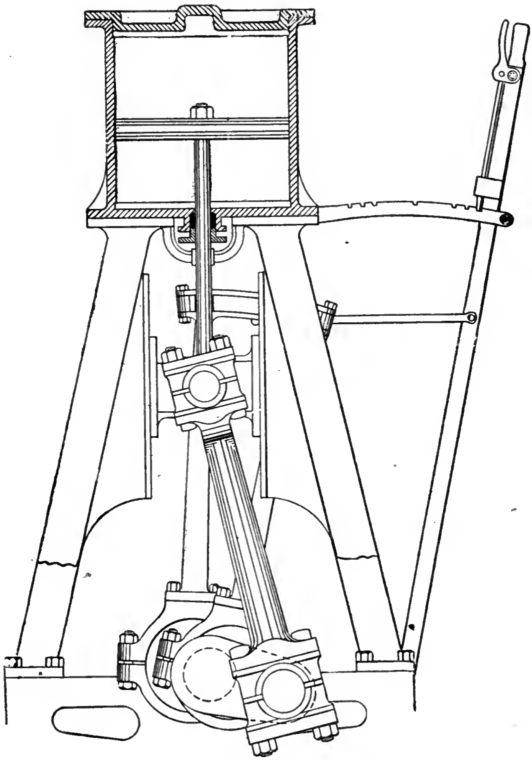


Fig. 7.

and multi-expansion engines completely revolutionized the marine engine. Although there are a few beam engines now in use and some of the older types of horizontal engines are occasionally

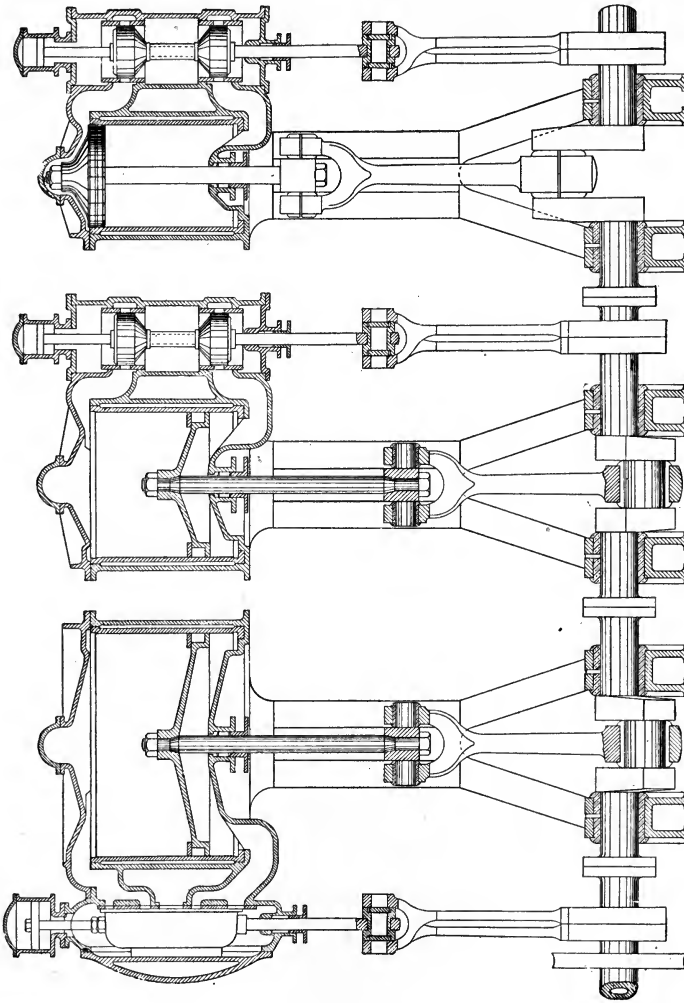


Fig. 8.

seen, the modern sea-going steamer is fitted with high pressure, multi-cylinder engines fitted with surface condensers and either cylindrical tubular boilers or water-tube boilers. These engines are direct-acting, vertical and of high piston speed.

The first screw engines were horizontal, working with a steam pressure of 20 to 25 pounds per square inch. The vertical type soon took the place of the horizontal because of the difficulty of fitting horizontal engines in ships.

A vertical engine for a launch is shown in Fig. 7. This engine has the same parts as the horizontal engine; piston, piston-rod, connecting-rod and crank. The chief difference is the frame. The cylinder is supported by a substantial upright framing which consists of a large back frame and a light front column or heavy frames as shown in Fig. 7 shaped like the letter A. The engines may have two guides as shown or but one guide. The positions of the links and eccentrics are changed by means of a lever but in large engines the link is shifted by means of a small steam engine or by worm gear and levers.

Fig. 8 shows the section of a triple expansion engine. The high pressure cylinder and intermediate cylinder are fitted with piston valves and the low pressure with a double ported slide valve. The pistons are of cast steel. The three cranks on the hollow steel shaft are placed 120° apart.

MULTI CYLINDER ENGINES.

The engines now used for marine work are compound, triple expansion and quadruple expansion, the triple expansion being the most common.

The advantages of the multi-expansion engine are briefly: The decreased loss due to cylinder condensation, the more even turning moment on the shaft and the reduction of pressure on the piston and consequent reduction of weight, friction, etc.

COMPOUND ENGINES.

The cylinders of compound engines are generally arranged in one of the three ways shown in Fig. 9. The **tandem or steeple** arrangement is shown at A; in this type both pistons are on the same piston rod and consequently there is but one crosshead and only one crank. The steeple engine is not expensive on account of the few parts, but as there is only one crank the turning moment is the same as with the single cylinder engine. In A the arrows show the direction of the steam.

At B, the **cross compound** arrangement is shown. This type is often called a **fore and aft** compound. There are two cranks which are placed at right angles to each other. For this reason a receiver is necessary. The advantages of this type are the reduction of pressure on a piston and the more even turning moments;

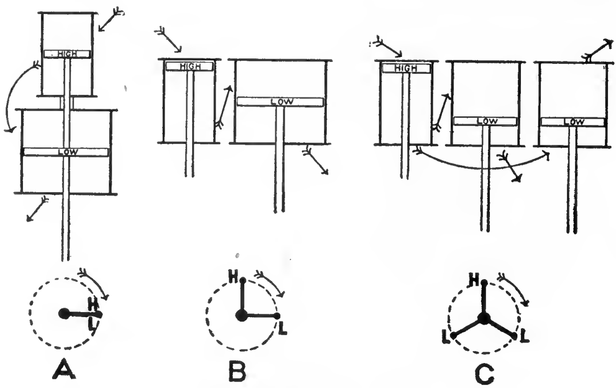


Fig. 9.

however, these engines having more parts are more expensive and they require more floor space than the tandem. Steam enters the high pressure cylinder and after pushing the piston through a stroke is exhausted into the receiver from which it enters the low pressure cylinder, is further expanded and then goes to the condenser.

The third arrangement C, called the **three cylinder compound**, consists of one high pressure cylinder and two low pressure cylinders. The high pressure cylinder is sometimes placed between the two low pressures. The cranks are usually set 120° apart and cause a more even turning movement than either of the compound arrangements shown at A or B. If a compound engine is to develop a large power the volume of the low pressure must be considerable; by dividing it, each cylinder may be made smaller and therefore more easily manufactured.

The **receiver** of a compound engine is the space between the high pressure piston when at the end of the stroke and the back of the low pressure valve and includes the ports of the high pressure cylinder and the pipe which leads from the high to the low. Formerly large reservoirs were fitted as receivers but it is now the custom to make the pipes between the cylinders large as experience

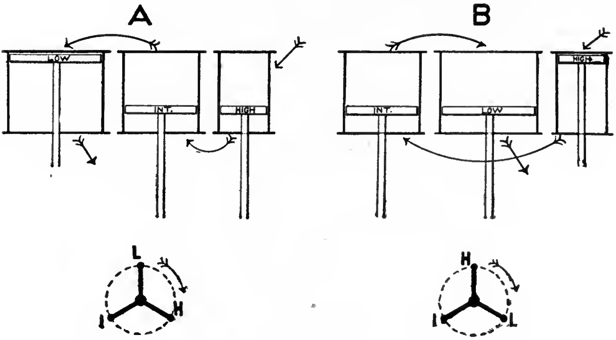


Fig. 10.

has shown the volume to be sufficient. The *capacity* of the receiver does not effect the total power of the engine but the effect of the size is shown on the back pressure line of the high pressure diagram and the admission line of the low pressure. As the volume of the receiver is increased the back pressure line of the high becomes more nearly straight and the admission line of the low more nearly parallel to the atmospheric line.

Triple expansion engines have two receivers called the first receiver and the second receiver. The same principles apply to the receivers of triple expansion engines as to compound engines.

TRIPLE EXPANSION ENGINES.

The triple expansion engine having three or more cylinders may have many different arrangements according to the fancy of the designer and the space in the ship. The three crank engine is the most common. The arrangement at A, Fig. 10 shows the natural sequence. It is the most used type; the steam going directly from one cylinder to another with a minimum amount of piping. The arrangement shown at B is similar to that of A but requires more piping. Sometimes the high pressure cylinder is placed in the middle. In the three crank engines the cranks exert an even turning movement on the shaft as they are usually placed at 120° apart.

Triple expansion engines may have but two cranks. A com-

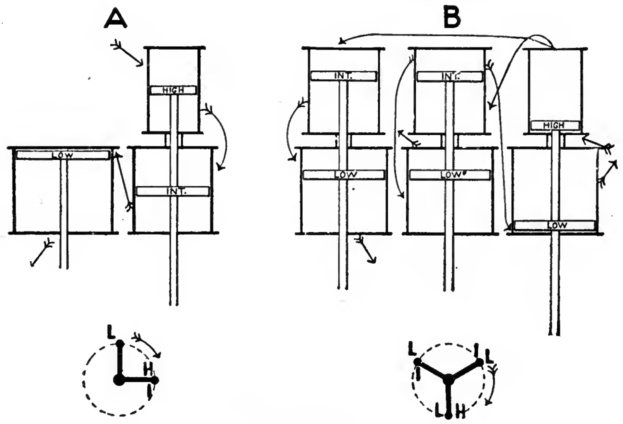
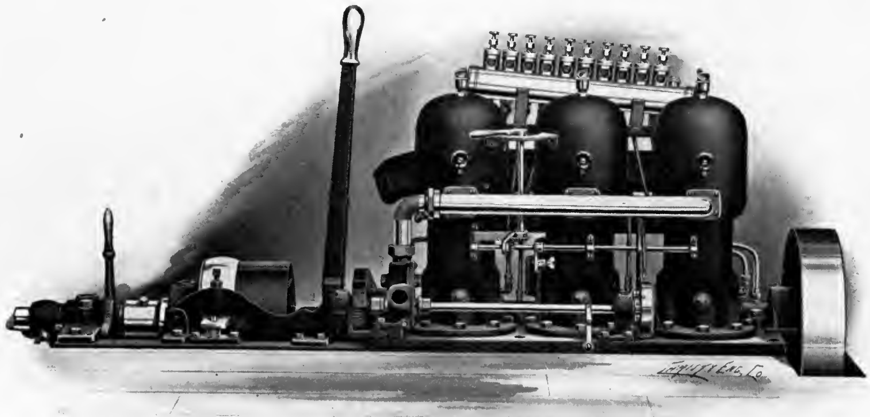


Fig. 11.

mon arrangement of this type is shown at A, Fig. 11. The cranks are placed at right angles to each other which does not permit of an even turning movement, especially as it is difficult to divide the power equally between the two cranks. It has the advantage of expanding the steam in three stages and is an easy way to make a steeple compound into a triple expansion. By using two high pressure cylinders, one over the low and one over the intermediate, this form is much improved.

An arrangement for very large triple expansion engines is shown at B, Fig. 11. In this case there are three low pressure



ROCHESTER 24-H. P. 3-CYLINDER MARINE GAS ENGINE, STARBOARD SIDE
Rochester Gas Engine Co., Rochester, N. Y.

cylinders and two intermediate. The large volume of the low pressure is thus divided among three of moderate size. Triple expansion engines are seldom made in very large sizes as twin screws are often used and in some cases each shaft has two separate engines. Thus in the U. S. S. "New York" there are four separate triple expansion engines, two for each screw.

QUADRUPLE EXPANSION ENGINES.

The quadruple expansion engine is a further development of the compound engine. The advantage gained by expanding the steam in four stages is slight unless the boiler pressure is at least 200 pounds per square inch. Even at this pressure the triple

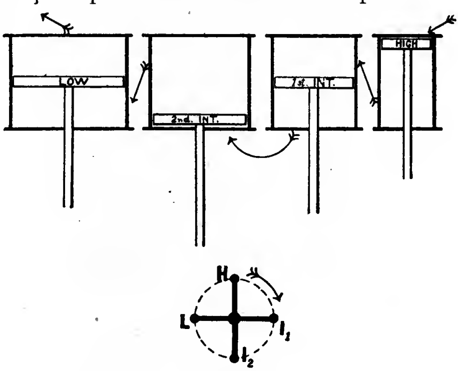


Fig. 12.

expansion engine is almost as economical and the increased first cost of a quadruple expansion engine often equals the slight gain in economy. The many cylinders of the quadruple expansion engine make it possible to use many combinations. An arrangement for a four cylinder quadruple expansion engine is shown in Fig. 12. The cranks are placed 90° apart. The four cranks are an advantage as far as turning moment is concerned, but the floor space occupied is considerable. The quadruple expansion engine can have two cranks; this plan, however, is not generally considered as good as the three crank triple, except in the floor space saved.

As the water-tube boiler is becoming more and more common, very high pressures can be carried with but slight risk. This increase of pressure will probably cause the quadruple expansion engine to take the place of the triple expansion in the same way that the triple expansion has taken the place of the compound.

NAUTICAL TERMS.

The plan of a vessel is represented in Fig. 13. The forward or front part is called the **bow**; the extremity A is called the **stem.** The rear end of the vessel is called the **stern.** If an object is near the bow it is said to be **forward**; if near the center C it is **amidship** and if near the stern it is **aft.** An object placed so that its direction is parallel to the line A B is said to be placed **fore and aft.** Thus, if a compound engine is so placed that the crank shaft lies along the line A B it is called a

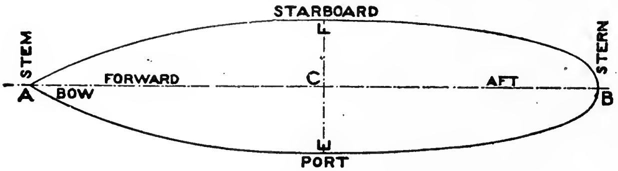


Fig. 13.

fore and aft compound engine. If, however, an object is so placed that its direction is at right angles to A B or is parallel to E F it is placed **athwartship.** To one standing on the deck and facing the bow, the **starboard** side is on his right and the larboard or **port** side is on his left.

The width of a vessel E F is its **beam** and the perpendicular distance from the lowest part of the vessel below the water line to the surface of the water is called the **draught.** The length of a vessel may be measured on the water line, between perpendiculars or over all. The beam, draught and length are expressed in feet and inches. The **displacement** of a vessel is equal to the weight of water that it displaces and is usually expressed in tons of 2,240 pounds. The displacement varies with the draught because the deeper the hull sets in the water the greater the amount of water it will displace. To find the displacement in tons, divide the number of cubic feet under the water line by 35. If the vessel is in fresh water divide by 35.93.

The **speed** of a ship is sometimes expressed in miles per hour; the mile containing 5,280 feet. More often, however, it is expressed in **knots** per hour. The knot contains 6,080 feet and is equal to about $1\frac{1}{6}$ miles. Whether the speed is expressed in miles or knots, it is always understood to mean per hour.

DETAILS.

The Cylinder. The steam cylinder for a marine engine is shown in Figs. 8 and 14. The cylinder consists of three distinct parts; the shell or outer casting, the liner and the cover.

The shell is the casting which encloses the liner in which the piston works. The shell also includes the bottom and the ports or passages through which steam enters and leaves the cylinder. The shell casting is very complicated and for this reason steel is seldom used. Cast iron that runs freely is the best material. This cast iron is suitable for the complicated shape but is not hard enough to form the working surface. At the side of the barrel the casting forms the steam and exhaust ports. If a piston valve is used the casting is made of such a shape that the circular seats may be fitted. If a slide valve is employed the cylinder terminates in a flat face, called the cylinder face, upon which the valve slides. As the iron of the cylinder shell is too soft for a wearing surface a false face of hard, close-grained cast iron is fitted to the casting as shown in Fig. 8. The casing which encloses the valve is sometimes cast with the shell and has a removable cover or is made entirely separate and bolted to the casting.

The bottom or crank end of the cylinder is usually cast with the shell although this portion is sometimes made separate like the cover. In large cylinders a manhole is placed in the bottom so that the inside may be examined without removing the cover and piston. In the center of the bottom is a circular hole in which the stuffing-box is fitted. This hole also facilitates the boring of the cylinder. The feet or lugs to which the columns are secured are cast on the bottom.

The cover is fitted to the top or open end of the cylinder.

and is usually of steel so that it will be strong and light. Sometimes both the cover and bottom are cast hollow, the space forming the steam jacket, but more often it is a single thickness strengthened by radial ribs. The shape of the cover depends upon the kind of piston used and upon the arrangements of the steam ports.

The liner or working barrel is a cylinder or bush of hard, close-grained cast iron or forged steel. It is usually fastened in

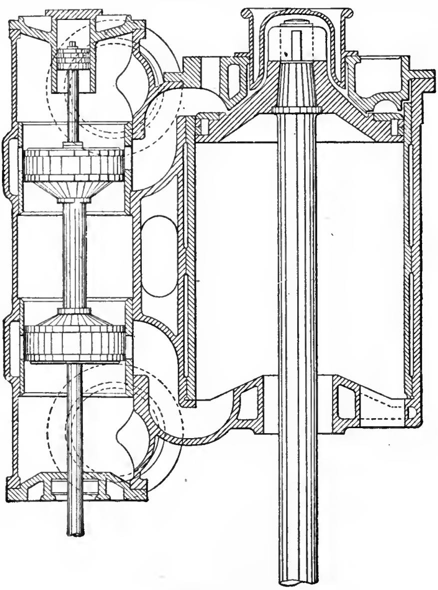


Fig. 14.

the cylinder shell by flanging the lower end and fitted with set screws or bolts as shown in Fig. 15. The top end is left free to expand. The joint is kept steam tight so that steam will not pass from the jacket to the cylinder. The methods of construction are shown in Figs. 15 and 16. The methods shown in Fig. 16 employ a copper ring secured by set-screws. These methods make a good lasting joint and the copper allows for expansion.

The space between the liner and the shell is from $\frac{3}{4}$ to $1\frac{1}{4}$ inches. It forms the steam jacket which reduces cylinder condensation and aids the warming of the cylinder previous to starting. In some cases the inner and outer casing have been made in one casting, but this causes a very complex casting and much trouble from unequal expansion. Also the separate liner allows the use of a harder iron or steel as the wearing surface. Another advantage of the separate liner is the ease with which it can be replaced or re-bored when worn.

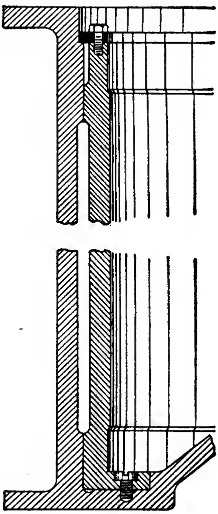


Fig. 15.

Cylinders of large marine engines are usually covered with some non-conducting material to prevent loss of heat by radiation. If high pressure is used the lagging must be incombustible, at least in the portions which are close to the hot surfaces.

Stuffing-boxes. In order that the piston-rod may enter and leave the cylinder without causing leakage, stuffing-boxes are fitted to the bottom of the cylinder and to the cover when the piston-rod is prolonged and passes through it. The principal requirement of a stuffing-box is that it should allow the rod to move freely without leakage.

Stuffing-boxes vary in detail but the principle is the same in all. Fig. 17 shows a simple form. A bush *b* is fitted where the rod passes through the bottom of the cylinder. This is usually of brass, gun-metal or babbitt. The gland *g* is fitted to the outer end of the stuffing-box and is adjusted by bolts. The space *l* between the bush and the gland is filled with some kind of packing. This is usually in the form of rings which encircle the piston-rod. When the gland *g* is pushed inward by means of the nuts, the packing is spread out laterally and fills the space. The farther the gland is forced in, the tighter the packing grips the rod. The tightness should be adjusted so that the rod will move with little friction but it must be tight enough to prevent leakage.

The material used for packing depends upon the conditions. With low pressure steam asbestos fibre has been used with more or less success depending upon the conditions. For high pressure

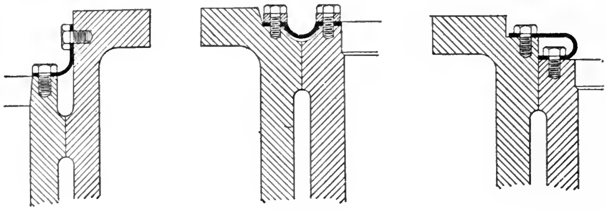


Fig. 16.

steam and continuous work, metallic packing is a necessity. A stuffing-box fitted with metallic packing is shown in Fig. 18. The packing is in the form of rings of white metal having a triangular section as shown at W. Each ring is made in two lengths. Alternating with these are rings of gun-metal G also of triangular section. A ring F containing a number of spiral springs is fitted next to the gun-metal bush. These springs tend to keep the metallic rings in contact with the rod by means of the pressure on the inclined surfaces. The gland V is screwed down to the stuffing-box and held in place by nuts on the bolts. This gland keeps the packing rings in place. The pressure of the springs takes up the slight wear. The gland V is recessed to form a space for ordinary asbestos packing which prevents the escape of any steam that may leak past the metallic rings. The gland H need not be screwed in very tight. A second recess is formed in the gland H for a soft gasket to hold oil or water lubricant on the rod.

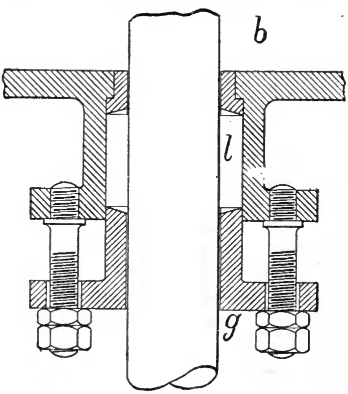


Fig. 17.

Pistons. The piston is a disc which is secured to the end of the piston-rod and on which the steam acts. Pistons were made of cast iron but in most modern marine engines they are of cast steel. Cast steel pistons are made of a single thickness and are much lighter than a cast iron piston of equal strength. Fig. 19 shows the general form. The main part or body B is dished to secure stiffness. At the circumference, which is made quite broad, there is a flange F which carries the packing ring R. The packing ring is made of hard, close-grained cast iron or phosphor bronze. It is cast as a hoop, is turned to the correct diameter and then cut at one part. It is pressed against the liner by the springs. The junk ring J holds the ring and springs in place. The ring R is carefully fitted and scraped to form a steam tight bearing with the surfaces of the junk ring and flange. The junk ring is secured by bolts which are sometimes screwed into gun-metal plugs M, Fig. 20, instead of into the piston itself. This construction is advantageous if the ring must be removed frequently. The bolt heads E are sometimes prevented from slacking back by the light guard ring O which bears against the bolt heads. The guard ring is secured by bolts the nuts of which may be secured by split pins.

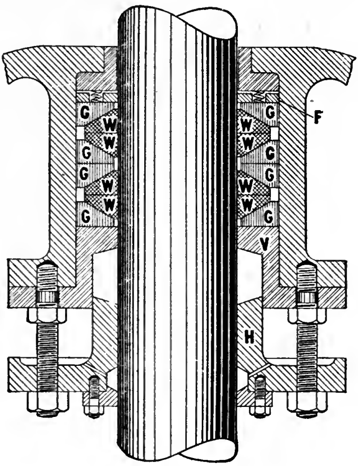


Fig. 18.

In the piston shown in Fig. 19 the packing ring is pressed against the liner by springs of the coach spring pattern. As the pressure is likely to vary at different points, spiral springs as shown in Fig. 21 may be used. These are sometimes preferred. Another plan is to use a continuous spring which encircles the entire piston.

Sometimes the packing ring is turned to a greater diameter than that of the inside of the liner. A piece is then cut out obliquely and the ring compressed to fit the liner. The elasticity of the ring tends to keep it against the liner. To prevent steam from leaking through the joint a tongue-piece is fitted back of the ring as shown in Fig. 19, at T. The tongue T fits into the slot in the ring, passes across the gap and enters the slot in the other end of

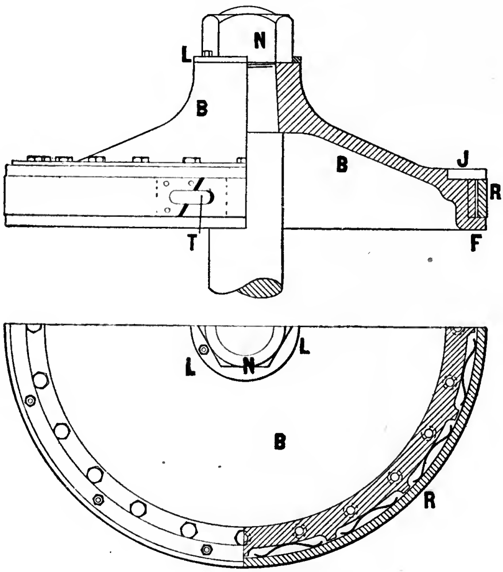


Fig. 19.

the ring. The plate D, Fig. 22, in the same piece with the tongue T is fitted to the inside of the ring. The tongue piece D is fastened to one end of the ring R by screws G, and as it is fastened to but one end the other is free to move.

The piston-rod is usually made of forged steel. The piston is secured to the rod by a variety of methods, but the simplest is the most common. By this plan a cone of slight taper is formed on the rod and a shoulder formed at the large end as shown in

Fig. 14. The coned end is carefully fitted to a similar hole in the boss of the piston and a nut fitted at the small end of the cone. The nut is used to tighten and hold the piston on the rod. Sometimes the shoulder at the base of the cone is omitted as shown in Figs. 8 and 19. The nut on the end of the piston-rod is kept from slacking back by the guard ring or other device.

ROTARY MOTION.

The marine engine, like the stationary, is a reciprocating and rotary engine. In other words, the steam drives the piston back and forth in a straight line in the cylinder and this motion is converted into rotary motion by means of the connecting-rod and crank.

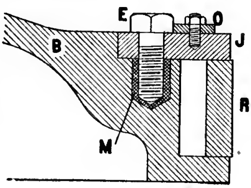


Fig. 20.

The motion of the reciprocating parts is illustrated by Fig. 23; one diagram representing the down stroke and the other the up stroke. In these diagrams, P represents the piston, PT the piston-rod, TR the connecting-rod, RS the crank and S the shaft. The end T of the piston-rod is made to move in a straight line by the guide G.

Suppose the engine is moving in the direction indicated by the arrows NN. The piston is driven first in one direction and then in the other, but for either direction the force acting along the piston-rod PT is resisted by the propeller. This produces tension or compression in the connecting-rod according to the stroke. The arrows indicate the direction of these forces. The forces acting in the piston-rod and connecting-rod produce a resultant force at the cross-head which is toward the guide, for the direction of rotation shown by the arrows NN. While the

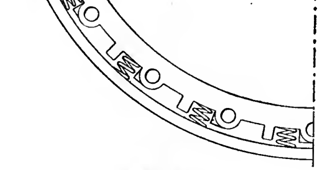


Fig. 21.

engine is turning in this direction the pressure is on the guide as shown during both strokes. If however, the engine turns in the opposite direction the crosshead will tend to leave the guide G or the resultant force will act in the opposite direction.

Fig. 22.

The force acting at the crosshead is resisted by the guide.

Crosshead. The end of the piston-rod terminates in the crosshead to which the connecting-rod is attached. There are many different forms of crossheads depending upon the frame and connecting-rod. In Fig. 7 is shown the arrangement when there are two heavy uprights. The crosshead has a bearing on both frames. For this form of crosshead the connecting-rod is almost always forked, that is, the connecting-rod divides and has a bearing at each side of the crosshead.

In Fig. 8 the crosshead is of the slipper type. In this type the guide is on one frame only and a portion of the crosshead called the slipper, slides on this bearing surface and is held in place in a sort of groove or channel of a shape as shown in Fig. 24. The slipper slides on surface A of the guide plate P which is secured to the frame. While the engine is going ahead the thrust on the crosshead keeps the slipper pressed against this surface. The flanges FF, secured by bolts, resist the thrust when the engine is going astern and keep the crosshead in the channel. Fig. 24 shows that the ahead surface is greater than the astern.

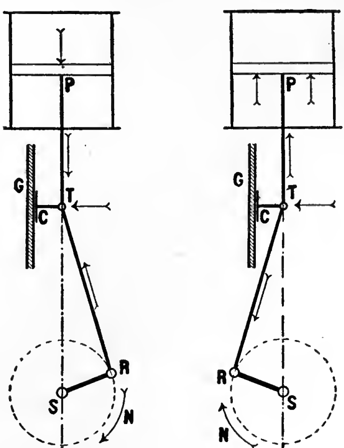


Fig. 23.

This arrangement works well, for a marine engine seldom runs astern at full power for any length of time. The space back of the plate P may be used for the circulation of sea-water to keep the plate cool. In some forms of slipper-crosshead the crosshead is built around the guide, which is a piece of steel of rectangular section, instead of being enclosed in the guide. In the crosshead shown in Fig. 7 the astern surface is equal to the ahead surface.

Connecting-rod. The connecting-rod is jointed to the crosshead at one end and to the crank-pin at the other. The rod itself is usually round or rectangular sometimes tapering with the small end at the crosshead. The large end is made to turn on the crank-pin and is formed as shown in Fig. 25. The end is made with a jaw J solid with the rod. The cap C is held to the jaw by two bolts BB which pass through the jaw and cap; the nuts of these bolts are usually prevented from slacking back by some approved locking device. The head and cap are shaped so as to receive the brasses OO which fit the crank pin.

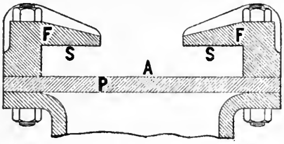


Fig. 24.

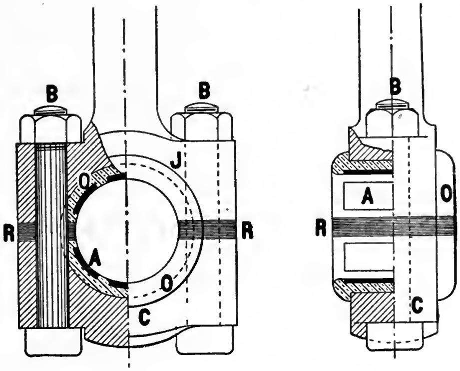


Fig. 25.

These brasses often have white metal strips AA fitted in the wearing surface. The white metal is an alloy which works well and can easily be replaced. The distance pieces or liners R are fitted for adjustment. When the brasses wear, these liners can be taken out and filed thinner but to obtain greater accuracy and lessen the time required the liners are often made up of thin strips of metal so that a thin strip can be removed. The liner may be made of a cast distance piece and several thinner pieces on each side. To obtain smooth working especially at high speed the brasses should be screwed hard to the liners.

If the small end of the connecting-rod is not forked, the end is made similar to the end shown in Fig. 25. When forked it has an appearance as shown in Fig. 26. The end carries a pair of brasses BB in each end which fit the pin F which projects each side of the crosshead. The caps C are held by bolts in the same manner as for the large end. The movement of the pin in the brasses is oscillatory and not rotary; for this reason the brasses are not always fitted with white metal. The pin has a tendency to wear oval and is usually case-hardened if worked in brass or gun-metal.

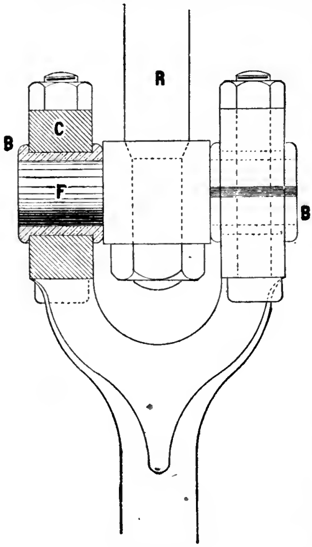


Fig. 26.

Crank-shafts. The cranks for marine engines are double, that is, they consist of two crank-arms as shown in Fig. 27. The crank-shafts are made in parts and these parts bolted together; that is, for a three-cylinder triple expansion engine, the crank-shaft would be made in three separate parts, one for each cylinder. These three are sometimes made alike so as to be interchangeable. This necessitates carrying but one spare length. The lengths are fastened together by flange couplings as shown at FF, Fig. 27. To insure the proper alignment one end is filleted into the next length as shown at N. The crank-pin is made of about the same diameter as the shaft. Shafts and crank-pins are usually hollow if they are large; the diameter of the hole being about one-half that of the shaft as shown by the dotted lines. The central portion of the shaft is the least effective in resisting twisting and when it is removed the shaft is almost as strong as when solid. The saving in weight thus effected is equal to about 20 per cent.

Bearings. The object of bearings is to enclose the shaft or journals in parts that are easily adjustable and renewable. The enclosing parts should be made of some material that will not injure the journal, will be strong and firm and that will work with little friction. Brass or gun-metal lined with strips of white metal answers the requirements in most cases. The white metal is usually melted and run into dove-tailed recesses as shown in the

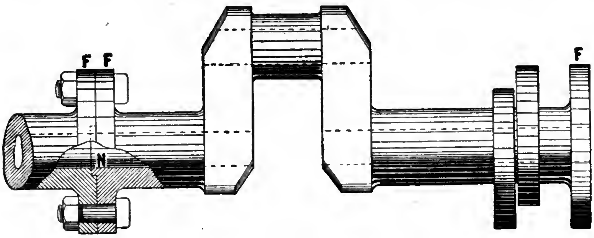


Fig. 27.

various figures and when finished stands just clear of the surface of the brass.

The brasses are fitted into the frames or bed-plate as the case may be, the frame being recessed to receive them. In the case of the main bearings, the forces act vertically and the brasses are therefore placed above and below the shaft. In large bearings, the bed for the bottom brass and the bottom of the brass itself are made cylindrical, to facilitate the removal of the brass while the shaft remains in place. To remove the lower brass, the shaft is supported and the brass moved around toward the position occupied by the top brass. Brasses are held in place and adjusted by bolts and nuts. The adjustment is facilitated by the insertion of thin strips of metal between the brasses as with the ends of connecting-rods.

In order to have good working, the bearing surfaces must be large, accurately fitted and adjusted and kept clean and well lubricated. Any dirt that finds its way between the journal and the brasses soon causes wear and perhaps heating. The lubrication also is important. For the main bearings there are several methods; siphon lubricators and various forms of oil cups and boxes being common. The oil finds its way to the inner surfaces of the brasses through oil holes and reaches the various parts of the bearing by channels cut in the faces of the brasses.

Crosshead guides and the connecting-rod bearings are supplied with suitable lubricator cups. The crank-pin and the brasses of the large end of the connecting-rod are moving so fast and continuously that they cannot be oiled as easily as are the other bear-

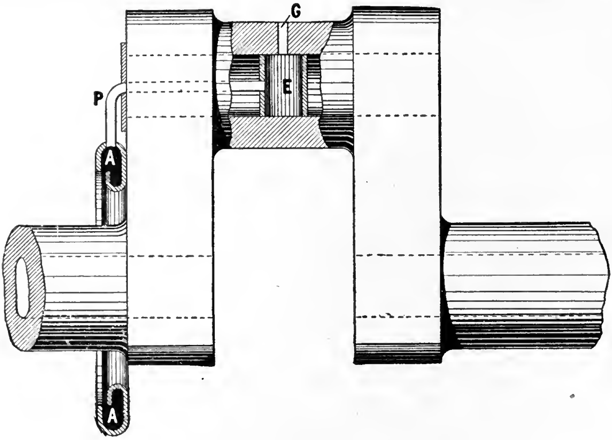


Fig. 28.

ings. For this reason, a centrifugal lubricator is sometimes used. The general idea of this device is shown in Fig. 28. The annular casing A shaped as shown is fastened to the crank-arm and communicates with the space E by means of the pipe P. From the space E the oil flows to the surface of the crank-pin by the small holes G. Oil poured into the casing from the outside is forced by centrifugal force from the casing to the crank-pin brasses.

Thrust Bearing. While the screw is revolving, the thrust or pressure tends to force the propeller-shaft forward or aft, according to the direction in which the vessel is going. To resist this tendency several collars are forged on the shaft, and these collars revolve in a block called a thrust bearing. Thus we may say that the office of the thrust bearing is to receive and transmit to the ship the thrust produced along the shaft by the revolving of the screw. This bearing is situated near the forward end of the screw-shaft, or in other words, it is just aft of the engines.

A simple form of thrust block is shown in Fig. 29. It consists of a cast iron block R, with a removable cap G. The portion of the shaft that lies in this block is forged with several collars C on it. These collars fit between gun-metal or brass rings B, which are fitted in grooves or recesses turned in the bearing R and the cap G. The rings B are prevented from turning by the tongue pieces F, which are placed at each side between the cap and base. The collars on the shaft press against the after or forward faces of the collars B according as the screw revolves for

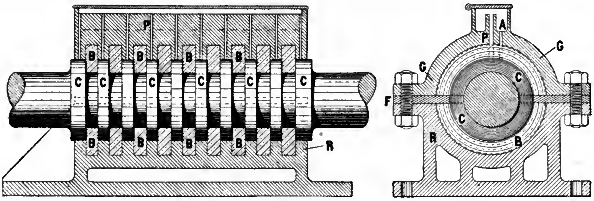


Fig. 29.

ahead or astern. In both cases the thrust is taken by the block. The thrust bearing can be adjusted in a fore and aft direction as the bolt holes are elongated. Sometimes the base is cored out so that water may be circulated to prevent heating of the rings. An arrangement for oil lubrication is shown at P, and water may be supplied through the holes A.

It is of great importance that the thrust should be distributed among the rings and not taken by one or two of them. In case a few of the rings take the thrust the pressure is so great that it is difficult to obtain sufficient lubrication to prevent heating. In the thrust block shown in Fig. 29, the thrust rings cannot be easily adjusted, and therefore this form is not used very much.

The thrust block shown in Fig. 30 represents the type most commonly used at the present time. In this block each thrust ring may be readily adjusted without moving any of the others.

There is only a lower part or base as the cap is formed of adjustable collars, which are in the form of horse-shoes. One of these horse-shoe rings is shown in Fig. 31. These rings are placed over the shaft between the shaft collars, and are secured to two large screws on each side by means of nuts which serve to adjust the rings and hold them in place. The horse-shoe collars are lined

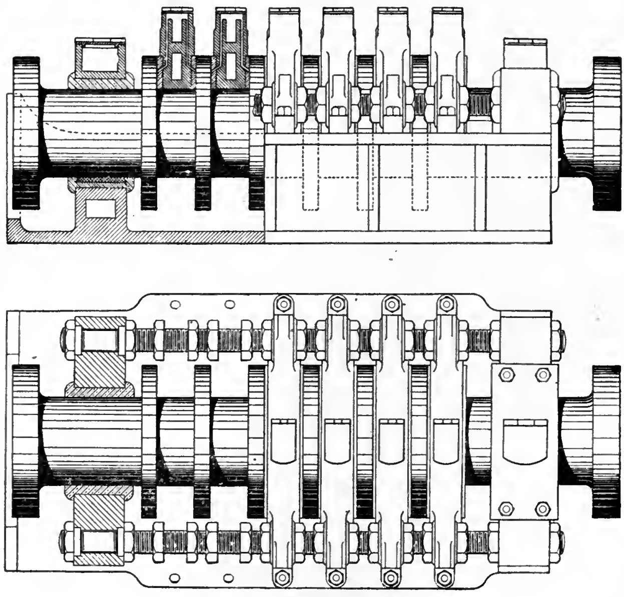
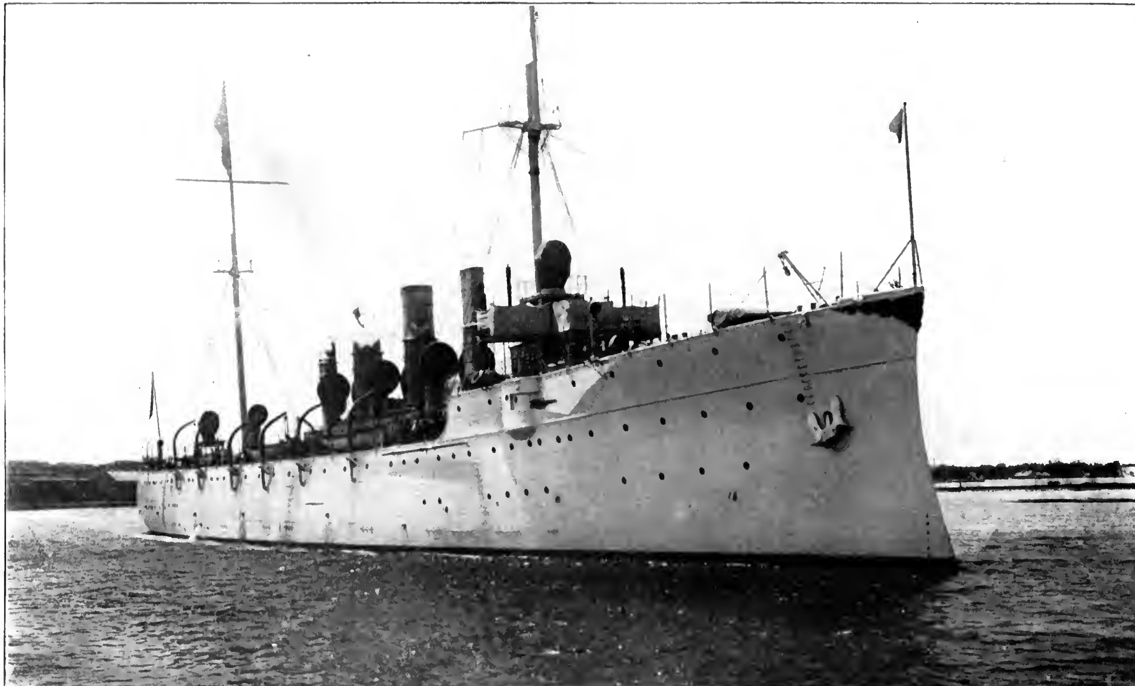


Fig. 30.

with white metal for steel shafts and bronze or brass for wrought iron shafts. These linings are usually fitted into recesses formed in the thrust rings.

The lower part of the base is cored out so that water may be circulated to keep the bearing surfaces cool.

Each collar is supplied with an oil box or cup so that the lubrication will be abundant. The oil should reach the collars at



UNITED STATES SCOUT CRUISER "SALEM"
Twin Screws. Curtis Marine Reversible Turbines. 20,000 H. P.
Fore River Ship Building Co.

the part nearest the center of the shaft because centrifugal force tends to throw it toward the outside edge.

Ordinary bearings are fitted at one or both ends to support the shaft and prevent vibration.

The thrust bearing is generally placed near the engine. The first length of shafting abaft the crank shaft is frequently the thrust shaft. Thus if placed near the engine it can receive proper attention and be kept clean and well lubricated. This bearing is of considerable importance, because if the rings heat they will wear rapidly, and then the whole line of shafting must be thrown forward to take up the wear. In addition to the inconvenience caused by heating, cutting and wear, the friction of a dirty, half lubricated, or poorly adjusted thrust bearing greatly reduces the power delivered to the propeller.

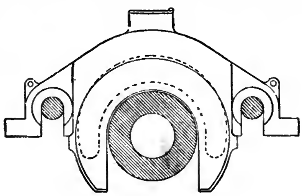


Fig. 31.

The *number of collars* depends upon the size of the shaft, which in turn depends upon the power of the engine, and the ideas of the designer. If the collars are many they will of course be of small diameter. In this case the thrust will probably be taken by several collars, but if for any reason it comes on one or two, the small diameter prevents their acting effectively without heating. The large collars are of necessity of large diameter and therefore expensive to forge, and have higher speed of rubbing surfaces; but the few collars allow a better design of block, and one or two of them are better able to take the whole thrust.

The number of collars is determined from the experience of the designer. To calculate the diameter of the collars, the number is first assumed.

Let n = the number of collars.
D = the diameter of collars.
d = the diameter of the shaft.
P = total load.
p = pressure per square inch of area.

Usually the allowable value of p is limited to about sixty pounds.

The following formula expresses the total load:

$$P = p\left(\frac{\pi D^2}{4} - \frac{\pi d^2}{4}\right) n.$$

Inserting the value of p as 60, we have

$$P = 60 \times \frac{\pi}{4}\left(D^2 - d^2\right) n.$$

$$P = 47\left(D^2 - d^2\right) n.$$

$$\text{Hence } D = \sqrt{d^2 + \frac{P}{47n}}$$

Suppose a shaft is 12 inches in diameter and there are six collars, what should be the diameter of the collars if the total thrust is 41,000 pounds?

$$D = \sqrt{144 + \frac{41,000}{282}}$$

$$= \sqrt{144 + 145} = \sqrt{289}$$

$$= 17 \text{ inches, Ans.}$$

STARTING GEAR.

The marine engine must be made so that it will run in either direction as required, and the gear must be so constructed that the engine may be reversed quickly and with little trouble. In a small engine the valve and links may be moved with so little force that a hand lever is fitted, as shown in Fig. 7. In a large engine, especially if large slide valves are used, considerable power is necessary to move the gear. For this reason it is customary to use a small steam engine to assist in moving the links and valves. This arrangement, called the *steam starting gear*, has several forms and the details vary considerably. Fig. 32 shows one form. In order that all the links of a multi-expansion engine may be moved at once, a shaft, called the weigh shaft, runs the length of the engine and is held in bearings on the frames. To this shaft (W in Fig. 32), all the links are connected, so that if the shaft is rotated all the links move together. To this shaft are keyed for each engine two rocker arms, M and N; at the end of N is connected one end of the reach rod X, which is connected at the other end to the centre or to the ahead end of the link. The end V of

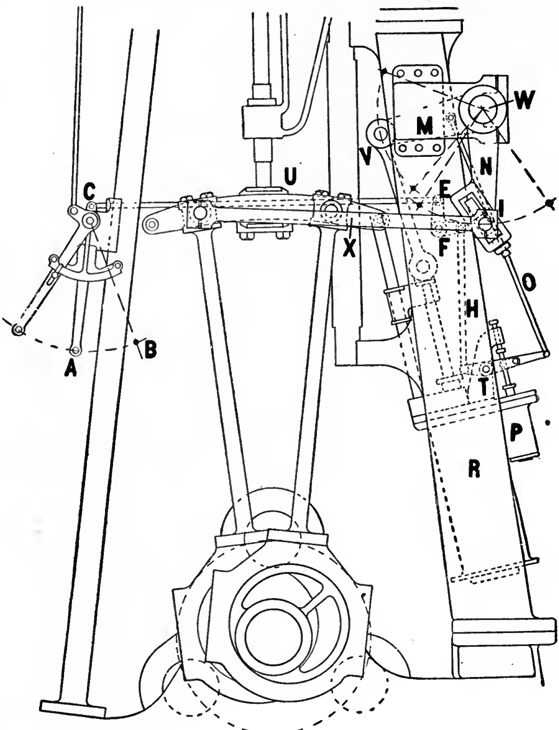


Fig. 32.

the arm M is jointed to the end of the connecting-rod of the small steam engine R. The rod O connects the arm M and the valve of the small engine. It will be seen from the sketch that if M is moved downward, N will move to the right, and as N moves to the right the reach rod and link will also move in that direction.

The action of the gear is as follows: When the handle is moved from A (the mid-position) to B, the point C moves to the left, c rrying with it the rod C E. This movement raises the rod H which is connected to the lever fulcrumed at T. When the rod H moves upward the rod O moves downward, which causes the arm M to move downward, thus moving N to the right. As has been stated, the moving of N moves the reach rod and the link. As all the links have similar reach rods and rock arms they also move. When the handle A is moved, the reach rod moves also, but as the power applied at A is not sufficient to move the gear rapidly or to any great extent, it is arranged so that when

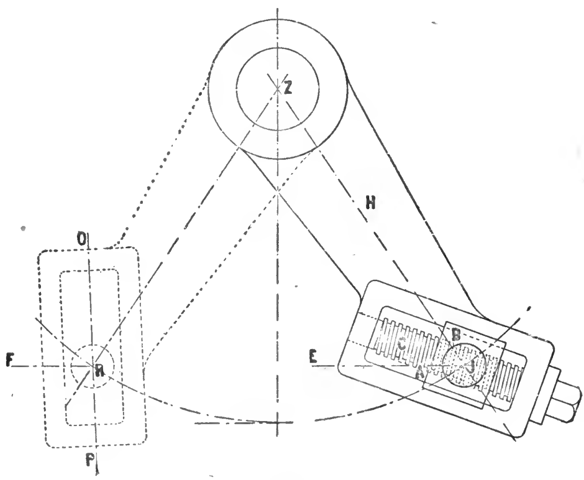


Fig. 33.

the link O moves, the valve P also moves and admits steam to the cylinder R; the piston in R moves its piston-rod, connecting-rod and the arm M. Thus it is readily seen that movement of the handle A moves the link slightly and at the same time starts the engine that aids in the movement of all the links.

From the study of "Valve Gears" we know that linking up shortens the travel of the valve and causes earlier cut-off. In compound and triple expansion engines the links for all the cylinders move the same amount, so that cut-off is altered the same amount in all the cylinders. When working at reduced powers it is often desirable to change the cut-off in one cylinder without changing it in others, or it is often necessary to make a greater change in some cylinders than in others. Expansion valves are undesirable for several reasons, and to accomplish the change in expansion the end of the reversing arm N is made with a slot and block as shown at I Fig. 32 and enlarged in Fig. 33. The reach rod is attached to the block B which can be moved and adjusted in the slot A by the screw C. Thus if the block B is moved, the position of the link is altered slightly which causes a slight change in the cut-off. In Fig. 33, the arm H is shown in the ahead position. From the position of the slot it is seen that this movement can be effected when in this position. The dotted lines show the arm and slot when in the astern position. If the link is in the astern position the movement of the block is vertical and the position of cut-off is not altered as there is no lateral movement. Thus if the link is in the ahead position and arranged for early cut-off and is suddenly shifted into astern position the links will be in full or nearly full gear.

In Fig. 33, the lines F R and E J show the approximate positions of the center of the reach rod. The angle JZR depends upon the amount of movement of the links, and is usually a little less than a right angle.

It is customary to fit a hand-reversing gear so that in case of accident to the steam starting engine, the main engines can be reversed by hand. This gear consists of a hand-wheel on a worm shaft. The worm turns a worm wheel which rotates the arms on the weigh shaft. Provision is made for throwing the worm in and out of gear.

CONDENSERS.

The general description and method of using condensers has already been given in previous discussions. In marine work the surface condensers is used almost exclusively, because with this type the injection water (sea-water) does not mingle with the condensed steam. If the jet condenser were used, the salt water would soon deposit so much salt on the heating surfaces that the boilers could not carry high pressure. Also there would be a loss in efficiency.

The condenser is advantageous for two reasons; it increases the power of the engine by reducing the back pressure, and it allows the feed water to be used over and over again.

The surface condenser is, briefly, a large closed vessel in which is a great number of small tubes. The general arrangement is shown in Fig. 34. The exhaust steam from the low pres-

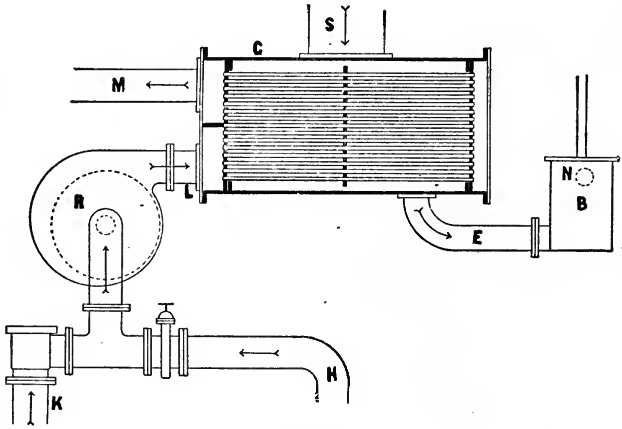


Fig. 34.

sure cylinder enters the condenser C and is condensed by the cold water because the latent heat is absorbed by the water. In the surface condenser the cold water may surround the tubes through which the steam flows, or it may circulate through the tubes and the steam surround them. The latter arrangement is the more common. Sea-water enters the vessel through the pipe K and flows to the circulating-pump R, which forces the water into the condenser through the pipe L. After flowing through the tubes it leaves the condenser by means of the exit M and flows overboard. Exhaust steam enters at S, and is condensed by coming in contact with the cold tubes; the water (condensed steam) then falls to the bottom of the condenser and flows to the air-pump B by the pipe E. The air-pump removes the air, vapor and condensed steam from the condenser and forces it through the pipe N into the hot well, from which it goes to the boilers or to the feed tank. The circulating water may be drawn from the bilges through the pipe H.

The **circulating-pump** is usually of the centrifugal type consisting of a fan or wheel which is made up of a central web or hub and arms or vanes, as shown in Fig. 35. The vanes are curved and as the water is drawn in at the central part the vanes throw it off at the circumference. A suitable casing directs the flow. This type of pump is advantageous because there are no

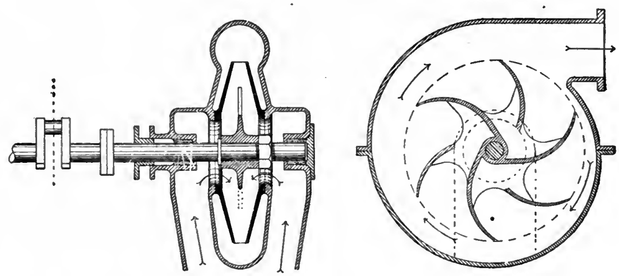


Fig. 35.

valves to get out of order, and as the lift is little, if any, the pump will discharge a large volume of water in a nearly constant stream. The circulating-pump is usually placed below the water line so that the water flows to it. The pump is driven by an independent engine so that the circulating water may cool the condenser even if the main engine is not working.

The centrifugal pump works more smoothly and with less trouble than an ordinary force pump because it is not reciprocating and it has no valves. The circulating-pump is also piped so that it will pump from the engine room bilges if necessary without the water passing through the condenser. Sometimes two circulating-pumps are fitted to each condenser, each pump being of sufficient capacity to supply the condenser. This arrangement provides for a large bilge pumping power and also duplicates the circulating arrangements.

A suction pipe from the bilge is connected to each pump, and the valves are arranged so that the pump may be cut off from the sea and connected to the bilge or *vice versa.*

When the steam is condensed the water falls to the bottom of the condenser and is drawn out by the air-pump. This pump is usually worked from the crosshead of the low-pressure cylinder. With this arrangement the air-pump cannot work while the main engine is not running, so that the condenser is full of air when the vessel is not in motion. It is often desirable to have a

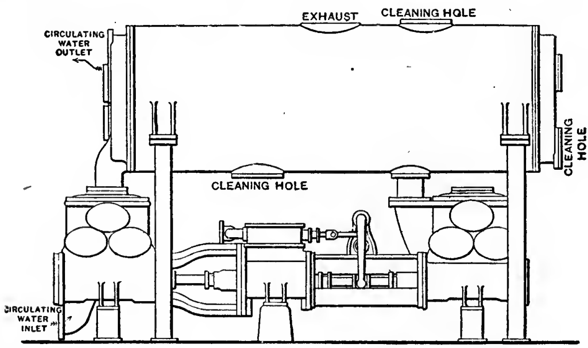


Fig. 36.

vacuum in the condenser before the engines start so that it will assist in starting. For this reason a condenser is sometimes used like that shown in Fig. 36. This condenser is of the surface type, the chief difference being in the pumps. The air-pump is independent of the main engine. The steam piston, the air-pump piston, and the circulating-pump piston are all on one rod. Thus the pumps may be started and a vacuum formed before the main engines are started.

A vacuum may be formed by admitting live steam to the condenser and then forcing in the circulating water. The live steam drives the air out of the snifting valve when the pressure in the condenser exceeds atmospheric pressure. The snifting

valve is a small check valve attached to a condenser; the pressure of the atmosphere keeps it closed. When live steam is admitted to the condenser, the pressure will become greater than atmospheric pressure and the air is driven out of the snifting valve. When the circulating water condenses the steam the pressure within the condenser decreases, because water occupies much less volume than the same weight of steam and the valve closes. In case there is no snifting valve, the drain cock may be used in its place, but it is not automatic.

On account of the oil in the exhaust steam, the condenser tubes become covered with a coating of grease and have to be boiled out. To do this the condenser is nearly filled with a solution of hot water and caustic soda; live steam is then taken from an auxiliary or donkey boiler.

In order to have the vacuum maintained the air must be exhausted from the condenser continuously. This is done by the air-pump which withdraws the condensed steam, any air that may leak in and any vapors that may rise from the water.

The **air or vacuum pump** is made in a variety of constructions, a common form being shown in Fig. 37. It consists of a cylindrical cast-iron casing or barrel B. Sometimes a brass barrel or liner is fitted within the iron casing. The pump is bolted to the condenser in such a manner that the condensed steam will flow into the pump at E. The bucket or piston P fits the barrel closely and moves up and down within it. At the bottom of the pump several *foot valves* F are fitted. Similar valves A, called *delivery valves*, are fitted to the top of the pump. In the pump shown there are four bucket and four delivery valves. Also there are four similar valves H, in the piston.

The valves C are usually made of hard rubber. They are circular flat plates which seat on flat brass seats perforated to allow water and air to pass. The valves are placed on studs on which are guards *a*, which limit the rise of the valves.

Sometimes a light brass spring is placed between the guard and the valve to help return the valve to the seat. It is seldom that these springs are placed on the foot valves but they are frequently found in the bucket and delivery valves. As the spring tends to keep the valve to its seat, more force is required to open the valve when a spring is used. Hence, if springs are fitted to the foot valves they may cause an imperfect vacuum since the force which opens them is the hydrostatic head and the air pressure in the condenser.

The action of the pump is as follows: When the piston descends, as shown by the arrow, the foot and delivery valves close and the bucket valves open. The water and air above the foot valves enter the space above the piston. When the piston rises, the bucket valves close because of the pressure of water on them. The water is therefore carried up by the piston and forced through the delivery valves. While the piston is rising a vacuum or partial vacuum is formed below the piston, and the pressure of water and air in E causes the foot valves to open and the water and air rushes through to fill the space under the piston. When the piston has reached the top of the pump the space below it is filled with water and air, and the water and air above it are being discharged to the hot well through N. When the piston commences the down stroke the delivery valves close and prevent the air and water from returning to the air-pump, the bucket valves open to admit a new supply to the top of the piston and the foot valves close.

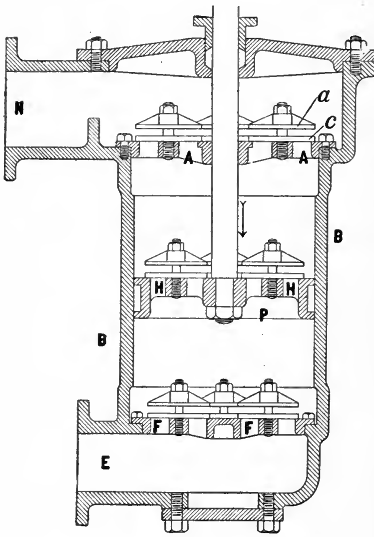


Fig. 37.

Foot valves are not absolutely necessary, in fact they are sometimes omitted but their use increases the reliability of the pump.

A small check valve or pet cock is generally fitted to the pump below the delivery valves. It is used for admitting air above the piston to prevent slamming of the pump. If there is no air cushion, the shock of the water on the up stroke is likely to cause slamming. When slamming occurs it may be stopped by admitting more air. This air does not effect the vacuum because it does not flow through the bucket valves. In Fig. 37 all the valves are shown down on their seats.

The vacuum that can be obtained depends upon the lightness of the valves, and the thoroughness with which the pressure is removed from above the foot valves by the air-pump. This in turn depends upon the nearness of the bucket to the foot and delivery valves at the ends of the stroke and the fit of the piston.

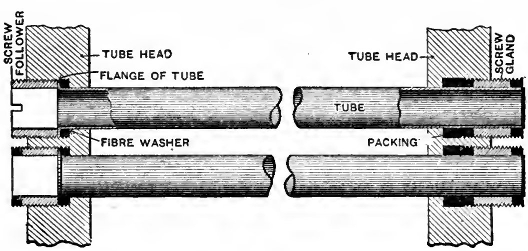


Fig. 38.

Details. The condenser is usually formed of a large number of solid drawn brass tubes $\frac{5}{8}$ or $\frac{3}{4}$ inch in diameter and about $\frac{1}{20}$ inch thick. The reason why they can be made so thin is because there is no pressure on them other than atmospheric pressure. These tubes are arranged zig-zag or staggered, between two end plates which may be circular, oval or rectangular. The entire condenser is often made of brass to prevent waste by galvanic action. The tubes must be fitted water-tight in the tube plates and at the same time free to lengthen and shorten under changes of temperature. For this reason they cannot be expanded in place like boiler tubes. They are fitted with a stuffing box at each end as shown in Figs. 38 and 39. The hole in the plate is slightly larger than the tube. The large part of the hole is provided with threads to receive a small gland or ferrule which compresses a ring of packing or a washer of fibre. It is of great importance that the condenser tubes should be tight for if leakage occurs, salt water will enter the feed water and coat the tubes of the boiler with salt.

It sometimes happens that the circulating-pump breaks down and the condenser cannot be run as a surface condenser. When this happens a pipe may be rigged so that the exhaust will go out of the engine room to the deck. The engines will then run non-condensing and will of course develop less power on account of the greater back pressure. Another method is to run jet condensing. This may be done by having the condenser piped so that the sea water will enter the top of the condenser and mingle with the exhaust steam by means of a perforated spray pipe within the condenser.

As the amount of water used for circulating water is greatly in excess of the amount used in the boilers, the air-pump removes a much larger quantity of water than can be used by the boilers. A part of the water from the condenser if running jet condensing goes to the hot well and is taken by the feed pumps, the remainder goes overboard.

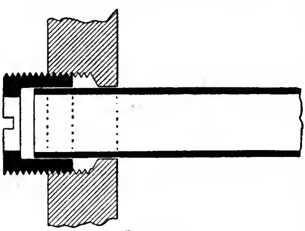


Fig. 39.

In running jet condensing, the water that is fed to the boilers contains considerable salt since the injection water is sea-water and the exhaust steam mingles with it and goes to the air-pump. For this reason, jet condensing is used only in case of emergency. For lake and river steamers, however, the jet condenser is frequently used, especially for low pressure, because it is cheaper and requires less injection water.

In case no arrangements are made for running the surface condenser as a jet condenser, a few tubes removed from the surface condenser will allow the injection water to mingle with the exhaust steam. Enough tubes should be removed to equal the area of the main injection pipe. In the surface condenser the space in which the condensation takes place is not in communication with the atmosphere. But the space occupied by the injection water communicates with the atmosphere by the discharge pipe if the discharge is above the water line. Hence when the surface condenser is changed to a jet, the valve in the delivery pipe must be closed to prevent the air from entering the condenser and thus destroying the vacuum.

The **vacuum** in the condenser is measured by a vacuum gage which is similar to a pressure gage. The pressure gage measures pressure in pounds per square inch but the vacuum gage is graduated to correspond to the barometric column; that is, in inches of mercury. A perfect vacuum represents about 30 inches of mercury and if there is atmospheric pressure in the condenser the pointer would stand at zero.

Since the pressure of the atmosphere is about 15 pounds per square inch and the mercury column is 30 inches high for atmospheric pressure, an inch of vacuum represents about $\frac{30}{15} = \frac{1}{2}$ pound pressure. Thus 10 inches of vacuum means that there is a vacuum corresponding to $10 \times \frac{1}{2} = 5$ pounds pressure. Or the 10 inches of vacuum means that 5 pounds of pressure have been removed from the condenser and $15 - 5 = 10$ pounds pressure remains.

Suppose the needle stands at 26. Then the pressure that has been removed equals 26 inches of mercury which equals 13 pounds. If 13 pounds have been removed the actual pressure in the condenser is $15 - 13 = 2$ pounds. Another way would be to subtract 26 from 30 and divide by 2. Thus, $30 - 26 = 4$ and 4 divided by 2 equals 2.

In case great accuracy is required, one inch of vacuum is taken to be .49 pound instead of .5 or $\frac{1}{2}$ pound. Thus, 22 inches of mercury indicates a pressure in the condenser of 3.92 pounds, for $22 \times .49 = 10.78$ and (atmospheric pressure) $14.7 - 10.78 = 3.92$; or $30 - 22 = 8$ and $8 \times .49 = 3.92$.

Amount of vacuum. In the study of the properties of steam, it was shown that there was a definite relation between the pressure and temperature of saturated steam. Thus if the pressure in the condenser is known, the temperature of the condensed steam can be readily found by referring to steam tables. This temperature decreases as the pressure decreases. Thus if an almost perfect vacuum is carried, there will be very slight pressure in the condenser and the temperature of the water removed will be low because the temperature given in the steam tables is the maximum temperature obtainable. On account of the heat lost by radiation and the difficulty of regulating exactly the amount of injection water, the temperature is a little lower than that given in the steam tables.

Suppose the pointer stands at 26. The pressure in the condenser is 30 — 26 = 4 and 4 × .5 = 2 pounds. The temperature is then about 126 degrees. If less water is circulated, and the pointer stands at 20 inches the pressure is 30 — 20 = 10 and 10 × .5 = 5 pounds; the corresponding temperature is then about 162 degrees. Thus a difference of 6 inches in the vacuum makes a difference of 36 degrees. Then this question arises: Shall we carry a good vacuum and thus increase the power of the engine and feed water to the boilers at (theoretically) about 126 degrees or shall we have a little greater back pressure (5 pounds) and feed water 36 degrees warmer? This question must be answered by the engineer in charge and as to which is the more economical can often be determined only by a test.

With the surface condensers, the vacuum usually carried is from 22 to 26 inches and with jet condensers 20 to 24 inches is common.

If the temperature of the hot well is to be high, a low vacuum must be carried in the condenser. To lower the vacuum decrease the amount of circulating water.

Imperfect vacuum. If the pointer of the vacuum gage stands less than 30 it means that the vacuum is not perfect or it is "low" as it is turned. We have already considered the results of a low vacuum. It may be caused by too little condensing water, air-pump out of order or the piston not coming close to the foot and delivery valves or by air leaks.

If the vacuum is low, and an increase in the amount of circulating water fails to increase it, but lowers the temperature of the hot well, it indicates that the exhaust is cooled to a low temperature and consequent low pressure. This state of affairs indicates an air leak about the engine or condenser. If a lighted candle is passed around the joints, the flame will be drawn toward the leak since the pressure outside is greater than the pressure inside, and the inrush of air would cause the flame to be drawn along with the current. A little red-lead putty applied to the crack will usually stop the leak.

If the fault is not in the condenser or in the amount of circulating water, probably the air-pump is out of order. A broken or hung-up valve often causes an imperfect vacuum.

The Keel Condenser. Steam launches for fresh water frequently have no condenser but use high-pressure steam and draw the feed water from the lake or river. For salt water, however, it is desirable to use the feed water over and over again on account of the boilers. In many launches, an ordinary surface condenser would take up considerable room and be an extra weight.

For such cases a brass or copper tube, or several tubes, are placed outside of the hull along the keel. The exhaust from the engine enters at one end, is condensed by the cold water, and drawn out of the other end by the air-pump. This is a very simple arrangement since no circulating arrangements are needed. The passing of the hull through the water takes the place of the circulating-pumps.

Feed Tanks. The air-pump of the condenser discharges into a feed tank which holds the feed water that is not immediately needed for the boilers. This tank is usually made large enough to contain all the discharge from the air-pump for four or five minutes when running at full power. From this tank the water is pumped into the boilers as needed. In some ships the air-pump discharges into the hot well, and is then either pumped directly to the boilers or is carried to a feed tank. A feed tank is usually fitted to each engine room.

The tank is provided with two overflow pipes; one leading to the reserve tank, and the other to the bilges. In case oily matter collects on the surface of the water in the feed tank, it can be discharged into the bilges by the overflow. The feed tank should have an arrangement for the escape of air, and should be provided with fittings to prevent grease from entering the reserve tanks or the feed pumps.

It is very important that feed water should contain as little grease as possible. For this reason some vessels are fitted with a tank, pump and grease filter between the air-pump and feed tank. It is a good plan to filter the water before it enters the feed pumps rather than to filter it while going from the feed pumps to the boilers. If a grease filter were placed between the air-pump and feed tank it would bring a great strain on the air pump. To prevent this the air-pump is made to discharge into the hot well from which the water is drawn by a pump called the hot well pump. This pump takes water from the hot well and forces it through the filter to the feed tank. A by-pass or escape valve is fitted so that when the filter becomes clogged or the hot well pump gives out the water will flow directly to the feed tank.

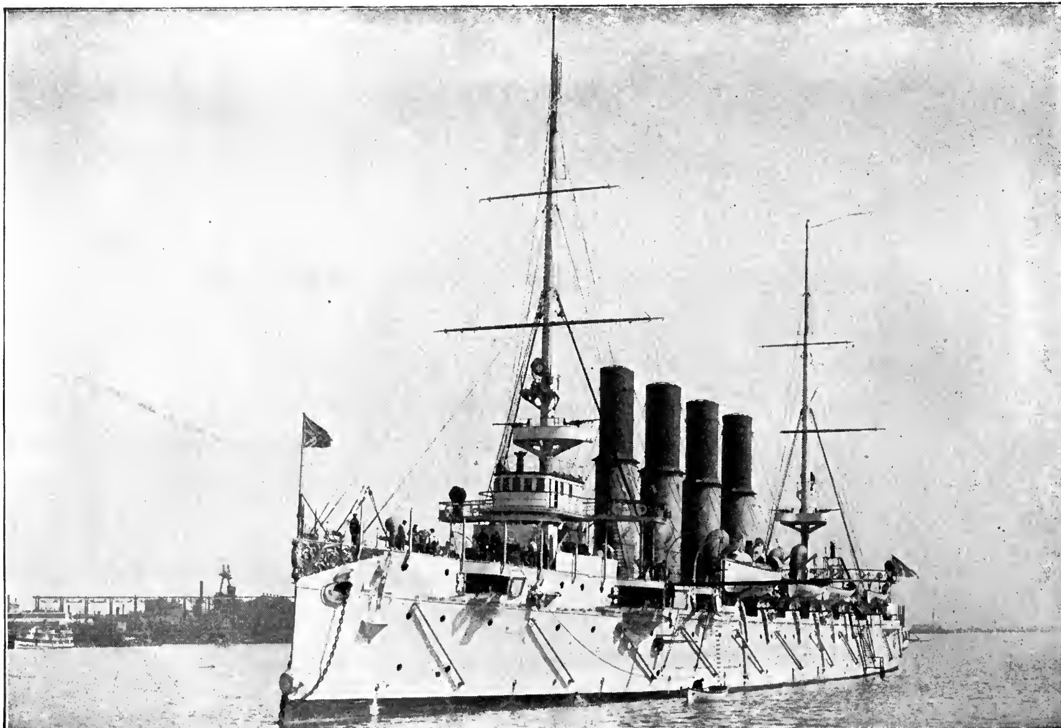
The *reserve tanks* are tanks placed in the double bottoms under the engine or boiler rooms for carrying a reserve supply of fresh water. They are fitted with valves and pipes, so that they can receive water from the feed tanks and from the boilers. Also, so that water can be drawn from them as required. On ships having evaporators and distillers, the reserve tanks need not be as large because it is not necessary to carry as large a quantity of fresh water.

Feed-Pumps. The feed water is taken from the bottom of the feed tanks or from the hot wells and pumped into the boilers. The pumps for this work are almost always of the independent, direct-acting type. They usually take steam from the main steam pipe and the auxiliary pumps from the auxiliary steam pipes. It is a good plan to place the main pumps in the engine rooms and the auxiliary pumps in the boiler rooms. The main pumps are piped to the feed tanks or hot wells, and can pump to all of the boilers. The auxiliary pumps draw from the feed tanks and from the auxiliary condensers, and are also piped to pump from the reserve tanks and from the sea.

Arrangements for Reducing Waste. In order to make the amount of make-up water as small as possible, there are fitted several devices for reducing waste.

Formerly all of the auxiliary engines, such as those for steering, circulating-pumps, hoisting, electric-lighting, etc., exhausted into the atmosphere. To prevent this waste, they are made to exhaust into **auxiliary condensers** which are like the main condensers in construction, arrangement and fittings. The air-pumps for these condensers, called the auxiliary air-pumps, discharge into the feed tanks.

In case the engines are eased or stopped, the **safety valves** are likely to blow off until the fires and draft can be regulated. The



RUSSIAN CRUISER "VARIAG" BUILT AT THE CRAMP SHIP YARDS.

Sunk by Japanese in the Harbor of Chemulpo, Korea, February 9, 1904.

steam that escapes is usually led to the main condensers and there condensed. Since the air-pump (if it is not independent) stops when the main engines stop, provision is made by means of a suction pipe, for keeping the vacuum in the main condenser by running the auxiliary air-pump which is independent.

At the present time, with surface condensers, evaporators, etc., the boilers need be **blown out** only at long intervals. After the boilers have been at work for a considerable length of time, the surface of the water becomes dirty and the surface blow must be used, but this does not happen frequently, and as the boilers are blown out but seldom, the loss from this cause is slight.

The **drains** from the main engines are usually connected to the main or auxiliary condensers, or with a drain pipe leading to a drain tank, thus greatly decreasing the waste from this cause. In case the drainage water from the auxiliary cylinders is very greasy, it must be filtered or discharged overboard.

Formerly it was the custom to fit small hot wells; this caused frequent discharges to the bilge or overboard. To reduce loss, the hot wells are either made larger or feed tanks are used having overflows to the reserve tanks.

In spite of all the precautions taken to reduce the waste of fresh water, considerable make-up water must be provided. This is usually from three to eight per cent. of the total water used, depending upon the condition of the machinery, etc. This make-up water may be taken from the sea or from evaporators. For vessels making short trips, fresh water may be carried and evaporators dispensed with. Distilling arrangements were discussed in "Marine Boilers."

Thus far we have considered the working fluid (water and steam) in the various parts of the machinery. Now let us trace its course in the boilers and engines by means of a brief summary.

Boilers to Engines.	Steam space, internal steam pipe, stop valve to main steam pipe. Then through bulkhead stop valves (if fitted) to regulating valve, to steam chest of high-pressure cylinder.
Through H. P. Cylinder.	From steam chest of high-pressure cylinder through the ports to the cylinder. After doing work, through the exhaust ports to the first receiver, and then to steam chest of the intermediate cylinder.

Through I. P. Cylinder.	From the steam chest through the ports to the cylinder. After expanding, through the passages and exhaust cavity to the second receiver, and then to the steam chest of the low-pressure cylinder.
Through L. P. Cylinder.	From the steam chest, through the ports to the low-pressure cylinder. After the expansion is completed, through the exhaust passages to the exhaust pipe, to the condenser.
Condenser to Feed Tanks.	The exhaust steam enters the condenser, is condensed, falls to the bottom of condenser. Through foot, bucket and delivery valves of the air pump to the discharge pipe, to hot well or feed tanks.
Feed Tank to Boiler.	From the feed tank to the feed pump suction pipe, through the suction and delivery valves, to the feed pipe. Through feed valve to internal feed pipe.

The water, entering by means of the internal feed pipe, is evaporated in the boiler, rises to the steam space and commences the circuit again.

AUXILIARY MACHINERY.

In modern steam vessels, especially if they are large or in war-vessels, the auxiliary machinery is of great importance. Some vessels have more than 100 different auxiliary engines, some steam, others hydraulic and some run by compressed air and electricity. In battleships there are many engines used for working turrets, loading, training and working guns. Compressed air is not used as extensively as steam, water and electricity, but it is often used for discharging torpedoes.

The large number of auxiliary engines makes it impossible to describe them here; among the most important uses in addition to propulsion are ventilation, forced draft, feeding boilers, weighing anchor, steering, electric-lighting, refrigerating, lifting coal, discharging ashes, etc.

The transmission of power and electric signalling on board ship have become of first importance. Wires can be conducted in places where the placing of steam pipes would be almost impossible.

The steam engines used for auxiliary purposes act upon the same principal as the main engines. Vertical engines are frequently used because of the saving in floor space. The pumps for feeding boilers, the engines for the circulating pumps, etc., being vertical in most instances. As before mentioned, the auxiliary engines exhaust into the auxiliary condenser both because of economy and on account of the feed water.

PROPULSION.

In order to move a ship the resistance must be overcome. When the engines are started, the paddle wheels or screw revolve for a short time before there is any appreciable headway. The power of the engine has, during this time, been expended in overcoming the inertia of the ship. When the inertia has been overcome the power is utilized in overcoming the resistance of the water and air and in increasing the speed of the ship. As the speed increases the resistance increases, and there comes a time when all the power is used for overcoming the resistance and there is none left for increasing the speed. The ship then moves along at an approximately constant speed.

The resistance offered to a ship's motion in smooth water may be divided into three elements:

Frictional resistance of the skin.

Eddy making resistance.

Wave making resistance.

Frictional resistance is by far the most important. The amount of friction between the immersed skin and the water depends upon the area and length of the immersed surface, upon the roughness and upon the speed. As a foul bottom causes a considerable increase in resistance and consequent reduction in speed, the ship's bottom and the propeller blades should be kept as clean as possible.

Eddy making resistance is usually small. It is caused by the form of the stern and by the churning of the propeller.

The amount of resistance due to **wave making** depends upon the form of the ship. At the bows of all ships some waves are formed, and if they pass away from the ship without producing a corresponding reaction under the stern the energy used in forming the waves is wasted.

Wind and waves also cause the resistance to be increased, but the resistance from these causes is difficult to estimate. The larger and longer a ship, the less the wind and waves affect its progress. This is shown by the regularity with which large ocean steamships make their voyages under varying conditions of wind and sea.

Experiment shows that within ordinary limits the resistance varies as the square of the speed, and the power required to overcome the resistance varies as the cube of the speed. In other words, if a ship has a certain resistance at a given speed the resistance will be four times as much if the speed is doubled; and the necessary power will be eight times as much.

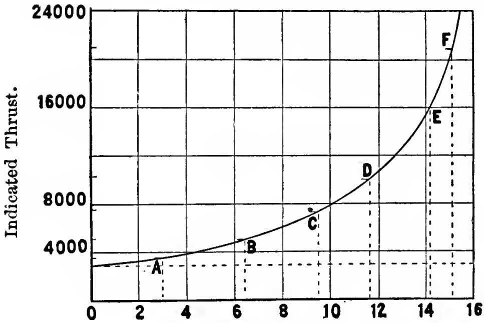


Fig. 40.

By considering the above law and the various resistances, there have been produced many formulas for finding the power necessary for a given speed. These formulas are of little value, however, unless the designer knows all the data of ships of similar form, size and speed.

The indicated horse-power is not a true measure of the work done by the propeller, because of the efficiency of the machinery and of lines of the ship.

Indicated thrust. The indicated thrust is a mathematical expression very commonly used in connection with propulsion. Its name is derived from indicated horse-power and is expressed in pounds. A horse-power is 33,000 foot pounds per minute, and hence the total work in foot pounds done by the engine is equal to I.H.P. × 33,000. This total work done divided by the distance through which it acts in one minute is the indicated thrust.

Let I.H.P. = indicated horse-power of the engine.

p = pitch of the screw in feet.

N = number of revolutions per minute.

T = indicated thrust.

$$T = \frac{33{,}000 \times \text{I.H.P.}}{pN}$$

$$\text{Since I.H.P.} = \frac{2\text{PLAN}}{33{,}000}$$

$$T = \frac{2\text{PLA}}{p}$$

Suppose a marine engine develops 1,200 I.H.P. when making 90 revolutions per minute. If the pitch of the propeller is 20 feet, what is the indicated thrust?

$$T = \frac{33{,}000 \times \text{I.H.P.}}{pN}$$

$$= \frac{33{,}000 \times 1{,}200}{20 \times 90}$$

$$= 22{,}000 \text{ pounds.}$$

By calculating the indicated thrust from the horse-power for given speeds, a curve may be drawn which will show the thrust for all speeds. Such a curve is shown in Fig. 40. The vertical components or ordinates are indicated thrusts in pounds and the horizontal components or abscissæ are speeds in knots.

The most economical speed is the speed at which the ship can steam a given distance with the least consumption of fuel. Or, it is the speed at which the coal burned per knot is least. In general, if the speed is reduced the expenditure of coal is reduced. However, the reduction continues only until a certain speed is reached, after which the coal consumption rises as the speed diminishes. There is no way to calculate the speed at which this change occurs; it can be found by trial only. The ship is run at various speeds and the engines carefully tested. The most economical speed then can be found by dividing the coal consumption per hour by the speed in knots. The lowest value shows the most economical speed.

It is practically impossible, or at least inconvenient, to make the trials at all speeds. To obviate this difficulty, the results are plotted graphically, as shown in Fig. 41. The consumption of coal per day in tons is plotted as the ordinates and the corresponding speed in knots as the abscissæ. If a straight line is drawn from O, tangent to the curve, the speed corresponding to the point of tangency will be the most economical speed. Thus for the conditions represented in Fig. 41, the most economical speed is a little less than 8 knots because O N is tangent to the curve H K at N. The Coal consumption is, from the diagram, about 9 tons per day. The curve shows that the machinery works

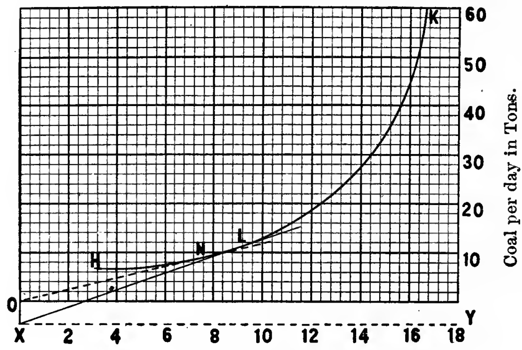


Fig. 41.

economically between 6 and 10 knots as the line O N lies near the curve for those speeds. If, however, the speed falls below 6 knots or rises above 10 knots the coal consumption increases rapidly.

The curve thus drawn is for the propelling machinery only. If the most economical speed, including auxiliary machinery, is to be determined, the distance O X is set off below O to represent the coal used for auxiliary purposes. The tangent X L is then drawn as before. This tangent shows the most economical speed to be about $8\frac{1}{2}$ knots.

PROPELLERS.

Of the three methods of propelling ships by steam, the screw propeller is by far the most important.

Jet propulsion is so uncommon that it requires no discussion. Paddle wheels are used for river and harbor boats, especially in shallow water. For sea-going vessels, lake steamers and steam yachts the screw propeller is almost universally adopted. It is taking the place of the paddle wheel even in its own territory. For war-ships the screw is especially desirable, as with it all the machinery, including the propeller itself, can be placed below the water line.

A **screw propeller** is a set of blades, usually of iron, bronze or steel, placed on a horizontal shaft and made to revolve by means of the engine.

Material. For small vessels, the screw propeller is often made of cast iron on account of cheapness. The blades, and boss or hub, form a single casting. If the propeller is large, the blades are made separate and bolted to the boss. This method has several advantages; the difficulty of manufacture is not as great, the whole propeller is not disabled in case one blade is broken, it is much more easily handled and the boss and blades may be of different material. With a propeller having detachable blades, extra blades are carried so that the propeller may be repaired in case of accident. Cast steel is used to some extent, but although the blades can thus be made thin (thereby increasing the efficiency) they are liable to corrosion. Bronze and gun-metal are perhaps the best materials, as they are strong, tough and resist corrosion. Sometimes the blades are made of bronze and the boss of cast iron.

Shape of the blades. Each blade may be considered as a small part of the thread of a screw of great pitch and depth. The simple screw first consisted of a part of a true helix cut off by two parallel planes perpendicular to the axis. By making a double helix, or double threaded screw, two blades were obtained. After a time the forward edges were cut away to reduce vibration and the blade gradually assumed the shape of the present time. The form of each blade may be conceived by imagining a straight line revolving around another straight line perpendicular to it and traveling along the line while it revolves.

The acting surface or front of the blade is the after face and the true screw surface, but the back or forward face has not the true screw surface on account of the thickness necessary for strength. The best shape for screw propeller blades is largely a matter of experiment. The form is practically elliptical and the transverse sections approximate semi-ellipses.

It is remarkable that small changes in form often make a great difference in speed and power.

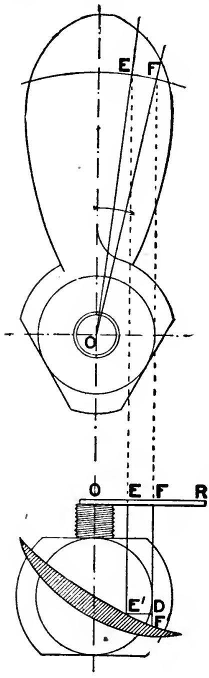


Fig. 42.

Number of blades. Propellers are made with two, three and four blades. For smooth water the two-bladed propeller is efficient; for rough water, when the boat pitches, three or four blades are more satisfactory. Three or four blades are the more common, as they have continuous action. Four is the most common for the merchant marine. If four blades are used and one becomes broken, the three remaining blades are sufficient, but if the propeller has but two blades and one of them is broken, the propeller, having but a single blade, is so badly balanced that the engines are severely strained.

Pitch of screw. The pitch of a screw propeller is the distance that a point on a blade travels in the direction of the axis during one revolution. It is the distance that the propeller will advance during one revolution provided there is no slip. A screw propeller is very similar to an ordinary wood or machine screw of coarse pitch. In the case of a wood screw or cork screw, the screw advances a distance equal to the pitch during every revolution.

The pitch is often uniform, that is, the pitch is the same for all points on the blades. Sometimes the pitch is increased slightly toward the tips of the blades so that shock will be reduced by making the action more gradual.

Alteration of pitch. If a propeller is made in one solid casting, there is no way to alter the pitch. With most propellers the blades are detachable, that is, they are made separate and bolted to the boss. The holes in the blade flanges of large propellers are made elongated so that the position of the blades may be altered slightly, thus changing the pitch. The allowable change in pitch is not greater than three or four feet even in large wheels.

The *pitch ratio* is the ratio of the pitch to the diameter. Suppose a screw propeller is 16 feet in diameter and has a pitch of 21 feet, the pitch ratio is $\frac{21}{16} = 1.31$.

To find the pitch. From the definition it is evident that to find the pitch of a propeller it is necessary to know how far a point moves in a line parallel to the axis while it moves through a known angle. These two measurements may be found as follows:

The tail-piece and cap-nut are first removed and a wooden bar of sufficient stiffness is fixed to the end of the shaft as shown in Fig. 42. The center of the bar should coincide with the center of the shaft and be made so that it can move about the point O in a plane perpendicular to the axis of the shaft. In the lower portion of Fig. 42, O R represents the radius bar, and in the upper portion O E and O F represent the center lines of O R.

First, place O R in some position, O E for example. Then measure by means of a rod or in some other manner the perpendicular distance from E to the blade. This will be E E′ in the lower portion of Fig. 42. Now move O R through a small arc as E F, and mark the angle E O F on the boss or measure it. Again measure the perpendicular distance from the bar to the blade which will be F F′. Subtracting E E′ from F F′ leaves D F′. Now, D F′ is parallel to the axis and is the distance that the given point E moves in that direction while it moves through the arc E F.

Suppose the angle E O F is $5\frac{5}{8}$ degrees or $\frac{1}{64}$ of 360°, ($360 \div 5\frac{5}{8} = 64$) and D F′ is three inches. Then, while the point moves through $\frac{1}{64}$ of the circumference it moves 3 inches. In moving through the whole circumference it would move $3 \times 64 = 192$ inches $= 16$ feet in the direction of the axis. Hence the pitch is 16 feet. This may be expressed as a simple proportion, because E O F is the same fraction of the complete circumference as D F′ is of the pitch. Or,

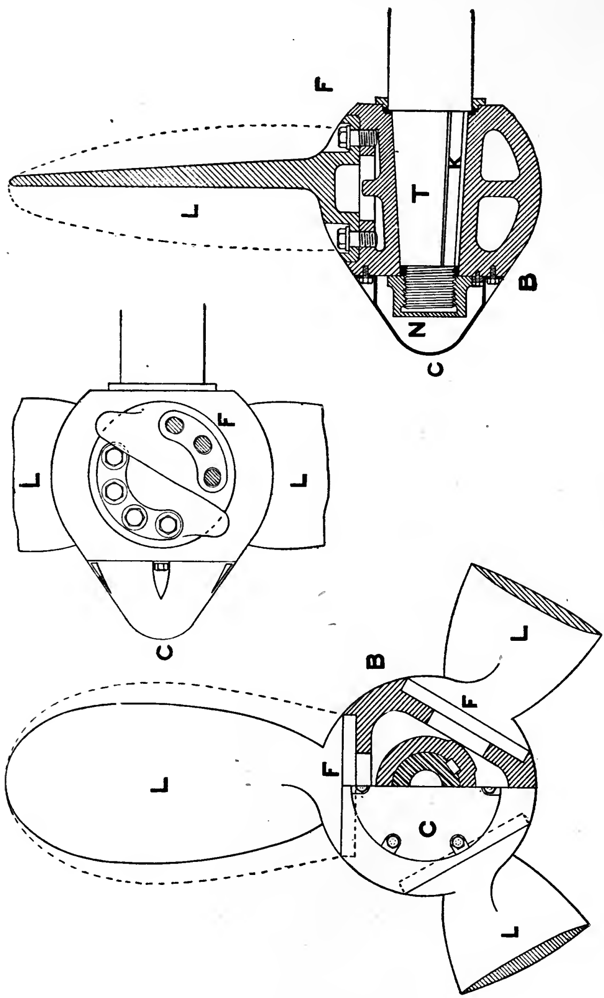


Fig. 43.

$$E\,O\,F : 360 :: D\,F' : \text{pitch}.$$

It may be more convenient to measure E F than to measure the angle. Then,

$$E\,F : 2\,\pi \times O\,E :: D\,F' : \text{pitch}.$$

This method assumes the pitch to be constant. If it is not constant and if it is desired to find the mean pitch, find the pitch in the manner described above for several points and then find the average pitch.

The Diameter of the Screw Propeller is the diameter of a circle described by the extreme end of the blades if the pitch is zero. As in the case of a wood screw the diameter is the outside diameter. The area of this circle is called the *disc area.*

Determination of Pitch and Diameter. There are many rules for determining the proper diameter and best pitch for propellers but they are of little value unless all the conditions are known and the conditions are similar to those in vessels already built. The diameter of the screw for a single screw steamer depends upon the amount of water the steamer draws aft. The screw is usually made large so that the pitch may be large and the engines run at moderate speed.

The pitch is determined from the diameter. The allowable range of pitch ratio is considerable; that is, there is no great change in efficiency for a slight change in pitch ratio. The best ratio seems to be between 1.1 and 1.5. Then for a wheel 14 feet in diameter, the pitch would probably be between 15 and 21 feet.

Details. A modern form of screw propeller is shown in Fig. 43. It consists of a boss B and three blades L which are bolted to it. The boss is made large, much larger than is necessary to fasten it to the shaft. The reason for making it large is that the portions of the blades near the boss are ineffective, that is, they simply churn the water without producing useful results. This churning is reduced by making the boss large. The boss is generally made spherical or pear-shaped so that it will offer little resistance while passing through the water. The hole through the boss and the portion of the shaft T which carries the propeller is tapered. A longitudinal key K, prevents the propeller from rotating on the shaft. The end of the shaft is threaded and the boss kept in place by the cap-nut N. This nut is secured by means of a keep-plate or other device.

A conical tail-piece C bolted to the end of the boss reduces eddying, prevents corrosion of the cap-nut and shaft and also prevents fouling by ropes. At the other end of the boss a stuffing-box prevents water from entering at the junction of the boss and shaft.

The flanges F of the blade are recessed into the boss and are bolted to it. The heads of the bolts are recessed into the flanges and covered with plates. By this means the spherical form is preserved.

Action of the Propeller. When a screw propeller is revolving in a given direction (for go-ahead motion for instance) the blades press on the water as the threads of an ordinary screw do upon the threads in the nut. The pressing of the blades on the water causes the water to be driven backward. The result of the reaction caused by projecting the mass of water sternward is the ahead motion of the boat. The useful work done by the propeller is that which forces the water directly sternward; the movement of water in any other direction is waste power.

Speed of the Screw. If the screw worked in an unyielding medium, it would advance a distance equal to its pitch at each revolution. Hence the speed of the screw per minute is the product of the pitch and the number of revolutions per minute.

Example. Suppose a screw is of 18 feet pitch and makes 72 revolutions per minute. What is the speed of the screw in feet per minute and knots per hour?

$$18 \times 72 = 1{,}296 \text{ feet per minute.}$$

$$1{,}296 \times 60 = 77{,}760 \text{ feet per hour.}$$

$$\frac{77{,}760}{6{,}080} = 12.78 \text{ knots per hour.}$$

However the water is a yielding medium and for this reason the pressure of the blades causes the water acted on to be driven back instead of remaining firm. Then the actual speed of the ship (when referred to the undisturbed water at a slight distance from the ship) is less than the speed of the screw. This difference is called slip.

Slip is the difference between the speed of the screw and the speed of the ship, relative to still water. It is expressed in feet per minute and as a per cent. of the speed of the screw.

Example. A ship is moving at the rate of 16 knots per hour. The screw has a pitch of 19 feet and makes 97 revolutions per minute. What is the slip?

$$19 \times 97 = 1{,}843 \text{ feet per minute} = \text{speed of screw.}$$

$$\frac{16 \times 6{,}080}{60} = 1{,}621 \text{ feet per minute} = \text{speed of ship.}$$

$$\text{Slip} = 1{,}843 - 1{,}621 = 222 \text{ feet per minute.}$$

$$= \frac{222}{1{,}843} = .1204 = 12.04 \text{ per cent.}$$

This may be expressed algebraically as follows:

Let S = speed of screw
s = speed of ship
L = slip in feet per minute.

Then

$$L = S - s$$

$$\frac{S - s}{S} \times 100 = \text{slip expressed in per cent.}$$

The slip thus found is not the *actual* slip but the *apparent* slip. It is not the actual or real slip because the screw does not act in still water but in water that has been set in motion by the screw itself or by the hull.

While the hull moves through the water, it sets in motion the water in contact with it; the direction being the same as that of the ship. The water close to the ship has a greater forward velocity than that at a distance. Since this water has a velocity a little less than that of the ship it soon falls behind the hull and is found at the stern. Thus the water in which the propeller acts has a forward velocity. Also the velocity is influenced by the waves and eddies due to the lines of the vessel. On account of the many conditions that make the velocity of the wake variable, it is difficult to calculate it.

When the propeller is considered it is evident that the condition of the water in which it works should be considered. Since the velocity is difficult to obtain, the real slip is not easily found.

When slip is referred to it is generally the apparent slip that is intended and not the real slip.

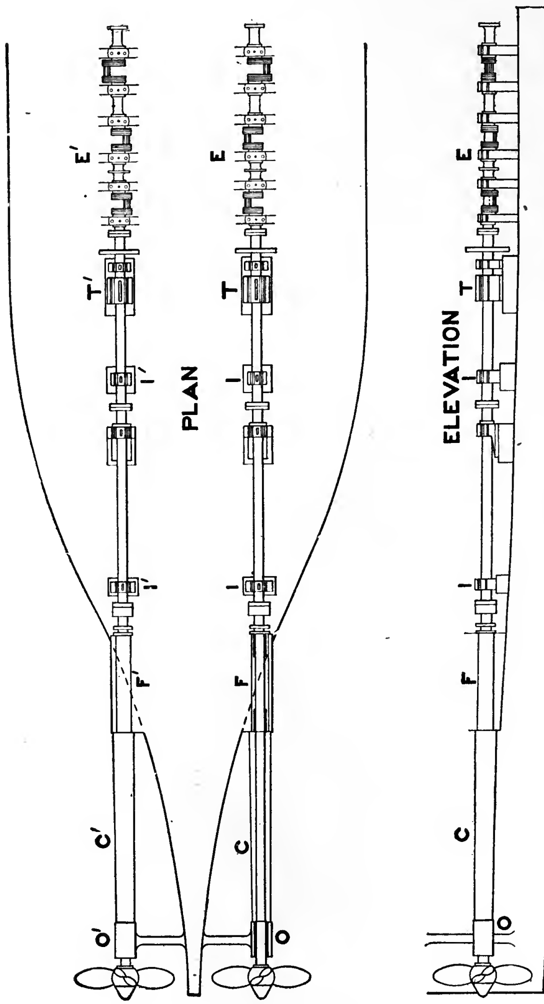


Fig. 44.

Apparent slip varies from 5 to 25 per cent., 15 to 20 being a fair average. The real slip is usually from 5 to 15 per cent. greater than the apparent.

Negative Slip. On account of the condition of the wake in which the propeller works, positive real slip is necessary. In some cases, the calculation has shown the apparent slip to be negative. This shows that the speed of the ship is greater than that of the propeller. If the real slip were small, 8 or 10 per cent. for instance, the apparent slip would probably be negative. There may be several reasons for negative slip, the most common one being the initial velocity of the wake.

Experiments show that with small percentage of real slip, the efficiency is low; hence if the apparent slip is negative or zero, it is generally considered that the propeller is not working efficiently.

In order to propel a large ship at a given speed the propeller must be large ; sometimes the ship draws too little water for such a propeller. Also, there are other conditions which sometimes make it desirable to use two propellers instead of one.

Twin-screws. Twin-screws are now common both in the navy and in the merchant marine. For twin-screws there are two separate engines, two shafts and two screws. These are placed on either side of the keel as shown in Fig. 44, which gives the arrangement of the shafting and bearings of a twin-screw ship. The bearings and cranks of the triple expansion engines are shown at E and E′. The shafting consists of the crank shafts of the engines and the screw shafts or propeller shafts which run aft from the engines to the screws. The shafting is made in convenient lengths and coupled together. The shafts are kept in place by means of bearings; main bearings at the engine, and screw-shaft bearings for the propeller shaft. The latter named bearings include the thrust blocks T and T′, the ordinary inboard bearings I and I′, the stern tubes F and F′ and the outboard bearings O and O′. The stern tubes are fitted where the shafts pass through the hull. The propeller shafts are enclosed in the casings C and C′ which extend from the stern tubes to the outboard bearings which are supported on brackets.

The shafting for large steamers is hollow, the internal diameter being about one-half the external. A slight addition to the diameter makes the hollow shaft as strong as the solid.

Twin-screws have the following advantages:

There being two screws, each may be of much less diameter, hence they may be run at greater speed, and for a given power the engines may be of shorter stroke. As the height of a vertical engine depends upon the length of stroke, engines for twin-screws need not be as high as the engine for a single screw.

The engines for twin-screws can be small as the necessary power for propulsion is divided; this is an advantage in manufacture.

With two engines, a bulkhead may be placed between them, thus forming two water-fight compartments.

If one engine is disabled the ship can be brought into port by the other.

With two screws the vessel can be turned more easily by going ahead with one and astern with the other. Also it can be steered to some extent by means of the two screws.

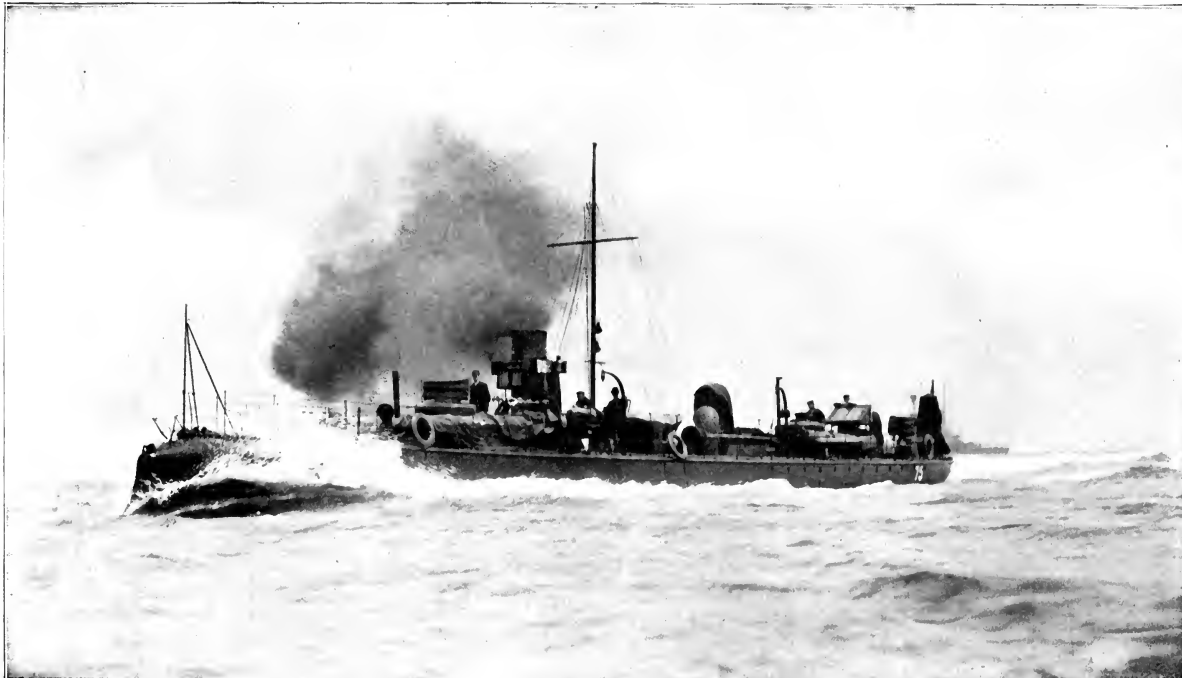
Triple Screws are used in very large vessels and in the navy. The triple screws give much the same advantages as twin screws. In the navy the center screw can be used for cruising, two for moderate speeds and all three for full speed.

ENGINE ROOM FITTINGS.

CYLINDER RELIEF VALVES.

It frequently happens that water collects in the cylinders because of condensation or priming of the boilers. If this water remains in the cylinder, it is likely to cause excessive strains or may even cause the cylinder heads to be blown off. To prevent accident, relief valves are often fitted to both ends of the cylinders. These valves are usually small spring-loaded safety valves as shown in Fig. 45. The springs are long so that the valves may have considerable lift without compressing the spring too much. They are set to open at about fifteen or twenty pounds above the initial working pressure.

Cylinder relief valves should be fitted to both ends of the cylinders of the main engines, although they are frequently



BRITISH FIRST-CLASS TORPEDO-BOAT AT FULL SPEED.

Tearing through the sea with red-hot funnel at nearly forty miles an hour, that she may get near a battleship and discharge one of her Whitehead torpedoes.

omitted from the top ends. These valves should be piped so that the hot water escaping from them will not scald those in attendance but will go to the condenser or the feed tank. Like other safety valves they should be provided with means for adjusting the tension of the springs and for locking them in position. Relief valves are also placed on feed pipes and the fire system to guard against split pipes in case the valves do not open.

DRAIN COCKS.

In addition to the cylinder relief valves, drain cocks are fitted to the lower ends of the cylinders. They should be fitted to any part of the engine where water is likely to collect, such as the cylinders, steam chest, jackets, etc. By means of these cocks, the cylinders may be drained while the engines are being warmed or while starting. They usually discharge into the condenser while under way or into the feed tank, thus saving the fresh water. The jacket drains often lead to a small vessel placed below the bottom of the cylinder and provided with a gage glass.

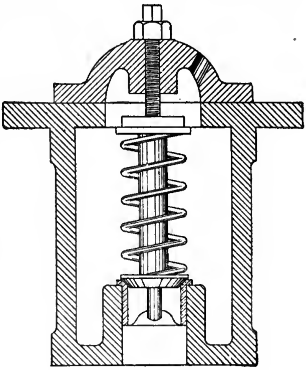


Fig. 45.

BY-PASS VALVES.

Compound, triple expansion and quadruple expansion engines are fitted with by-pass valves or auxiliary starting valves. **Auxiliary starting valves** are those which admit steam *directly* to the top and bottom of the cylinders without going through the receivers. This valve is a flat plate similar to a plain slide valve but without the exhaust cavity. It slides on a flat seat and the two ports communicate with the two ends of the cylinder. It is moved by means of a hand lever; if the lever is moved in one direction the valve admits steam to one end and when moved in the opposite direction steam is admitted to the other end. The levers are often arranged to move in the direction that the steam will move the piston. With these valves a triple expansion engine may be started if the valve of the high pressure cylinder covers both ports.

By means of the **by-pass valves,** live steam is admitted to the *receivers* so that the engines may be warmed before starting or easily started if both ports to the high pressure cylinder are closed, or if the high pressure crank is on dead center. As the steam is admitted to the receivers, it finds its way to the proper side of the pistons through the main valves. Thus it is not necessary to consider in which direction the piston is to move.

Starting by means of by-pass valves is slower than with auxiliary starting valves because the steam must first fill the receivers as well as the cylinder space on one side of the piston; also it increases the back pressure on the preceding piston, since that cylinder is in communication with the receiver by means of the exhaust cavity. The by-pass valves are often used, mainly because of their simplicity and the freedom from error.

RECEIVER SAFETY VALVES.

The receivers are sometimes constructed for a working pressure somewhat less than that of the high pressure cylinder In starting, or in case the preceding valve were to get off its seat or should become broken, steam pressure is likely to accumulate in the receiver and exceed the allowable pressure. To relieve the pressure, small safety valves are fitted to the receivers. They discharge the steam into the engine room and so give warning of excessive pressure.

For an initial steam pressure of about 150 pounds, the safety valves on the intermediate and low pressure receivers should be set to blow at about 80 pounds and 30 pounds respectively.

The pressures in the receivers are shown by pressure gages. These gages are of the same form of construction as those used on the boilers, and are often piped so they may be seen from the starting platform.

JACKING GEAR.

In order that the engines may be turned over when not under steam, a large worm wheel is keyed on the after end of the crankshaft. In small engines, the jacking wheel may have holes or recesses in the rim so that it may be turned by means of a crowbar, or it may be turned by a ratchet and lever. For large engines, a small auxiliary steam engine is fitted on the frame to work the worm, so the engines may be turned rapidly in case of adjustment or repairs. When not under steam, the engines should be turned over daily to keep them in good condition

The worm and worm wheel must be so arranged that when the engines are under steam the worm may be disconnected.

REDUCING VALVES

The main boilers usually carry a steam pressure much higher than that used in the auxiliary engines. Although it is usual to supply auxiliary engines from auxiliary boilers or donkey boilers, yet it frequently happens that steam must be taken from the main steam pipe to run the steering-engine, electric-lighting engine, winches, etc. Also the pressure in the steam jackets is usually somewhat less than that of the boilers. To reduce automatically and retain the pressure for these purposes, reducing valves are fitted. There are several forms of reducing valves used, the Foster valve as described in "Marine Boilers" being the most common.

Frequently a small safety valve is placed on the low pressure side for relief in case the reducing valve gets out of order. Pressure gages are also fitted on the discharge side and sometimes on both sides. Reducing valves are especially desirable for dynamo engines or where high pressure water-tube boilers are used; if the pressure in the boilers varies, the reducing valve will keep it constant in the auxiliary engine for the close regulation necessary for electric lighting.

MAIN INJECTION VALVE.

The holes below the water line in the hulls of vessels must be fitted with valves to control the flow of water. In the case of the inlet for the condensing water for the circulating-pump, the **Kingston valve** was the one most commonly fitted. This valve is simply a conical valve opening outward so that the pressure of water keeps it closed. The valves are fitted with long spindles so that they may be opened and closed inside the ship. This form of valve was much used for wooden ships and is sometimes used for steel vessels. The ordinary screw-down valve is, however, frequently used in steel vessels as it is lighter and cheaper, and the Kingston valve has no especial advantage for such hulls.

The screw-down valves close against the pressure of water. In case of fracture, the sea-water will close the Kingston valve but will rush into the hull if the screw-down valve is used. Thus the former will automatically prevent the sinking of the ship. If the screw-down valve breaks, the inrush of sea-water may be reduced until repairs can be made, by passing a tarpaulin over the side and securing it over the opening.

The opening in the skin of the ship is provided with a strainer or grating of large area, to prevent sea-weed and other foreign matter from entering the pumps.

It is a good plan to fit a screw-down valve inside the ship near the sea-valve for additional security. This is especially desirable in case the main injection valve is a screw-down valve.

BILGE SUCTION.

As stated in discussing condensers, most vessels are piped so that the circulating-pumps can pump from the bilges as well as from the sea. This may be done by having pipes lead from the bilges to the main injection pipe. This bilge suction pipe is provided with a non-return valve, called the bilge injection valve, so that in case of a leak water may be drawn from the bilges and discharged overboard. When pumping from the bilges the sea-valve is closed and the bilge injection valve opened. This valve is similar in construction to an adjustable lift feed valve. When pumping from the bilges, this valve will allow water to pass from the bilges to the pumps, but when the pumps are drawing from the sea, the sea water holds the valve down.

The end of the bilge pipe should always be provided with a strainer, so that waste, chips, etc. will not enter the pumps. Bilge piping is almost always ot lead as it is durable and easily fitted. The bilge water corrodes iron quickly unless it is well protected. Lead bilge piping should be inspected frequently because being easily flattened and dented it may be damaged so as to prevent or greatly reduce the flow of water.

DIRECTING-BOX.

To simplify the bilge piping and to allow the various pumps to draw water without complex piping, all the bilge suctions are usually led to a rectangular box or chest called the **directing-box, mud-box** or **communication-box.** This is a rectangular, closed cast-iron chest, situated in the engine-room near the pumps. It is divided into two compartments by a strainer. All the suction pipes of the various pumps are connected to one end of this box by valves. The bilge pipes are connected to the other end by valves or stop-cocks. Thus any pump may draw from any bilge through the same pipe if the valves are properly arranged. As this box has considerable capacity the velocity of the water will be slight, and consequently the sediment will either be deposited or caught by the strainer. The cover should be easily removed, so that the interior may be examined and the strainer cleaned.

DELIVERY VALVES.

Delivery or discharge valves should be fitted to each outboard delivery pipe at the outlet. This valve is simply a check-valve or non-return valve having a spindle passing through the covers, so that they may be lifted or pressed down on the seats. It is arranged so that water may be discharged from the ship but no sea-water can flow back. If the valves have no external spindles, no one knows whether or not they are shut.

WATER SERVICE.

In order to supply cold water to the thrust-block, crosshead slides, eccentrics, and the various bearings, a system of piping is installed. The pipes lead from the sea, condenser, or from a donkey pump to the points where the water is needed. Water for the bearings and the various parts of the engine is usually taken from the sea, while the water for the thrust-bearing is taken from the stern tube or from the sea. If the water is taken from the sea, the pressure is sufficient to cause the flow. In case of stoppage a pump is put in to clear the pipes.

In large ships a fire main runs around the ship; from this pipe branches lead to the various stations. The fire system carries a pressure of 25 to 40 pounds, and is useful for washing decks and flushing. The system is piped both from the sea and from the bilges.

MANAGEMENT OF ENGINES.

It is of great importance that the chief engineer and all of the assistants should be familiar with the machinery of the ship. The steam and exhaust pipes, both main and auxiliary, and the location of the valves should be traced; also the feed pipes to the boilers, and the piping to the condensers. It is necessary that each officer should know the function of every pump and the piping from the bilges. Unless the engineer on watch is well acquainted with all the machinery he cannot act promptly in case of emergency but will be compelled to send for the chief or find someone under him who can furnish detailed knowledge of the part in question. The promptness and confidence with which he can act at all times depend upon his knowledge of all the parts of the machinery.

Before Starting. Just what to do before starting depends largely upon the prevailing conditions and the arrangement of the machinery. In general the following should be observed:

All gear used in port or for repairs should be stowed away and all covers replaced. Such valves as the inlet and outlet valves of the circulating pump and all valves to bilge pipes should be tried and put in proper condition. The outboard delivery valves from all pumps should receive especial attention. The valves to jackets and the bulkhead and regulating valves should be opened and inspected. The valves in the main steam pipe should not be closed tightly or they will be set fast when steam enters.

The oil-cups and lubricators should be examined and put in good working order and the necessary worsteds adjusted.

The various joints should be inspected and the glands packed.

Pressure and vacuum gages should be connected and the shut-off cocks tried.

The bright parts of the machinery that are likely to become splashed with water should be oiled.

Auxiliary engines should be tried by steam if possible; if not, by hand. Such auxiliaries as the steering engine, circulating engines and the electric-lighting engines should receive careful attention. In all cases, the reversing engine should be tried before using the main engines and before entering port it should again be tried to make sure that it works properly.

The main engine should be oiled at all the rubbing and rotating parts.

An important item is the examination of the crank-pits and all the working parts. If these parts are not examined, some obstruction may prevent the engine from starting. The main engines should be turned through at least one revolution, both ahead and astern, by hand.

In case forced draft is used with closed stokeholds, the draft gages should be cleaned and filled with water and the air-tight doors should be examined and rigged. The fans should be carefully oiled and adjusted.

To Start the Engine. In starting an engine the engineer in charge must use the knowledge gained from experience as no set rules will apply to all engines. For instance, a small single cylinder engine is not started in the same manner as a large triple expansion engine. In the following we will consider the types of machinery most used — the triple expansion engine and surface condenser.

In general, to start an engine it is first necessary to warm the cylinders and form a vacuum in the condenser; the engine can then be started by admitting steam to the cylinders.

To form the vacuum. It is usual to fit an independent circulating-pump so the Kingston or sea-valve should be opened and the discharge valve tested to see if it lifts readily. The circulating-pump is then started so that the condenser will not become heated by the drains and exhaust steam. The auxiliary air-pumps should then be started to keep the main and auxiliary condensers free from water and to form a partial vacuum. If the air-pump for the main condenser is independent, it may be started so as to form a vacuum.

To warm the engines, all cylinder, receiver and steam chest drains are put in communication with the condenser. In order to ascertain whether or not the drains are working properly a by-pass arrangement is often fitted. This arrangement connects the drains to the bilges. The jackets are usually trapped to the hot well or feed tanks but can be drained directly to the bilges. If all the drains are in order, open slightly the throttle valve and all valves in the main steam pipe. This will admit a little steam to the high pressure steam chest. Steam is also admitted to the jackets to assist in warming the cylinders.

Now open the by-pass valves a little to admit steam to the receivers. The steam in the receivers finds its way into the cylinders and helps in the warming up. To warm both ends of the cylinders move the valve gear back and forth slowly from full gear ahead to full gear astern. This is done by moving the weight shaft by means of the worm and wheel. The throttle may now be opened a little wider, enough to set the engine in motion. By means of the reversing gear the cranks can be made to move back and forth without making a complete revolution.

We will assume that the engine is thoroughly warm and (as the drains are open) free from water. Steam is in the jackets, and the starting-engine and starting-valves ready. The centrifugal pump is at work circulating water through the condenser and either the auxiliary air-pump or an independent air-pump is at work.

To start the engines run the links into full gear ahead or astern and open the throttle valve. In case the engines do not start, use the by-pass or auxiliary starting valves. The engines should be started slowly and the speed gradually increased by admitting more steam. After the engines have made about 200 revolutions the drain cocks may be closed.

Marine engines may fail to start from many causes, but if proper precautions are observed before trying to start there should be no difficulty.

Among the causes which are not apparent from the exterior are:

The throttle valve spindle may be broken.

The high pressure valve (if a slide valve) may be off its seat and admit steam to both ends.

The engine may be gagged; that is, the throttle will supply steam to one side of the high pressure cylinder and the by-pass valves admit steam to the opposite side of the intermediate or low. In this case the engine will not move, as the pressures are equal.

ized. In using the by-pass valves, the valve or valves should be used which will produce a turning moment on the shaft. Let us suppose that both the high and low pressure valves cover the ports, and the intermediate slide valve is in such a position that steam can enter that cylinder. If now the throttle is opened, the engine will not start because both ports are closed. If the by-pass valves to both receivers are opened, steam will be admitted to the proper side of the intermediate piston. Also the steam in the low pressure receiver will find its way through the exhaust cavity of the low pressure slide valve to the other side of the intermediate cylinder. The result will be that the engine will not start because the high and low are not available for starting and the pressures on the intermediate piston will balance. In this case steam should be admitted to the intermediate receiver only. If steam is admitted to the low pressure receiver only, it tends to force the intermediate valve off its seat.

The opening of the wrong starting valves will frequently produce a similar situation.

If the engine has become gagged, it should be freed from steam. This may be done by closing the throttle and moving the link to the opposite extreme position. The engine can then be started in this direction and then be quickly reversed; or it may be started in the proper direction if the mistake is not repeated.

The valve stem may have become broken inside the chest or the valve may have become loose on the stem.

One of the eccentrics may be broken or slipped on the shaft.

Bearings set up too tightly or too much compression on the packing in stuffing boxes often prevent starting.

The propeller may be fouled by a rope or other obstruction.

The turning gear may not be disconnected; that is, the worm may still be in gear with the worm wheel.

After the engine has been running for a short time, the following **adjustments** should be made:

The speed of the feed pumps to maintain the proper water level in the boilers.

The supply of circulating water to the main condenser. The amount of circulating water should be such that the temperature of the feed will be from 90° to 125°, averaging about 110°.

The amount of circulating water around the main bearings should be reduced as low as possible to relieve the work of the bilge pumps.

The pressures in the steam jackets and the valves in the drains should be regulated.

Lubrication of Bearings. The oil cups on bearings require special attention. The caps of lubricators should be kept in place on the oil cups to prevent dirt and water from entering. The lubricators should be examined frequently because the pipes and passages are likely to become clogged with dirt or the worsteds may work downward and fill up the oilways.

Crank-pin bearings are lubricated by a wiper on the crank-pin box with the oil cup over it. Both crank-pins and eccentrics are frequently oiled by a centrifugal lubricator already described.

Internal Lubrication. In most engines the steam is sufficiently wet to insure internal lubrication. For this reason, very little oil is supplied to the cylinders. In many modern engines no lubricators are fitted. In case they are fitted, they should be of the sight-feed type as explained in discussing the Steam Engine. It is advantageous not to use oil in the cylinders as it is then much less trouble to keep the boilers free from grease.

Hot Bearings. There are many causes for hot bearings. The most common cause is dirt. To prevent the accumulation of dirt in the bearings the engine room should be kept clean and the oil cups and pipes kept clean. The bearings should be opened and cleaned whenever convenient.

Insufficient and improper lubrication will almost always cause heating. If the oil enters at the top where the pressure is greatest, suitable oil ways should be cut to allow the entrance of the oil. Another method is to lead the oil to a point of low pressure.

Other causes are improper adjustment or alignment and deficient surface. These defects lead to excessive pressure in some parts which causes heating.

In many large, modern engines, the main bearings have the castings cored out so that water circulates through the bearing continuously but does not come in contact with the rubbing surfaces. In the caps there are holes to allow the hand to feel of the bearings and to allow air to circulate. The temperature of the circulating water and the hand test indicate the condition of the bearing.

In case a bearing tends to become too warm the amount of circulating water is increased. In extreme cases of heating, the bearing may be flooded with water, thus washing out all of the dirt and reducing the temperature. If this water douche is used, plenty of oil should be supplied and the bearing given careful attention.

It may be necessary to slack back the nuts on the caps for a short time, but they should be slacked but little or there will be pounding. Sometimes the power distribution may be temporarily altered, that is, the power given out by any one cylinder may be decreased, and the power given out by the others increased by running the link in or out and adjusting the expansion gear. It may even be necessary to reduce the speed for a time, but this is not done unless necessary as it causes delay.

If the bearing is discovered to be *hot* the water service should not be applied as the sudden cooling may cause fracture. In this case the engine should be slowed down or stopped and the bearing cooled with oil, sulphur, or a mixture of soft soap, water and oil.

Bearings that are lined with white metal should receive special attention as the white metal soon becomes plastic and melts at about 400°F.

The water douche should be used only in extreme cases and with caution because it may cause fracture and is likely to corrode and destroy the bearings. If water must be used, the parts should be cleaned and oiled as soon as the engines stop.

Hot Rods. Piston-rods and valve-rods are often kept lubricated by means of a large brush called a swab. Frequently in starting, a man with a swab is stationed to keep the rods cool. If these rods become warm because of tight glands, they may be cooled by slacking back the gland and applying water and oil by means of a swab or syringe. If the rod is hot and water applied, one side may be cooled and shortened; the result will be a bent rod. Instead of water, the engines should be eased. If the rod cannot be felt, a few drops of oil or water syringed on the rod will show whether or not it is hot. If hot, the water will hiss or the oil will burn and cause smoke.

As with bearings, piston-rods that are packed with metal packing should receive careful attention, as the packing may run and cut the rods. The principal causes for hot rods are glands too tight or not properly packed, piston-rod not in line and insufficient lubrication.

Knocks. Bearings should be adjusted while the engines are running. If a bearing is loose it will knock at both ends of the stroke. Usually knocks can be located by the sound or by the feeling. Knocking in the cylinder may be due to a loose or broken piston ring, piston loose on the rod or a nut or bolt loose. If knocking occurs, open the cylinder and jacket drains, to be sure it is not due to an accumulation of water. If the noise continues at various speeds it is probably due to looseness of the piston rings. If this is the case the ring must be rescraped and fitted.

Jackets. The pressures in the jackets should be maintained at the desired amount. The jacket drains are led either to the condenser or to the feed tank. If led to the feed tank the temperature of the feed water is then raised. The jackets should be well drained, as water causes a crackling noise at each stroke. The remedy is to open the drains wide, and when clear of water, regulate the drain valves by increasing the opening.

Bilges. The bilge pumps should be at work constantly while the vessel is steaming, so that water will not accumulate in the bilges or crank pits. The crank pits should not be in communication with the bilges, or the oil from the crank pits will be spread over the bilges. If the stokehold bilges empty into the engine room bilges the bilge water should be strained, on account of the fine coal in the stokeholds. Strainers should be carefully attended to, as fine coal, waste and articles carelessly left in the bilges are likely to choke them. It is considered good practice to pump from wells about 8 inches deep, formed in the bilges and covered with strainers.

Linking Up. When starting, the links are placed in full gear. When running at the required speed the engine is linked up so that the expansive working of the steam may be utilized. The best position of the links for a given speed is determined by experience. Trial will show at what position the engine will run smoothly, economically and without too much noise. The throttle valve should be wide open so that steam will enter the high pressure chest at nearly boiler pressure. If the engine is running at reduced speed it is a good plan to link up the high pressure engine by the use of the block in the slot of the arm on the weigh shaft. This will increase the total ratio of expansion but will not reduce the port opening of the intermediate and low pressure cylinders. If there is any probability of a change in speed, the engineer in charge should see that the starting engine is warmed and drained from time to time and be sure that it is ready for use. Grunting of the slide valves is sometimes stopped by running the links into full gear for a short time then adjusting them in a slightly different position.

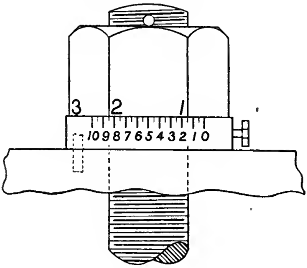


Fig. 46.

Marking off Nuts. In order to have a record of adjustments and to aid in adjusting bearings the following marks are made. At each corner of the hexagonal nut near the face that bears on the washer, a number is stamped as shown in Fig. 46. The washer is prevented from moving by some device. A part of the circumference of the washer is marked off in say 10 divisions about one-half inch apart These divisions are then sub-divided and numbered. It is then easy to record the position of the nut by noting what number on the washer coincides with the corner of the nut. Thus, 1 on $1\frac{1}{2}$ or 2 on $8\frac{1}{2}$.

Refitting Bearings. To find out whether or not a bearing needs refitting and to ascertain the amount of play, a lead is taken. The cap is first removed and a piece of lead wire is laid along the journal parallel to the axis. Some engineers place two pieces around the journals near the ends and others place them diagonally. The cap is then replaced and screwed down hard on the liners. The cap is again removed and the leads taken out and examined. They should be flattened uniformly. The thickness shows the clearance. If the marks on the nuts at which the leads were taken are noted they may be compared with the marks and leads taken sometime afterward and the location and extent of wear known.

If the leads show that the bearing needs refitting, the caps are first removed and the journal, caps and oilways cleaned. The journal is then carefully calipered and if found oval, cut or rough, should be filed all over until smooth and true. This process requires considerable care and skill for the new surface must be concentric with the axis. The filed surfaces are smoothed by an oil stone or emery. If emery is used, care must be taken to clean all surfaces.

After the journals are in proper condition the brasses, if used, are fitted by filing and scraping. A little red lead smeared on the journal will assist in the fitting. The brasses should be eased away at the sides as the metal at those points is of no assistance but increases the friction.

If the bearings are lined with white metal they must be relined when the white metal is worn through. To do this a mandrel of the same size as the journal is placed in position in the bearing and the molten metal poured in or the strips of white metal are hammered into the recesses. The metal stands clear of the brass about $\frac{1}{4}$ inch when finished.

STOPPING.

When near port the fires should be burned light so that there will be no difficulty in keeping the steam pressure down. If the pressure rises when the engines are slowed down there may be an unnecessary waste of fresh water on account of the blowing of the safety valve; the loss of fuel will also be considerable.

Before entering port have all ashes dumped overboard and pump out all the water possible from the bilges. The reversing and capstan engines should be warmed ready for use. When the engines are slowed down, the water service should be shut off and the oil supply increased to prevent rusting of the bearings while in port. The pressures in the receivers and jackets should be watched as they have a tendency to rise when the engines slow down.

When the engines are done with, the valves in the main steam pipe and the jacket valves should be closed but not too suddenly; the steam should then be allowed to escape from the pipe or used up by the reversing or other auxiliary engine. All drains and receiver relief valves should then be opened and steam shut off from the steering and reversing engines.

The hand turning gear may be put in gear as soon as there is no steam left in the engine room main steam pipe. The engines should now be cleaned while warm by wiping down the rods and shafting with cotton waste and oiling the bright parts to prevent rusting.

In case the engines are stopped suddenly, notice should be immediately given in the fire room so that the draft may be checked and the evaporation reduced. If the water level is low, water should be pumped into the boilers. Every precaution should be taken to prevent an over-supply of steam but if it is impossible to prevent the rise of pressure the excess of steam may be used in the evaporators, distillers, etc., and in pumping out bilges and crank pits. The engines should be kept warm and well drained so as not to cause delay in starting. If the air-pump is worked by an independent engine, it should be kept working for a time so that the condenser will not be flooded with water and injure the air-pump. If the air-pump is worked from the main engine, it will of course stop as soon as the engines stop; in this case put on a feed-pump to keep the condenser free from water. The circulating engines may be stopped soon after the engines stop.

As in the case of entering harbor, watch receiver and jacket pressures and stop the supply of water to bearings, etc. If there is any chance of starting again soon, keep the reversing engine warm and well drained.

If the stay in port is to be long, the main condensers and air-pumps should be well drained and several of the boilers may be cleaned and repaired if necessary. The fires should be allowed to burn themselves out gradually. If the stop is for a short time, the fires should be banked.

EMERGENCIES.

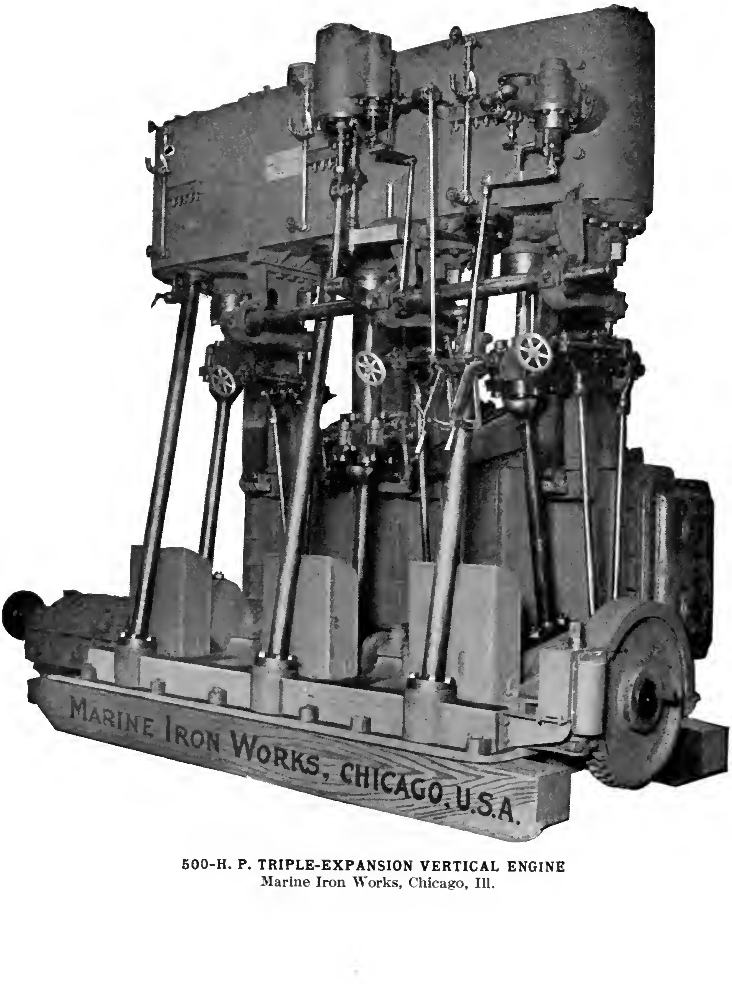
What to do in emergencies depends upon the arrangement of the machinery. The kind of engine, number of engines and arrangement and capacities of the condensers and auxiliary machinery often determine what course to pursue in case any part breaks or gets out of position.

Cylinder Head Broken. If a cylinder head breaks it should be repaired if proper means are at hand. If it cannot be repaired, the steam port which admits steam to that end may be blocked up by driving in plugs of soft pine and the engine run single acting. This is comparatively simple if the valve is a plain slide but with a piston valve the many ports make it more difficult. If a cylinder head of a triple expansion engine breaks, and one engine must run single acting, the expansion gear should be arranged so that the work will be properly divided.

Fracture in the Crank Shaft. What to do in this case depends upon many conditions. If the engine is of the multi-cylinder type, and the crank shaft is made in interchangeable lengths, fit the spare length in place of the disabled one. In case no spare length is carried and the crank shaft of the low pressure engine is damaged slightly, change the low pressure length to the high pressure engine and place the high pressure length in place of the low. The low pressure length transmits the most power. If the damage is considerable, such as the breaking of the crank-pin, the length cannot be used and the high pressure engine must be disconnected. If the pumps are worked from the high pressure crosshead, repair the broken shaft, place it in the high pressure engine and block up the steam ports to the high pressure cylinder. The power is then developed in the intermediate and low pressure cylinders; the amount of power transmitted to the high pressure crank shaft being just sufficient to work the pumps. Probably it will be necessary to run the engines slowly because of the weak shaft.

Piston Broken. If the piston, piston-rod or valve stem becomes broken and cannot be repaired, the damaged engine must be disconnected and the power furnished by the others.

Air-Pump Broken. In case the air-pump breaks and cannot be repaired the exhaust may be carried to the deck and the engines run non-condensing. This is a great disadvantage if the amount of fresh water carried is slight and the ship is far from



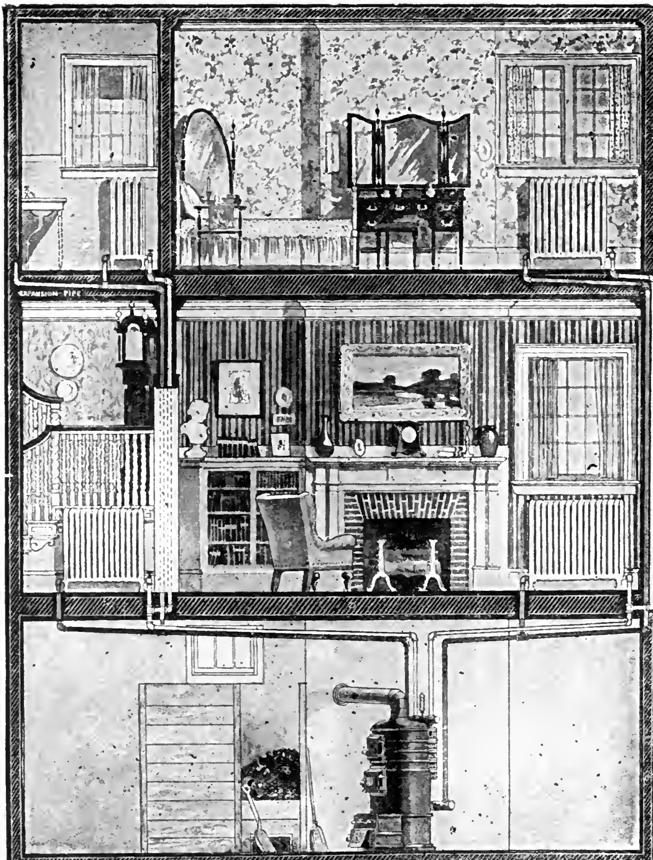
500-H. P. TRIPLE-EXPANSION VERTICAL ENGINE
Marine Iron Works, Chicago, Ill.

port. In case no separate exhaust is possible, the auxiliary air-pumps may be connected and the ship proceed. In most cases, however, the auxiliary air-pumps are not of sufficient capacity to remove all of the condensed exhaust steam and the air; therefore no vacuum will be carried but the condensation may be returned to the boilers.

Bent Piston-Rod. In the case of a small rod and a long slight bend, the rod may be straightened by placing it in a lathe and applying a powerful lever. A large rod or one with a quick bend, should be heated to a dull red in a wood fire. The rod is then placed in a large lathe and straightened by a hydraulic jack. In doing this work care must be taken that the rod is not heated too hot, does not scale and the points of contact are protected by copper plates.

Eccentric Broken. If the go-ahead eccentric or eccentric rod breaks and cannot be repaired, the go-astern eccentric can be shifted in its place. The engine will now run ahead but cannot be reversed. The go-astern end of the links must be kept from dropping by some flexible support such as a rope or chain.

Another method is to disconnect the connecting-rod from the crank-pin and crosshead of the disabled engine, and block up the steam ports so that the steam will flow to the other cylinders by the shortest passage. The piston should be secured on the bottom of the cylinder. The valve should be removed. After removing the broken valve gear the engine is ready to start. This method may be used if the pumps are worked from the low pressure crosshead and the low pressure engine is intact. If, however, the high pressure eccentric is broken and the pumps are worked from that crosshead the same method may be pursued as described for a fractured crank shaft. That is, the valve gear should be removed, the ports blocked and the piston, the piston-rod, crosshead and connecting-rod left in place. The moving parts of the high pressure engine will then work the pumps by means of the power transmitted to the high pressure crank. The engine must be run slowly but can be reversed.



HOT WATER HEATER AND CONNECTIONS.

HEATING AND VENTILATION

PART I

SYSTEMS OF WARMING

Any system of warming must include, *first,* the combustion of fuel, which may take place in a fireplace, stove, or furnace, or a steam, or hot-water boiler; *second,* a system of transmission, by means of which the heat may be carried, with as little loss as possible, to the place where it is to be used for warming; and *third,* a system of diffusion, which will convey the heat to the air in a room, and to its walls, floors, etc., in the most economical way.

Stoves. The simplest and cheapest form of heating is the stove. The heat is diffused by radiation and convection directly to the objects and air in the room, and no special system of transmission is required. The stove is used largely in the country, and is especially adapted to the warming of small dwelling-houses and isolated rooms.

Furnaces. Next in cost of installation and in simplicity of operation, is the hot-air furnace. In this method, the air is drawn over heated surfaces and then transmitted through pipes, while at a high temperature, to the rooms where heat is required. Furnaces are used largely for warming dwelling-houses, also churches, halls, and schoolhouses of small size. They are more costly than stoves, but have certain advantages over that form of heating. They require less care, as several rooms may be warmed from a single furnace; and, being placed in the basement, more space is available in the rooms above, and the dirt and litter connected with the care of a stove are largely done away with. They require less care, as only one fire is necessary to warm all the rooms in a house of ordinary size. One great advantage in the furnace method of warming comes from the constant supply of fresh air which is required to bring the heat into the rooms. While this is greatly to be desired from a sanitary standpoint, it calls for the consumption of a larger amount of fuel than would otherwise be necessary. This is true because heat is required to warm the fresh air from out of doors up to the temperature of the rooms, in addition to replacing the heat lost by leakage and conduction through walls and windows.

A more even temperature may be maintained with a furnace than by the use of stoves, owing to the greater depth and size of the fire, which allows it to be more easily controlled.

When a building is placed in an exposed location, there is often difficulty in warming rooms on the north and west sides, or on that side toward the prevailing winds. This may be overcome to some extent by a proper location of the furnace and by the use of extra large pipes for conveying the hot air to those rooms requiring special attention.

Direct Steam. Direct steam, so called, is widely used in all classes of buildings, both by itself and in combination with other systems. The first cost of installation is greater than for a furnace; but the amount of fuel required is less, as no outside air supply is necessary. If used for warming hospitals, schoolhouses, or other buildings where a generous supply of fresh air is desired, this method must be supplemented by some form of ventilating system.

One of the principal advantages of direct steam is the ability to heat all rooms alike, regardless of their location or of the action of winds.

When compared with hot-water heating, it has still another desirable feature—which is its freedom from damage by the freezing of water in the radiators when closed, which is likely to happen in unused rooms during very cold weather in the case of the former system.

On the other hand, the sizes of the radiators must be proportioned for warming the rooms in the coldest weather, and unfortunately there is no satisfactory method of regulating the amount of heat in mild weather, except by shutting off or turning on steam in the radiators at more or less frequent intervals as may be required, unless one of the expensive systems of automatic control is employed. In large rooms, a certain amount of regulation can be secured by dividing the radiation into two or more parts, so that different combinations may be used under varying conditions of outside temperature. If two radiators are used, their surface should be proportioned, when convenient, in the ratio of 1 to 2, in which case one-third, two-thirds, or the whole power of the radiation can be used as desired.

Indirect Steam. This system of heating combines some of the advantages of both the furnace and direct steam, but is more costly to install than either of these. The amount of fuel required is about the same as for furnace heating, because in each case the cool fresh air must be warmed up to the temperature of the room, before it can become a medium for conveying heat to offset that lost by leakage and conduction through walls and windows.

A system for indirect steam may be so designed that it will supply a greater quantity of fresh air than the ordinary form of furnace, in which case the cost of fuel will of course be increased in proportion to the volume of air supplied. Instead of placing the radiators in the rooms, a special form of heater is supported near the basement ceiling and encased in either galvanized iron or brick. A cold-air supply duct is connected with the space below the heater, and warm air pipes are taken from the top and connected with registers in the rooms to be heated the same as in the case of furnace heating.

A separate stack or heater may be provided for each register if the rooms are large; but, if small and so located that they may be reached by short runs of horizontal pipe, a single heater may serve for two or more rooms.

The advantage of indirect steam over furnace heating comes from the fact that the stacks may be placed at or near the bases of the flues leading to the different rooms, thus doing away with long, horizontal runs of pipe, and counteracting to a considerable extent the effect of wind pressure upon exposed rooms. Indirect and direct heating are often combined to advantage by using the former for the more important rooms, where ventilation is desired, and the latter for rooms more remote or where heat only is required.

Another advantage is the large ratio between the radiating surface and grate-area, as compared with a furnace; this results in a large volume of air being warmed to a moderate temperature instead of a smaller quantity being heated to a much higher temperature, thus giving a more agreeable quality to the air and rendering it less dry.

Indirect steam is adapted to all the buildings mentioned in connection with furnace heating, and may be used to much better advantage in those of large size. This applies especially to cases where more than one furnace is necessary; for, with steam heat, a single boiler, or a battery of boilers, may be made to supply heat for a building of any size, or for a group of several buildings, if desired, and is much easier to care for than several furnaces widely scattered.

Direct-Indirect Radiators. These radiators are placed in the room the same as the ordinary direct type. The construction is such that when the sections are in place, small flues are formed between them; and air, being admitted through an opening in the outside wall, passes upward through them and becomes heated before entering the room. A switch damper is placed in the casing at the base of the radiator, so that air may be taken from the room itself instead of from out of doors, if so desired. Radiators of this kind are not used to any great extent, as there is likely to be more or less leakage of cold air into the room around the base. If ventilation is required, it is better to use the regular form of indirect heater with flue and register, if possible. It is sometimes desirable to partially ventilate an isolated room where it would be impossible to run a flue, and in cases of this kind the direct-indirect form is often useful.

Direct Hot Water. Hot water is especially adapted to the warming of dwellings and greenhouses, owing to the ease with which the temperature can be regulated. When steam is used, the radiators are always at practically the same temperature, while with hot water the temperature can be varied at will. A system for hot-water heating costs more to install than one for steam, as the radiators must be larger and the pipes more carefully run. On the other hand, the cost of operating is somewhat less, because the water need be carried only at a temperature sufficiently high to warm the rooms properly in mild weather, while with steam the building is likely to become overheated, and more or less heat wasted through open doors and windows.

A comparison of the relative costs of installing and operating hot-air, steam, and hot-water systems, is given in Table I.

TABLE I

Relative Cost of Heating Systems

	Hot Air	Steam	Hot Water
Relative cost of apparatus	9	13	15
Relative cost, adding repairs and fuel for five years	29½	29¾	27
Relative cost, adding repairs and fuel for fifteen years	81	63	52½

One disadvantage in the use of hot water is the danger from freezing when radiators are shut off in unused rooms. This makes it necessary in very cold weather to have all parts of the system turned on sufficiently to produce a circulation, even if very slow. This is sometimes accomplished by drilling a very small hole (about $\frac{1}{8}$ inch) in the valve-seat, to that when closed there will still be a very slow circulation through the radiator, thus preventing the temperature of the water from reaching the freezing point.

Indirect Hot Water. This is used under the same conditions as indirect steam, but more especially in the case of dwellings and hospitals. When applied to other and larger buildings, it is customary to force the water through the mains by means of a pump. Larger heating stacks and supply pipes are required than for steam; but the arrangement and size of air-flues and registers are practically the same, although they are sometimes made slightly larger in special cases.

Exhaust Steam. Exhaust steam is used for heating in connection with power plants, as in shops and factories, or in office buildings which have their own lighting plants. There are two methods of using exhaust steam for heating purposes. One is to carry a back pressure of 2 to 5 pounds on the engines, depending upon the length and size of the pipe mains; and the other is to use some form of *vacuum system* attached to the returns or air-valves, which tends to reduce the back pressure rather than to increase it.

Where the first method is used and a back pressure carried, either the boiler pressure or the cut-off of the engines must be increased, to keep the mean effective pressure the same and not reduce the horse-power delivered. In general it is more economical to utilize the exhaust steam for heating. There are instances, however, where the relation between the quantities of steam required for heating and for power are such—especially if the engines are run condensing—that it is better to throw the exhaust away and heat with live steam. Where the vacuum method is used, these difficulties are avoided; and for this reason that method is coming into quite common use. If the condensation from the exhaust steam is returned to the boilers, the oil must first be removed; this is usually accomplished by passing the steam through some form of grease extractor as it leaves the engine. The water of condensation is often passed through a separating tank in addition to this, before it is delivered to the return pumps. It is better, however, to remove a portion of the oil before the steam enters the heating system; otherwise a coating will be formed upon the inner surfaces of the radiators, which will reduce their efficiency to some extent.

Forced Blast. This method of heating, in different forms, is used for the warming of factories, schools, churches, theaters, halls—in fact, any large building where good ventilation is desired. The air for warming is drawn or forced through a heater of special design, and discharged by a fan or blower into ducts which lead to registers placed in the rooms to be warmed. The heater is usually made up in sections, so that steam may be admitted to or shut off from any section independently of the others, and the temperature of the air regulated in this manner. Sometimes a *by-pass damper* is attached, so that part of the air will pass through the heater and part around or over it; in this way the proportions of cold and heated air may be so adjusted as to give the desired temperature to the air entering the rooms. These forms of regulation are common where a blower is used for warming a single room, as in the case of a church or hall; but where several rooms are warmed, as in a schoolhouse. it is customary to use the main or primary heater at the blower for warming the air to a given temperature (somewhat below that which is actually required), and to supplement this by placing secondary coils or heaters at the bottoms of the flues leading to the different rooms. By means of this arrangement, the temperature of each room can be regulated independently of the others. The so-called *double-duct* system is sometimes employed. In this case, two ducts are carried to each register, one supplying hot air and the other cold or tempered air; and a damper for mixing these in the right proportions is placed in the flue, below the register.

Electric Heating. Unless electricity can be produced at a very low cost, it is not practicable for heating residences or large buildings. The electric heater, however, has quite a wide field of application in heating small offices, bathrooms, electric cars, etc. It is a convenient method of warming isolated rooms on cold mornings, in late spring and early fall, when the regular heating apparatus of the building is not in operation. It has the advantage of being instantly available, and the amount of heat can be regulated at will. Electric heaters are clean, do not vitiate the air, and are easily moved from place to place.

PRINCIPLES OF VENTILATION

Closely connected with the subject of heating is the problem of maintaining air of a certain standard of purity in the various buildings occupied.

The introduction of pure air can be done properly only in connection with some system of heating; and no system of heating is complete without a supply of pure air, depending in amount upon the kind of building and the purpose for which it is used.

Composition of the Atmosphere. Atmospheric air is not a simple substance but a mechanical mixture. Oxygen and nitrogen, the principal constituents, are present in very nearly the proportion of one part of oxygen to four parts of nitrogen by weight. Carbonic acid gas, the product of all combustion, exists in the proportion of 3 to 5 parts in 10,000 in the open country. Water in the form of vapor, varies greatly with the temperature and with the exposure of the air to open bodies of water. In addition to the above, there are generally present, in variable but exceedingly small quantities, ammonia, sulphuretted hydrogen, sulphuric, sulphurous, nitric, and nitrous acids, floating organic and inorganic matter, and local impurities. Air also contains ozone, which is a peculiarly active form of oxygen; and lately another constituent called *argon* has been discovered.

Oxygen is the most important element of the air, so far as both heating and ventilation are concerned. It is the active element in the chemical process of combustion and also in the somewhat similar process which takes place in the respiration of human beings. Taken into the lungs, it acts upon the excess of carbon in the blood, and possibly upon other ingredients, forming chemical compounds which are thrown off in the act of respiration or breathing.

Nitrogen. The principal bulk of the atmosphere is nitrogen, which exists uniformly diffused with oxygen and carbonic acid gas. This element is practically inert in all processes of combustion or respiration. It is not affected in composition, either by passing through a furnace during combustion or through the lungs in the process of respiration. Its action is to render the oxygen less active, and to absorb some part of the heat produced by the process of oxidation.

Carbonic acid gas is of itself only a neutral constituent of the atmosphere, like nitrogen; and—contrary to the general impression—its presence in moderately large quantities (if uncombined with other substances) is neither disagreeable nor especially harmful. Its presence, however, in air provided for respiration, decreases the readiness with which the carbon of the blood unites with the oxygen of the air; and therefore, when present in sufficient quantity, it may cause indirectly, not only serious, but fatal results. The real harm of a vitiated atmosphere, however, is caused by the other constituent gases and by the minute organisms which are produced in the process of respiration. It is known that these other impurities exist in fixed proportion to the amount of carbonic acid present in an atmosphere vitiated by respiration. Therefore, as the relative proportion of carbonic acid can easily be determined by experiment, the fixing of a standard limit of the amount in which it may be allowed, also limits the amounts of other impurities which are found in combination with it.

When carbonic acid is present in excess of 10 parts in 10,000 parts of air, a feeling of weariness and stuffiness, generally accompanied by a headache, will be experienced; while with even 8 parts in 10,000 parts a room would be considered close. For general considerations of ventilation, the limit should be placed at 6 to 7 parts in 10,000, thus allowing an increase of 2 to 3 parts over that present in outdoor air, which may be considered to contain four parts in 10,000 under ordinary conditions.

Analysis of Air. An accurate qualitative and quantitative analysis of air samples can be made only by an experienced chemist. There are, however, several approximate methods for determining the amount of carbonic acid present, which are sufficiently exact for practical purposes. Among these the following is one of the simplest:

The necessary apparatus consists of six clean, dry, and tightly corked bottles, containing respectively 100, 200, 250, 300, 350, and 400 cubic centimeters, a glass tube containing exactly 15 cubic centimeters to a given mark, and a bottle of perfectly clear, fresh limewater. The bottles should be filled with the air to be examined by means of a hand-ball syringe. Add to the smallest bottle 15 cubic centimeters of the limewater, put in the cork, and shake well. If the limewater has a milky appearance, the amount of carbonic acid will be at least 16 parts in 10,000. If the contents of the bottle remain clear, treat the bottle of 200 cubic centimeters in the same manner; a milky appearance or turbidity in this would indicate 12 parts in 10,000. In a similar manner, turbidity in the 250 cubic centimeter bottle indicates

10 parts in 10,000; in the 300, 8 parts; in the 350, 7 parts; and in the 400, less than 6 parts. The ability to conduct more accurate analyses can be attained only by special study and a knowledge of chemical properties and of methods of investigation.

Another method similar to the above, makes use of a glass cylinder containing a given quantity of limewater and provided with a piston. A sample of the air to be tested is drawn into the cylinder by an upward movement of the piston. The cylinder is then thoroughly shaken, and if the limewater shows a milky appearance, it indicates a certain proportion of carbonic acid in the air. If the limewater remains clear, the air is forced out, and another cylinder full drawn in, the operation being repeated until the limewater becomes milky. The size of the cylinder and the quantity of limewater are so proportioned that a change in color at the first, second, third, etc., cylinder full of air indicates different proportions of carbonic acid. This test is really the same in principle as the one previously described; but the apparatus used is in more convenient form.

Air Required for Ventilation. The amount of air required to maintain any given standard of purity can very easily be determined, provided we know the amount of carbonic acid given off in the process of respiration. It has been found by experiment that the average production of carbonic acid by an adult at rest is about .6 cubic foot per hour. If we assume the proportion of this gas as 4 parts in 10,000 in the external air, and are to allow 6 parts in 10,000 in an occupied room, the gain will be 2 parts in 10,000; or, in other words, there will be $\frac{2}{10{,}000} = .0002$ cubic foot of carbonic acid mixed with each cubic foot of fresh air entering the room. Therefore, if one person gives off .6 cubic foot of carbonic acid per hour, it will require $.6 \div .0002 = 3{,}000$ cubic feet of air per hour per person to keep the air in the room at the standard of purity assumed—that is, 6 parts of carbonic acid in 10,000 of air.

Table II has been computed in this manner, and shows the amount of air which must be introduced for each person in order to maintain various standards of purity.

While this table gives the theoretical quantities of air required for different standards of purity, and may be used as a guide, it will be better in actual practice to use quantities which experience has shown to give good results in different types of buildings. In auditoriums where the cubic space per individual is large, and in which the atmosphere is thoroughly fresh before the rooms are occupied, and the occupancy is of only two or three hours' duration, the air-supply may be reduced somewhat from the figures given below.

TABLE II

Quantity of Air Required per Person

Standard Parts of Carbonic Acid in 10,000 of Air in Room	Cubic Feet of Air Required per Person	
	Per Minute	Per Hour
5	100	6,000
6	50	3,000
7	33	2,000
8	25	1,500
9	20	1,200
10	16	1,000

Table III represents good modern practice and may be used with satisfactory results:

TABLE III

Air Required for Ventilation of Various Classes of Buildings

Air-Supply per Occupant for	Cubic Feet per Minute	Cubic Feet per Hour
Hospitals	80 to 100	4, 800 to 6, 000
High Schools	50	3, 000
Grammar Schools	40	2, 400
Theaters and Assembly Halls	25	1, 500
Churches	20	1, 200

When possible, the air-supply to any given room should be based upon the number of occupants. It sometimes happens, however, that this information is not available, or the character of the room is such that the number of persons occupying it may vary, as in the case of public waiting rooms, toilet rooms, etc. In instances of this kind, the required air-volume may be based upon the number of changes per hour. In using this method, various considerations must be taken into account, such as the use of the room and its condition as to crowding, character of occupants, etc. In general, the following will be found satisfactory for average conditions:

TABLE IV

Number of Changes of Air Required in Various Rooms

Use of Room	Changes of Air per Hour
Public Waiting Room	4 to 5
Public Toilets	5 " 6
Coat and Locker Rooms	4 " 5
Museums	3 " 4
Offices, Public	4 " 5
Offices, Private	3 " 4
Public Dining Rooms	4 " 5
Living Rooms	3 " 4
Libraries, Public	4 " 5
Libraries, Private	3 " 4

Force for Moving Air. Air is moved for ventilating purposes in two ways: (1) by expansion due to heating; (2) by mechanical means. The effect of heat on the air is to increase its volume and therefore lessen its density or weight, so that it tends to rise and is replaced by the colder air below. The available force for moving air obtained in this way is very small, and is quite likely to be overcome by wind or external causes. It will be found in general that the heat used for producing velocity in this manner, when transformed into work in the steam engine, is greatly in excess of that required to produce the same effect by the use of a fan.

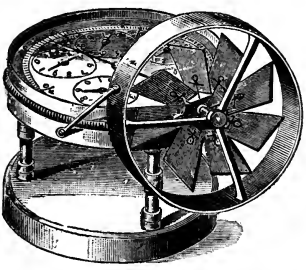


Fig. 1. Common Form of Anemometer, for Measuring Velocity of Air-Currents.

Ventilation by mechanical means is performed either by pressure or by suction. The former is used for delivering fresh air into a building, and the latter for removing the foul air from it. By both processes the air is moved without change in temperature, and the force for moving must be sufficient to overcome the effects of wind or changes in outside temperature. Some form of fan is used for this purpose.

Measurements of Velocity. The velocity of air in ventilating ducts and flues is measured directly by an instrument called an anemometer. A common form of this instrument is shown in Fig. 1. It consists of a series of flat vanes attached to an axis, and a series of dials.

The revolution of the axis causes motion of the hands in proportion to the velocity of the air, and the result can be read directly from the dials for any given period.

For approximate results the anemometer may be slowly moved across the opening in either vertical or horizontal parallel lines, so that the readings will be made up of velocities taken from all parts of the opening. For more accurate work, the opening should be divided into a number of squares by means of small twine, and readings taken at the center of each. The mean of these readings will give the average velocity of the air through the entire opening.

AIR DISTRIBUTION

The location of the air inlet to a room depends upon the size of the room and the purpose for which it is used. In the case of living rooms in dwelling-houses, the registers are placed either in the floor or in the wall near the floor; this brings the warm air in at the coldest part of the room and gives an opportunity for warming or drying the feet if desired. In the case of schoolrooms, where large volumes of warm air at moderate temperatures are required, it is best to discharge it through openings in the wall at a height of 7 or 8 feet from the floor; this gives a more even distribution, as the warmer air tends to rise and hence spreads uniformly under the ceiling; it then gradually displaces other air, and the room becomes filled with pure air without sensible currents or drafts. The cooler air sinks to the bottom of the room, and can be taken off through ventilating registers placed near the floor. The relative positions of the inlet and outlet are often governed to some extent by the building construction; but, if possible, they should both be located in the same side of the room. Figs. 2, 3, and 4 show common arrangements.

The vent outlet should always, if possible, be placed in an inside wall; otherwise it will become chilled and the air-flow through it will become sluggish. In theaters and churches which are closely packed, the air should enter at or near the floor, in finely-divided streams; and the discharge ventilation should be through openings in the ceiling. The reason for this is the large amount of animal heat given off from the bodies of the audience; this causes the air to become still further heated after entering the room, and the tendency is to rise continuously from floor to ceiling, thus carrying away all impurities from respiration as fast as they are given off.

All audience halls in which the occupants are closely seated should be treated in the same manner, when possible. This, however, cannot always be done, as the seats are often made removable so that the

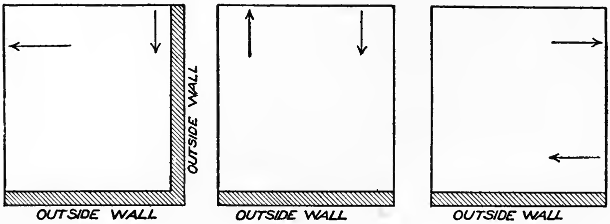


Fig. 2. Fig. 3. Fig. 4.
Diagrams Showing Relative Positions of Air Inlets and Outlets as Commonly Arranged.

floor can be used for other purposes. In cases of this kind, part of the air may be introduced through floor registers placed along the outer aisles, and the remainder by means of wall inlets the same as for schoolrooms. The discharge ventilation should be partly through registers near the floor, supplemented by ample ceiling vents for use when the hall is crowded or the outside temperature high.

The matter of air-velocities, size of flues, etc., will be taken up under the head of "Indirect Heating."

HEAT LOSS FROM BUILDINGS

A *British Thermal Unit*, or B. T. U., has been defined as the amount of heat required to raise the temperature of one pound of water one degree F. This measure of heat enters into many of the calculations involved in the solving of problems in heating and ventilation, and one should familiarize himself with the exact meaning of the term.

Causes of Heat Loss. The heat loss from a building is due to the following causes: (1) radiation and conduction of heat through walls and windows; (2) leakage of warm air around doors and windows and through the walls themselves; and (3) heat required to warm the air for ventilation.

Loss through Walls and Windows. The loss of heat through the walls of a building depends upon the material used in construction

TABLE V

Heat Losses in B. T. U. per Square Foot of Surface per Hour—Southern Exposure

Material	Difference between Inside and Outside Temperatures									
	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
8-in. Brick Wall	5	9	13	18	22	27	31	36	40	45
12-in. Brick Wall	4	7	10	13	16	20	23	26	30	33
16-in. Brick Wall	3	5	8	10	13	16	19	22	24	27
20-in. Brick Wall	2.8	4.5	7	9	11	14	16	18	20	23
24-in. Brick Wall	2.5	4	6	8	10	12	14	16	18	20
28-in. Brick Wall	2	3.5	5	7	9	11	13	14	16	18
32-in. Brick Wall	1.5	3	4.5	6	8	10	11	13	15	16
Single Window	12	24	36	49	60	73	85	93	110	122
Double Window	8	16	24	32	40	48	56	62	70	78
Single Skylight	11	21	31	42	52	63	73	84	94	104
Double Skylight	7	14	20	28	35	42	48	56	62	70
1-in. Wooden Door	4	8	12	16	20	24	28	32	36	40
2-in. Wooden Door	3	5	8	11	14	17	20	23	25	28
2-in. Solid Plaster Partition	6	12	18	24	30	36	42	48	54	60
3-in. Solid Plaster Partition	5	10	15	20	25	30	35	40	45	50
Concrete Floor on Brick Arch	2	4	6.5	9	11	13	15	18	20	22
Wood Floor on Brick Arch	1.5	3	4.5	6	7	9	10	12	13	15
Double Wood Floor	1	2	3	4	5	6	7	8	9	10
Walls of Ordinary Wooden Dwellings	3	5	8	10	13	16	19	22	24	27

For *solid stone walls*, multiply the figures for brick of the same thickness by 1.7. Where rooms have a *cold attic above or cellar beneath*, multiply the heat loss through walls and windows by 1.1.

Correction for Leakage. The figures given in the above table apply only to the most thorough construction. For the average well-built house, the results should be increased about 10 per cent; for fairly good construction, 20 per cent; and for poor construction, 30 per cent.

Table V applies only to a southern exposure; for other exposures multiply the heat loss given in Table V by the factors given in Table VI.

of the wall, the thickness, the number of layers, and the difference between the inside and outside temperatures. The exact amount of heat lost in this way is very difficult to determine theoretically, hence we depend principally on the results of experiments.

Loss by Air-Leakage. The leakage of air from a room varies from one to two or more changes of the entire contents per hour, depending upon the construction, opening of doors, etc. It is common practice to allow for one change per hour in well-constructed buildings where two walls of the room have an outside exposure. As the amount of leakage depends upon the extent of exposed wall and window surface, the simplest way of providing for this is to increase

TYPICAL HEATING INSTALLATION SHOWING SECTIONAL BOILER AND RADIATOR.

American Radiator Company.

TABLE VI
Factors for Calculating Heat Loss for Other than Southern Exposures

Exposure	Factor
N.	1.32
E.	1.12
S.	1.0
W.	1.20
N. E.	1.22
N. W.	1.26
S. E.	1.06
S. W.	1.10
N., E., S., and W., or total exposure	1.16

the total loss through walls and windows by a factor depending upon the tightness of the building construction. Authorities differ considerably in the factors given for heat losses, and there are various methods for computing the same. The figures given in Table V have been used extensively in actual practice, and have been found to give good results when used with judgment. The table gives the heat losses through different thicknesses of walls, doors, windows, etc., in B. T. U., per square foot of surface per hour, for varying differences in inside and outside temperatures.

In computing the heat loss through walls, only those exposed to the outside air are considered.

In order to make the use of the table clear, we shall give a number of examples illustrating its use:

Example 1. Assuming an inside temperature of 70°, what will be the heat loss from a room having an exposed wall surface of 200 square feet and a glass surface of 50 square feet, when the outside temperature is zero? The wall is of brick, 16 inches in thickness, and has a southern exposure; the windows are single; and the construction is of the best, so that no account need be taken of leakage

We find from Table V, that the factor for a 16-inch brick wall with a difference in temperature of 70° is 19, and that for glass (single window) under the same condition is 85; therefore,

Loss through walls = 200 × 19 = 3,800
Loss through windows = 50 × 85 = 4,250

Total loss per hour = 8,050 B. T. U.

Example 2. A room 15 ft. square and 10 ft. high has two exposed walls, one toward the north, and the other toward the west. There are 4 windows, each 3 feet by 6 feet in size. The two in the north wall are double, while the other two are single. The walls are of brick, 20 inches in thickness. With an inside temperature of 70°, what will be the heat loss per hour when it is 10° below zero?

Total exposed surface $= 15 \times 10 \times 2 = 300$
Glass surface $= 3 \times 6 \times 4 = 72$

Net wall surface $= 228$

Difference between inside and outside temperature 80°.
Factor for 20-inch brick wall is 18.
Factor for single window is 93.
Factor for double window is 62.
The heat losses are as follows:

Wall,	$228 \times 18 =$	4,104
Single windows,	$36 \times 93 =$	3,348
Double windows,	$36 \times 62 =$	2,232
		9,684 B. T. U.

As one side is toward the north, and the other toward the west, the actual exposure is N. W. Looking in Table VI, we find the correction factor for this exposure to be 1.26; therefore the total heat loss is

$$9{,}684 \times 1.26 = 12{,}201.84 \text{ B. T. U.}$$

Example 3. A dwelling-house of fair wooden construction measures 160 ft. around the outside; it has 2 stories, each 8 ft. in height; the windows are single, and the glass surface amounts to one-fifth the total exposure; the attic and cellar are unwarmed. If 8,000 B. T. U. are utilized from each pound of coal burned in the furnace, how many pounds will be required per hour to maintain a temperature of 70° when it is 20° above zero outside?

Total exposure $= 160 \times 16 = 2{,}560$
Glass surface $= 2{,}560 \div 5 = 512$

Net wall $= 2{,}048$

Temperature difference $= 70 - 20 = 50°$

Wall	$2{,}048 \times 13$	$= 26{,}624$
Glass	512×60	$= 30{,}720$
		57,344 B. T. U.

As the building is exposed on all sides, the factor for exposure will be the average of those for N., E., S., and W., or

$$(1.32 + 1.12 + 1.0 + 1.20) \div 4 = 1\ 16$$

The house has a cold cellar and attic, so we must increase the heat loss

10 per cent for each of the first two conditions, and 20 per cent for the last. Making these corrections we have:

$$57,344 \times 1.16 \times 1.10 \times 1.10 \times 1.20 = 96,338 \text{ B. T. U.}$$

If one pound of coal furnishes 8,000 B. T. U., then 96,338 ÷ 8,000 = 12 pounds of coal per hour required to warm the building to 70° under the conditions stated.

Approximate Method. For dwelling-houses of the average construction, the following simple method for calculating the heat loss may be used. Multiply the total exposed surface by 45, which will give the heat loss in B. T. U. per hour for an inside temperature of 70° in zero weather.

This factor is obtained in the following manner: Assume the glass surface to be one-sixth the total exposure, which is an average proportion. Then each square foot of exposed surface consists one-sixth of glass and five-sixths of wall, and the heat loss for 70° difference in temperature would be as follows:

$$\text{Wall } \frac{5}{6} \times 19 = 15.8$$

$$\text{Glass } \frac{1}{6} \times 85 = \underline{14.1}$$

$$29.9$$

Increasing this 20 per cent for leakage, 16 per cent for exposure, and 10 per cent for cold ceilings, we have:

$$29.9 \times 1.20 \times 1.16 \times 1.10 = 45.$$

The loss through floors is considered as being offset by including the kitchen walls of a dwelling-house, which are warmed by the range, and which would not otherwise be included if computing the size of a furnace or boiler for heating.

If the heat loss is required for outside temperatures other than zero, multiply by 50 for 10 degrees below, and by 40 for 10 degrees above zero.

This method is convenient for approximations in the case of dwelling-houses; but the more exact method should be used for other types of buildings, and in all cases for computing the heating surface for separate rooms. *When calculating the heat loss from isolated rooms, the cold inside walls as well as the outside must be considered.*

The loss through a wall next to a cold attic or other unwarmed space may in general be taken as about two-thirds that of an outside wall.

Heat Loss by Ventilation. One B. T. U. will raise the temperature of 1 cubic foot of air 55 degrees at average temperatures and pressures, or will raise 55 cubic feet 1 degree, so that the heat required for the ventilation of any room can be found by the following formula:

$$\frac{\text{Cu. ft. of air per hour} \times \text{Number of degrees rise}}{55} = \text{B. T. U. required.}$$

To compute the heat loss for any given room which is to be ventilated, first find the loss through walls and windows, and correct for exposure and leakage; then compute the amount required for ventilation as above, and take the sum of the two. An inside temperature of 70° is always assumed unless otherwise stated.

Examples. What quantity of heat will be required to warm 100,000 cubic feet of air to 70° for ventilating purposes when the outside temperature is 10 below zero?

$$100{,}000 \times 80 \div 55 = 145{,}454 \text{ B. T. U.}$$

How many B. T. U. will be required per hour for the ventilation of a church seating 500 people, in zero weather?

Referring to Table III, we find that the total air required per hour is $1{,}200 \times 500 = 600{,}000$ cu. ft.; therefore $600{,}000 \times 70 \div 55 = 763{,}636$ B. T. U.

The factor $\frac{\text{Rise in Temperature}}{55}$ is approximately 1.1 for 60°, 1.3 for 70°, and 1.5 for 80°. Assuming a temperature of 70° for the entering air, we may multiply the air-volume supplied for ventilation by 1.1 for an outside temperature of 10° above 0, by 1.3 for zero, and by 1.5 for 10° below zero—which covers the conditions most commonly met with in practice.

EXAMPLES FOR PRACTICE

1. A room in a grammar school 28 ft. by 32 ft. and 12 feet high is to accommodate 50 pupils. The walls are of brick 16 inches in thickness; and there are 6 single windows in the room, each 3 ft. by 6 ft.; there are warm rooms above and below; the exposure is S. E. How many B. T. U. will be required per hour for warming the room, and how many for ventilation, in zero weather, assuming the building to be of average construction?

Ans. 24,261 + for warming; 152,727 + for ventilation.

2. A stone church seating 400 people has walls 20 inches in thickness. It has a wall exposure of 5,000 square feet, a glass expos-

ure (single windows) of 600 square feet, and a roof exposure of 7,000 square feet; the roof is of 2-inch pine plank, and the factor for heat loss may be taken the same as for a 2-inch wooden door. The floor is of wood on brick arches, and has an area of 4,000 square feet. The building is exposed on all sides, and is of first-class construction. What will be the heat required per hour for both warming and ventilation when the outside temperature is 20° above zero?

Ans. 296,380 for warming; 436,363 + for ventilation.

3. A dwelling-house of average wooden construction measures 200 feet around the outside, and has 3 stories, each 9 feet high. Compute the heat loss by the approximate method when the temperature is 10° below zero.

Ans. 270,000 B. T. U. per hour.

FURNACE HEATING

In construction, a furnace is a large stove with a combustion chamber of ample size over the fire, the whole being inclosed in a casing of sheet iron or brick. The bottom of the casing is provided with a cold-air inlet, and at the top are pipes which connect with registers placed in the various rooms to be heated. Cold, fresh air is brought from out of doors through a pipe or duct called the *cold-air box;* this air enters the space between the casing and the furnace near the bottom, and, in passing over the hot surfaces of the fire-pot and combustion chamber, becomes heated. It then rises through the warm-air pipes at the top of the casing, and is discharged through the registers into the rooms above.

As the warm air is taken from the top of the furnace, cold air flows in through the cold-air box to take its place. The air for heating the rooms does not enter the combustion chamber.

Fig. 5 shows the general arrangement of a furnace with its connecting pipes. The cold-air inlet is seen at the bottom, and the hot-air pipes at the top; these are all provided with dampers for shutting off or regulating the amount of air flowing through them. The feed or fire door is shown at the front, and the ash door beneath it; a *water-pan* is placed inside the casing, and furnishes moisture to the warm air before passing into the rooms; water is either poured into the pan through an opening in the front, provided for this purpose, or is supplied automatically through a pipe.

The fire is regulated by means of a draft slide in the ash door, and a cold-air or regulating damper placed in the smoke-pipe. Clean-out doors are placed at different points in the casing for the removal of

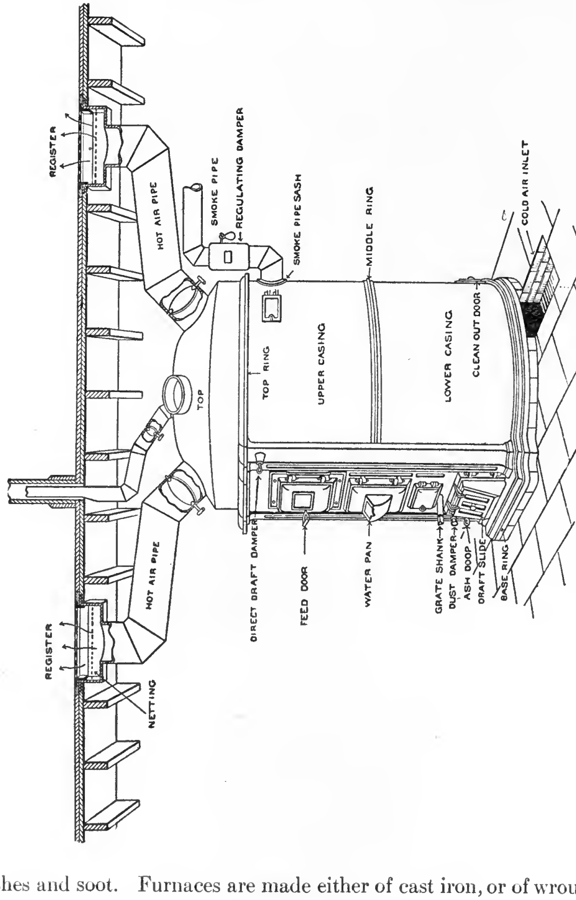


Fig. 5. General Arrangement of Details of a Hot-Air Furnace, with Connecting Pipes.

ashes and soot. Furnaces are made either of cast iron, or of wrought-iron plates riveted together and provided with brick-lined firepots.

Types of Furnaces. Furnaces may be divided into two general types known as *direct-draft* and *indirect-draft.* Fig. 6 shows a common form of *direct-draft* furnace with a brick setting; the better class have a radiator, generally placed at the top, through which the gases pass before reaching the smoke-pipe. They have but one damper, usually combined with a cold-air check. Many of the cheaper direct-

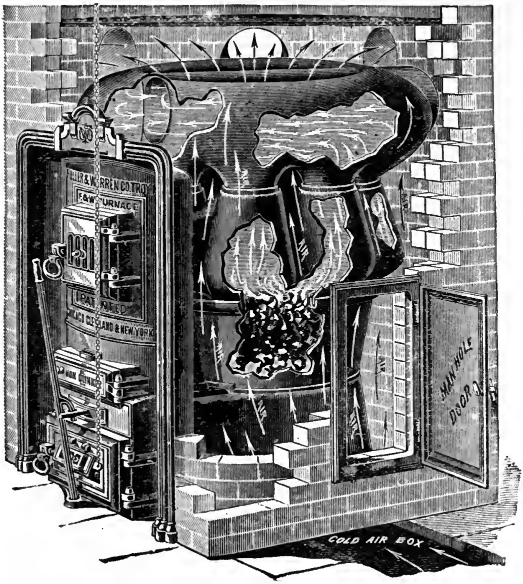


Fig. 6. A Common Type of Direct-Draft Furnace in Brick Setting. Cast-Iron Radiator at Top.

draft furnaces have no radiator at all, the gases passing directly into the smoke-pipe and carrying away much heat that should be utilized.

The furnace shown in Fig. 6 is made of cast iron and has a large radiator at the top; the smoke connection is shown at the rear.

Fig. 7 represents another form of direct-draft furnace. In this case the radiator is made of sheet-steel plates riveted together, and the outer casing is of heavy galvanized iron instead of brick.

In the ordinary *indirect-draft* type of furnace (see Fig. 8), the gases pass downward through flues to a radiator located near the base, thence upward through another flue to the smoke-pipe. In addition to the damper in the smoke-pipe, a direct-draft damper is required to give direct connection with the funnel when coal is first put on, to facilitate the escape of gas to the chimney. When the chimney draft

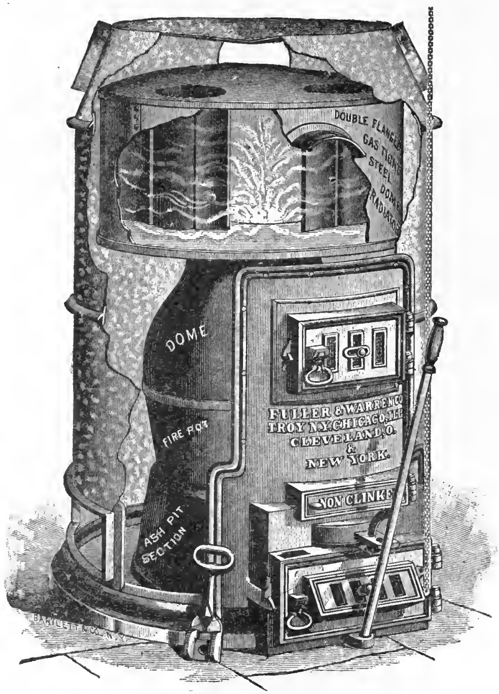


Fig. 7. Direct-Draft Furnace with Galvanized-Iron Casing. Radiator (at top) Made of Riveted Steel Plates.

is weak, trouble from gas is more likely to be experienced with furnaces of this type than with those having a direct draft.

Grates. No part of a furnace is of more importance than the grates. The plain grate rotating about a center pin was for a long time the one most commonly used. These grates were usually provided with a clinker door for removing any refuse too large to pass between the grate bars. The action of such grates tends to leave a cone of ashes in the center of the fire causing it to burn more freely around the edges. A better form of grate is the revolving triangular pattern, which is now used in many of the leading furnaces. It consists of a series of triangular bars having teeth. The bars are connected by gears, and are turned by means of a detachable lever. If

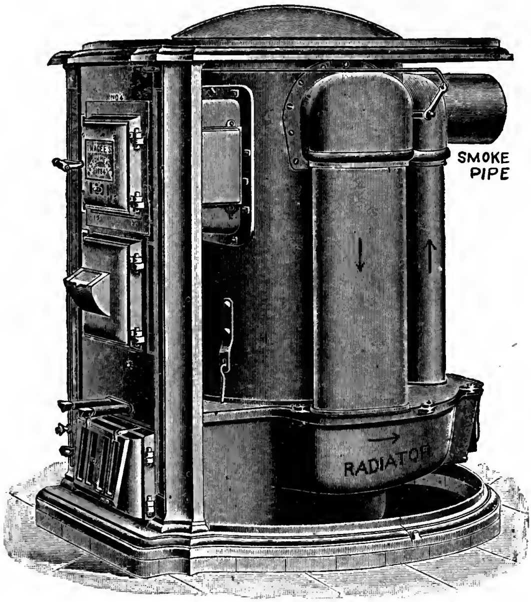


Fig. 8. Indirect-Draft Type of Furnace. Gases Pass Downward to Radiator at Bottom, Thence Upward to Smoke-Pipe.

properly used, this grate will cut a slice of ashes and clinkers from under the entire fire with little, if any loss of unccnsumed coal.

The Firepot. Firepots are generally made of cast iron or of steel plate lined with firebrick. The depth ranges from about 12 to 18 inches. In cast-iron furnaces of the better class, the firepot is made very heavy, to insure durability and to render it less likely to become red-hot. The firepot is sometimes made in two pieces, to reduce the liability to cracking. The heating surface is sometimes increased by corrugations, pins, or ribs.

A firebrick lining is necessary in a wrought-iron or steel furnace to protect the thin shell from the intense heat of the fire. Since brick-lined firepots are much less effective than cast-iron in transmitting heat, such furnaces depend to a great extent for their efficiency on the heating surface in the dome and radiator; and this, as a rule, is much greater than in those of cast iron.

Cast-iron furnaces have the advantage when coal is first put on (and the drop flues and radiator are cut out by the direct damper) of still giving off heat from the firepot, while in the case of brick linings very little heat is given off in this way, and the rooms are likely to become somewhat cooled before the fresh coal becomes thoroughly ignited.

Combustion Chamber. The body of the furnace above the firepot, commonly called the *dome* or *feed section*, provides a combustion chamber. This chamber should be of sufficient size to permit the gases to become thoroughly mixed with the air passing up through the fire or entering through openings provided for the purpose in the feed door. In a well-designed furnace, this space should be somewhat larger than the firepot.

Radiator. The radiator, so called, with which all furnaces of the better class are provided, acts as a sort of reservoir in which the gases are kept in contact with the air passing over the furnace until they have parted with a considerable portion of their heat. Radiators are built of cast iron, of steel plate, or of a combination of the two. The former is more durable and can be made with fewer joints, but owing to the difficulty of casting radiators of large size, steel plate is commonly used for the sides.

The effectiveness of a radiator depends on its form, its heating surface, and the difference between the temperature of the gases and the surrounding air. Owing to the accumulation of soot, the bottom surface becomes practically worthless after the furnace has been in use a short time; surfaces, to be effective, must therefore be self-cleaning.

If the radiator is placed near the bottom of the furnace the gases are surrounded by air at the lowest temperature, which renders the radiator more effective for a given size than if placed near the top and surrounded by warm air. On the other hand, the cold air has a tendency to condense the gases, and the acids thus formed are likely to corrode the iron.

Heating Surface. The different heating surfaces may be described as follows: Firepot surface; surfaces acted upon by direct rays of heat from the fire, such as the dome or combustion chamber; gas- or smoke-heated surfaces, such as flues or radiators; and extended surfaces, such as pins or ribs. Surfaces unlike in character and location, vary greatly in heating power, so that, in making comparisons of different furnaces, we must know the kind, form, and location of the heating surfaces, as well as the area.

In some furnaces having an unusually large amount of surface, it will be found on inspection that a large part would soon become practically useless from the accumulation of soot. In others a large portion of the surface is lined with firebrick, or is so situated that the air-currents are not likely to strike it.

The ratio of grate to heating surface varies somewhat according to the size of furnace. It may be taken as 1 to 25 in the smaller sizes, and 1 to 15 in the larger.

Efficiency. One of the first items to be determined in estimating the heating capacity of a furnace, is its efficiency—that is, the proportion of the heat in the coal that may be utilized for warming. The efficiency depends chiefly on the area of the heating surface as compared with the grate, on its character and arrangement, and on the rate of combustion. The usual proportions between grate and heating surface have been stated. The rate of combustion required to maintain a temperature of 70° in the house, depends, of course, on the outside temperature. In very cold weather a rate of 4 to 5 pounds of coal per square foot of grate per hour must be maintained.

One pound of good anthracite coal will give off about 13,000 B. T. U., and a good furnace should utilize 70 per cent of this heat. The efficiency of an ordinary furnace is often much less, sometimes as low as 50 per cent.

In estimating the required size of a first-class furnace with good chimney draft, we may safely count upon a maximum combustion of 5 pounds of coal per square foot of grate per hour, and may assume that 8,000 B. T. U. will be utilized for warming purposes from each pound burned. This quantity corresponds to an efficiency of 60 per cent.

Heating Capacity. Having determined the heat loss from a building by the methods previously given, it is a simple matter to compute the size of grate necessary to burn a sufficient quantity of coal to furnish the amount of heat required for warming.

In computing the size of furnace, it is customary to consider the whole house as a single room, with four outside walls and a cold attic. The heat losses by conduction and leakage are computed, and increased 10 per cent for the cold attic, and 16 per cent for exposure. The heat delivered to the various rooms may be considered as being made up of two parts—*first,* that required to warm the outside air up to 70° (the temperature of the rooms); and *second,* the quantity which must be added to this to offset the loss by conduction and leakage. Air is usually delivered through the registers at a temperature of 120°, with zero conditions outside, in the best class of residence work; so that $\frac{70}{120}$ of the heat given to the entering air may be considered as making up the first part, mentioned above, leaving $\frac{50}{120}$ available for purely heating purposes. From this it is evident that the heat supplied to the entering air must be equal to $1 \div \frac{50}{120} = 2.4$ times that required to offset the loss by conduction and leakage.

Example. The loss through the walls and windows of a building is found to be 80,000 B. T. U. per hour in zero weather. What will be the size of furnace required to maintain an inside temperature of 70 degrees?

From the above, we have the total heat required, equal to 80,000 $\times$ 2.4 = 192,000 B. T. U. per hour. If we assume that 8,000 B. T. U. are utilized per pound of coal, then 192,000 $\div$ 8,000 = 24 pounds of coal required per hour; and if 5 pounds can be burned on each square foot of grate per hour, then $\frac{24}{5} = 4.8$ square feet required. A grate 30 inches in diameter has an area of 4.9 square feet, and is the size we should use.

When the outside temperature is taken as 10° below zero, multiply by 2.6 instead of 2.4; and multiply by 2.8 for 20° below.

Table VII will be found useful in determining the diameter of firepot required.

TABLE VII

Firepot Dimensions

Average Diameter of Grate, in Inches	Area in Square Feet
18	1.77
20	2.18
22	2.64
24	3.14
26	3.69
28	4.27
30	4.91
32	5.58

EXAMPLES FOR PRACTICE

1. A brick apartment house is 20 feet wide, and has 4 stories, each being 10 feet in height. The house is one of a block, and is exposed only at the front and rear. The walls are 16 inches thick, and the block is so sheltered that no correction need be made for exposure. Single windows make up $\frac{1}{8}$ the total exposed surface. Figure for cold attic but warm basement. What area of grate surface will be required for a furnace to keep the house at a temperature of 70° when it is 10° below zero outside? Ans. 3.5 square feet.

2. A house having a furnace with a firepot 30 inches in diameter, is not sufficiently warmed, and it is decided to add a second furnace to be used in connection with the one already in. The heat loss from the building is found by computation to be 133,600 B. T. U. per hour, in zero weather. What diameter of firepot will be required for the extra furnace? Ans. 24 inches.

Location of Furnace. A furnace should be so placed that the warm-air pipes will be of nearly the same length. The air travels most readily through pipes leading toward the sheltered side of the house and to the upper rooms. Therefore pipes leading toward the north or west, or to rooms on the first floor, should be favored in regard to length and size. The furnace should be placed somewhat to the north or west of the center of the house, or toward the points of compass from which the prevailing winds blow.

Smoke-Pipes. Furnace smoke-pipes range in size from about 6 inches in the smaller sizes to 8 or 9 inches in the larger ones. They are generally made of galvanized iron of No. 24 gauge or heavier. The pipe should be carried to the chimney as directly as possible, avoiding bends which increase the resistance and diminish the draft. Where a smoke-pipe passes through a partition, it should be protected by a soapstone or double-perforated metal collar having a diameter at least 8 inches greater than that of the pipe. The top of the smoke-pipe should not be placed within 8 inches of unprotected beams, nor less than 6 inches under beams protected by asbestos or plaster with a metal shield beneath. A collar to make tight connection with the chimney should be riveted to the pipe about 5 inches from the end, to prevent the pipe being pushed too far into the flue. Where the pipe is of unusual length, it is well to cover it to prevent loss of heat and the condensation of smoke.

Chimney Flues. Chimney flues, if built of brick, should have walls 8 inches in thickness, unless terra-cotta linings are used, when only 4 inches of brickwork is required. Except in small houses where an 8 by 8-inch flue may be used, the nominal size of the smoke flue should be at least 8 by 12-inches, to allow for contractions or offsets. A clean-out door should be placed at the bottom of the flue, for removing ashes and soot. A square flue cannot be reckoned at its full area, as the corners are of little value. To avoid down drafts, the top of the chimney must be carried above the highest point of the roof unless provided with a suitable hood or top.

Cold-Air Box. The cold-air box should be large enough to supply a volume of air sufficient to fill all the hot-air pipes at the same time. If the supply is too small, the distribution is sure to be unequal, and the cellar will become overheated from lack of air to carry away the heat generated.

If a box is made too small, or is throttled down so that the volume of air entering the furnace is not large enough to fill all the pipes, it will be found that those leading to the less exposed side of the house or to the upper rooms will take the entire supply, and that additional air to supply the deficiency will be drawn down through registers in rooms less favorably situated. It is common practice to make the area of the cold-air box three-fourths the combined area of the hot-air pipes. The inlet should be placed where the prevailing cold winds will blow into it; this is commonly on the north or west side of the house. If it is placed on the side away from the wind, warm air from the furnace is likely to be drawn out through the cold-air box.

Whatever may be the location of the entrance to the cold-air box, changes in the direction of the wind may take place which will bring the inlet on the wrong side of the house. To prevent the possibility of such changes affecting the action of the furnace, the cold-air box is sometimes extended through the house and left open at both ends, with check-dampers arranged to prevent back-drafts. These checks should be placed some distance from the entrance, to prevent their becoming clogged with snow or sleet.

The cold-air box is generally made of matched boards; but galvanized iron is much better; it costs more than wood, but is well worth the extra expense on account of tightness, which keeps the dust and ashes from being drawn into the furnace casing to be discharged through the registers into the rooms above.

The cold-air inlet should be covered with galvanized wire netting with a mesh of at least three-eighths of an inch. The frame to which it is attached should not be smaller than the inside dimensions of the cold-air box. A door to admit air from the cellar to the cold-air box is generally provided. As a rule, air should be taken from this source, only when the house is temporarily unoccupied or during high winds.

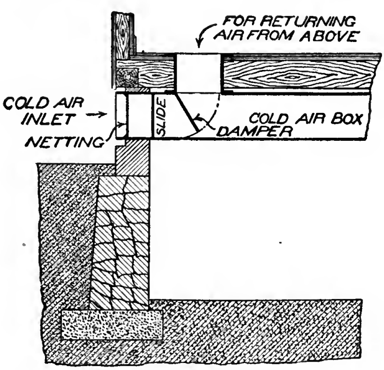


Fig 9. Common Method of Connecting Return Duct to Cold-Air Box.

Return Duct. In some cases it is desirable to return air to the furnace from the rooms above, to be reheated. Ducts for this purpose are common in places where the winter temperature is frequently below zero. Return ducts when used, should be in addition to the regular cold-air box. Fig. 9 shows a common method of making the connection between the two. By proper adjustment of the swinging damper, the air can be taken either from out of doors or through the register from the room above. The return register is often placed in the hallway of a house, so that it will take the cold air which rushes in when the door is opened and also that which may leak in around it while closed. Check-valves or flaps of light gossamer or woolen cloth should be placed between the cold-air box and the registers to prevent back-drafts during winds.

The return duct should not be used too freely at the expense of outdoor air, and its use is not recommended except during the night when air is admitted to the sleeping rooms through open windows.

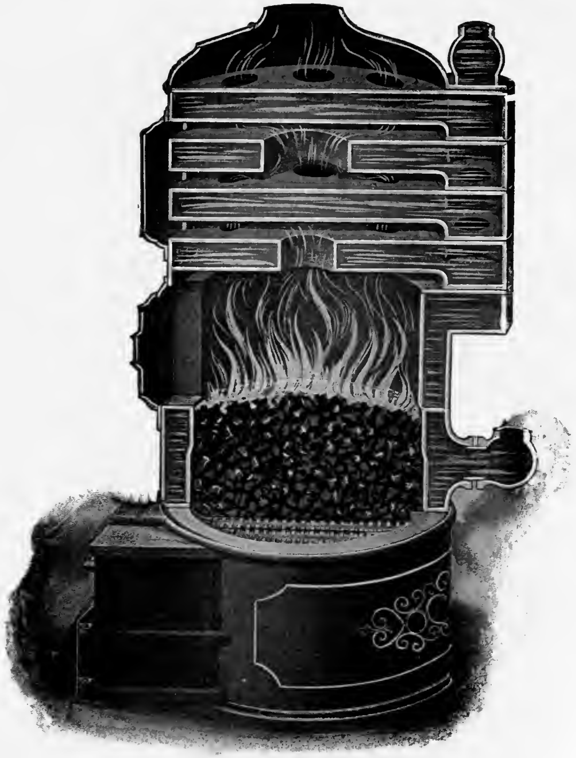
Warm-Air Pipes. The required size of the warm-air pipe to any given room, depends on the heat loss from the room and on the volume of warm air required to offset this loss. Each cubic foot of air warmed from zero to 120 degrees brings into a room 2.2 B. T. U. We have already seen that in zero weather, with the air entering the registers at 120 degrees, only $\frac{50}{120}$ of the heat contained in the air is available for offsetting the losses by radiation and conduction, so that only $2.2 \times \frac{50}{120} = .9$ B. T. U. in each cubic foot of entering air can be utilized for warming purposes. Therefore, if we divide the computed heat loss in B. T. U. from a room, by .9, it will give the number of cubic feet of air at 120 degrees necessary to warm the room in zero weather.

As the outside temperature becomes colder, the quantity of heat brought in per cubic foot of air increases; but the proportion available for warming purposes becomes less at nearly the same rate, so

TABLE VIII

Warm-Air Pipe Dimensions

Diameter of Pipe, in Inches	Area in Square Inches	Area in Square Feet
6	28	.196
7	38	.267
8	50	.349
9	64	.442
10	79	.545
11	95	.660
12	113	.785
13	133	.922
14	154	1.07
15	177	1.23
16	201	1.40



SECTIONAL VIEW OF CAST IRON HOT WATER HEATER that for all practical purposes we may use the figure .9 for all usual conditions. In calculating the size of pipe required, we may assume maximum velocities of 260 and 380 feet per minute for rooms on the first and second floors respectively. Knowing the number of cubic feet of air per minute to be delivered, we can divide it by the velocity, which will give us the required area of the pipe in square feet.

Round pipes of tin or galvanized iron are used for this purpose. Table VIII will be found useful in determining the required diameters of pipe in inches.

Example. The heat loss from a room on the second floor is 18,000 B. T. U. per hour. What diameter of warm-air pipe will be required?

18,000 ÷ .9 = 20,000 = cubic feet of air required per hour. 20,000 ÷ 60 = 333 per minute. Assuming a velocity of 380 feet per minute, we have 333 ÷ 380 = .87 square foot, which is the area of pipe required. Referring to Table VIII, we find this comes between a 12-inch and a 13-inch pipe, and the larger size would probably be chosen.

EXAMPLES FOR PRACTICE

1. A first-floor room has a computed loss of 27,000 B. T. U. per hour when it is 10° below zero. The air for warming is to enter through two pipes of equal size, and at a temperature of 120 degrees. What will be the required diameter of the pipes?

Ans. 14 inches.

2. If in the above example the room had been on the second floor, and the air was to be delivered through a single pipe, what diameter would be required?

Ans. 16 inches.

Since long horizontal runs of pipe increase the resistance and loss of heat, they should not in general be over 12 or 14 feet in length. This applies especially to pipes leading to rooms on the first floor, or to those on the cold side of the house. Pipes of excessive length should be increased in size because of the added resistance.

Figs. 10 and 11 show common methods of running the pipes in the basement. The first gives the best results, and should be used where the basement is of sufficient height to allow it. A damper should be placed in each pipe near the furnace, for regulating the flow of air to the different rooms, or for shutting it off entirely when desired.

While round pipe risers give the best results, it is not always possible to provide a sufficient space for them, and flat or oval pipes are substituted. When vertical pipes must be placed in single partitions, much better results will be obtained if the studding can be

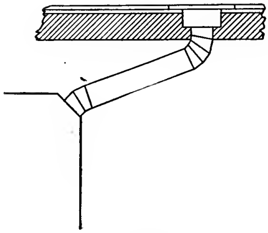


Fig. 10.

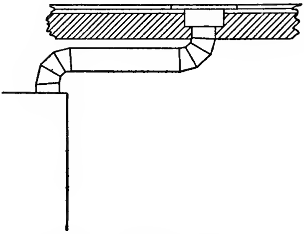


Fig. 11.

Common Methods of Running Hot-Air Pipes in Basement. Method Shown in Fig. 10 is Preferable where Feasible.

made 5 or 6 inches deep instead of 4 as is usually done. Flues should never in any case be made less than 3½ inches in depth. Each room should be heated by a separate pipe. In some cases, however, it is allowable to run a single riser to heat two unimportant rooms on an upper floor. A clear space of at least ½ inch should be left between the risers and studs, and the latter should be carefully tinned, and the

TABLE IX

Dimensions of Oval Pipes

Dimension of Pipe	Area in Square Inches
6 ovaled to 5 in.	27
7 " " 4 "	31
7 " " 3½ "	29
7 " " 6 "	38
8 " " 5 "	43
9 " " 4 "	45
9 " " 6 "	57
9 " " 5 "	51
10 " " 3½ "	46
11 " " 4 "	58
12 " " 3½ "	55
10 " " 6 "	67
11 " " 5 "	67
14 " " 4 "	76
15 " " 3½ "	73
12 " " 6 "	85
12 " " 5 "	75
19 " " 4 "	96
20 " " 3½ "	100

space between them on both sides covered with tin, asbestos, or wire lath.

Table IX gives the capacity of oval pipes. A 6-inch pipe ovaled to 5 means that a 6-inch pipe has been flattened out to a thickness of 5 inches, and column 2 gives the resulting area.

Having determined the size of round pipe required, an equivalent oval pipe can be selected from the table to suit the space available.

Registers. The registers which control the supply of warm air to the rooms, generally have a net area equal to two-thirds of their gross area. The net area should be from 10 to 20 per cent greater than the area of the pipe connected with it. It is common practice to use registers having the short dimensions equal to, and the long dimensions about one-half greater than, the diameter of the pipe. This would give standard sizes for different diameters of pipe, as listed in Table X.

TABLE X

Sizes of Registers for Different Sizes of Pipes

Diameter of Pipe	Size of Register
6 in.	6 × 10 in.
7 "	7 × 10 "
8 "	8 × 12 "
9 "	9 × 14 "
10 "	10 × 15 "
11 "	11 × 16 "
12 "	12 × 17 "
13 "	14 × 20 "
14 "	14 × 22 "
15 "	15 × 22 "
16 "	16 × 24 "

Combination Systems. A combination system for heating by hot air and hot water consists of an ordinary furnace with some form of surface for heating water, placed either in contact with the fire or suspended above it. Fig. 12 shows a common arrangement where part of the heating surface forms a portion of the lining to the firepot and the remainder is above the fire.

Care must be taken to proportion properly the work to be done by the air and the water; else one will operate at the expense of the other. One square foot of heating surface in contact with the fire is capable of supplying from 40 to 50 square feet of radiating surface, and one square foot suspended over the fire will supply from 15 to 25 square feet of radiation.

The value or efficiency of the heating surface varies so widely in different makes that it is best to state the required conditions to the

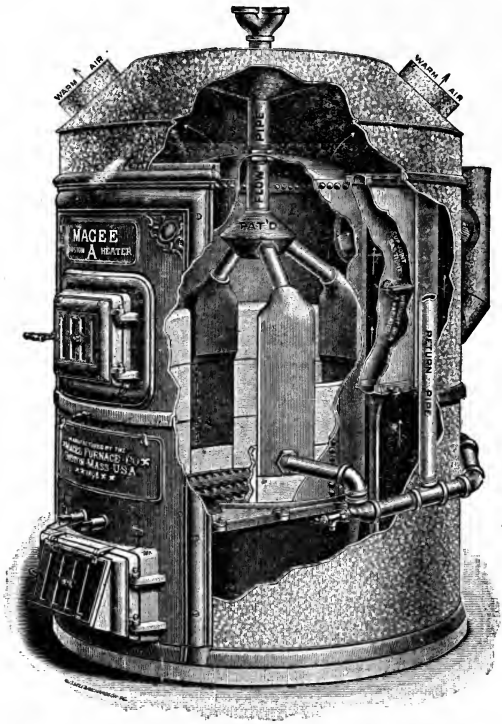


Fig. 12. Combination Furnace, for Heating by Both Hot Air and Hot Water.

manufacturers and have them proportion the surfaces as their experience has found best for their particular type of furnace.

Care and Management of Furnaces. The following general rules apply to the management of all hard coal furnaces.

The fire should be thoroughly shaken once or twice daily in cold weather. It is well to keep the firepot heaping full at all times. In this way a more even temperature may be maintained, less attention is required, and no more coal is burned than when the pot is only partly filled. In mild weather the mistake is frequently made of carrying a thin fire, which requires frequent attention and is likely to die out. Instead, to diminish the temperature in the house, keep the firepot full and allow ashes to accumulate on the grate (not under it) by shaking less frequently or less vigorously. The ashes will hold the heat and render it an easy matter to maintain and control the fire. When feeding coal on a low fire, open the drafts and neither rake nor shake the fire till the fresh coal becomes ignited. The air supply to the fire is of the greatest importance. An insufficient amount results in incomplete combustion and a great loss of heat. To secure proper combustion, the fire should be controlled principally by means of the ash-pit through the ash-pit door or slide.

The smoke-pipe damper should be opened only enough to carry off the gas or smoke and to give the necessary draft. The openings in the feed door act as a check on the fire, and should be kept closed during cold weather, except just after firing, when with a good draft they may be partly opened to increase the air-supply and promote the proper combustion of the gases.

Keep the ash-pit clear to avoid warping or melting the grate. The cold-air box should be kept wide open except during winds or when the fire is low. At such times it may be partly, but never completely closed. Too much stress cannot be laid on the importance of a sufficient air-supply to the furnace. It costs little if any more to maintain a comfortable temperature in the house night and day than to allow the rooms to become so cold during the night that the fire must be forced in the morning to warm them up to a comfortable temperature.

In case the warm air fails at times to reach certain rooms, it may be forced into them by temporarily closing the registers in other rooms. The current once established will generally continue after the other registers have been opened.

It is best to burn as hard coal as the draft will warrant. Egg size is better than larger coal, since for a given weight small lumps expose more surface and ignite more quickly than larger ones. The furnace and smoke-pipe should be thoroughly cleaned once a year.

This should be done just after the fire has been allowed to go out in the spring.

STEAM BOILERS

Types. The boilers used for heating are the same as have already been described for power work. In addition there is the cast-iron sectional boiler, used almost exclusively for dwelling-houses.

Tubular Boilers. Tubular boilers are largely used for heating purposes, and are adapted to all classes of buildings except dwelling-houses and the special cases mentioned later, for which sectional boilers are preferable. A *boiler horse-power* has been defined as the evaporation of $34\frac{1}{2}$ pounds of water from and at a temperature of 212 degrees, and in doing this 33,317 B. T. U. are absorbed, which are again given out when the steam is condensed in the radiators. Hence to find the boiler H. P. required for warming any given building, we have only to compute the heat loss per hour by the methods already given, and divide the result by 33,330. It is more common to divide by the number 33,000, which gives a slightly larger boiler and is on the side of safety.

The commercial horse-power of a well-designed boiler is based upon its heating surface; and for the best economy in heating work, it should be so proportioned as to have about 1 square foot heating of surface for each 2 pounds of water to be evaporated from and at 212 degrees F. This gives $34.5 \div 2 = 17.2$ square feet of heating surface per horse-power, which is generally taken as 15 in practice. Makers of tubular boilers commonly rate them on a basis of 12 square feet of heating surface per horse-power. This is a safe figure under the conditions of power work, where skilled firemen are employed and where more care is taken to keep the heating surfaces free from soot and ashes. For heating plants, however, it is better to rate the boilers upon 15 square feet per horse-power as stated above.

There is some difference of opinion as to the proper method of computing the heating surface of tubular boilers. In general, all surface is taken which is exposed to the hot gases on one side and to the water on the other. A safe rule, and the one by which Table XII is computed, is to take $\frac{1}{2}$ the area of the shell, $\frac{2}{3}$ of the rear head, less the tube area, and the interior surface of all the tubes.

The required amount of grate area, and the proper ratio of heating surface to grate area, vary a good deal, depending on the character of the fuel and on the chimney draft. By assuming the probable rates of combustion and evaporation, we may compute the required grate area for any boiler from the formula:

$$S = \frac{H.P. \times 34.5}{E \times C},$$

in which

S = Total grate area, in square feet;

E = Pounds of water evaporated per pound of coal;

C = Pounds of coal burned per square foot of grate per hour.

Table XI gives the approximate grate area per H. P. for different rates of evaporation and combustion as computed by the above equation.

TABLE XI

Grate Area per Horse-Power for Different Rates of Evaporation and Combustion

Pounds of Steam per Pound of Coal	Pounds of Coal Burned per Square Foot of Grate per Hour		
	8 lbs.	**10 lbs.**	**12 lbs.**
	Square Feet of Grate Surface per Horse-Power		
10	.43	.35	.28
9	.48	.38	.32
8	.54	.43	.36
7	.62	.49	.41
6	.72	.58	.48

For example, with an evaporation of 8 pounds of steam per pound of coal, and a combustion of 10 pounds of coal per square foot of grate, .43 of a square foot of grate surface per H. P. would be called for.

The ratio of heating to grate surface in this type of boiler ranges from 30 to 40, and therefore allows under ordinary conditions a combustion of from 8 to 10 pounds of coal per square foot of grate. This is easily obtained with a good chimney draft and careful firing. The larger the boiler, the more important the plant usually, and the greater the care bestowed upon it, so that we may generally count on a higher rate of combustion and a greater efficiency as the size of the boiler increases. Table XII will be found very useful in determining the size of boiler required under different conditions. The grate area is computed for an evaporation of 8 pounds of water per pound

TABLE XII

Diameter of Shell in Inches	Number of Tubes	Diameter of Tubes in Inches	Length of Tubes in Feet	Horse-Power	Size of Grate in Inches	Size of Uptake in Inches	Size of Smoke-pipe in Sq. In
30	28	2½	6	8.5	24 x 36	10 x 14	140
			7	9.9	24 x 36	10 x 14	140
			8	11.2	24 x 36	10 x 14	140
			9	12.6	24 x 42	10 x 14	140
			10	14.0	24 x 42	10 x 14	140
36	34	2½	8	13.6	30 x 36	10 x 16	160
			9	15.3	30 x 42	10 x 18	180
			10	16.9	30 x 42	10 x 18	180
			11	18.6	30 x 48	10 x 20	200
			12	20.9	30 x 48	10 x 20	200
42	34	3	9	18.5	36 x 42	10 x 20	200
			10	20.5	36 x 42	10 x 20	200
			11	22.5	36 x 48	10 x 25	250
			12	24.5	36 x 48	10 x 25	250
			13	26.5	36 x 48	10 x 28	280
			14	28.5	36 x 54	10 x 28	280
48	44	3	10	30.4	42 x 48	10 x 28	280
			11	33.2	42 x 48	10 x 28	280
			12	35.7	42 x 54	10 x 32	320
			13	38.3	42 x 54	10 x 32	320
			14	40.8	42 x 60	10 x 36	360
			15	43.4	42 x 60	10 x 36	360
			16	45.9	42 x 60	10 x 36	360
54	54	3	11	34.6	48 x 54	10 x 38	380
			12	37.7	48 x 54	10 x 38	380
			13	40.8	48 x 54	10 x 38	380
			14	43.9	48 x 54	10 x 38	380
			15	47.0	48 x 60	10 x 40	400
			16	50.1	48 x 60	10 x 40	400
	46	3½	17	53.0	48 x 60	10 x 40	400
60	72	3	12	48.4	54 x 60	12 x 40	460
			13	52.4	54 x 60	12 x 40	460
			14	56.4	54 x 60	12 x 40	460
			15	60.4	54 x 66	12 x 42	500
			16	64.4	54 x 66	12 x 42	500
	64	3½	17	71.4	54 x 72	12 x 48	550
			18	75.6	54 x 72	12 x 48	550
66	90	3	14	70.1	60 x 66	12 x 48	500
			15	75.0	60 x 72	12 x 52	620
			16	80.0	60 x 72	12 x 52	620
	78	3½	17	86.0	60 x 78	12 x 56	670
			18	91.1	60 x 78	12 x 56	670
			19	96.2	60 x 78	12 x 56	670
	62	4	20	93.1	60 x 78	12 x 56	670
72	114	3	14	87.4	66 x 72	12 x 56	670
			15	93.6	66 x 72	12 x 56	670
			16	99.7	66 x 78	12 x 62	740
	98	3½	17	106.4	66 x 78	12 x 62	740
			18	112.6	66 x 84	12 x 66	790
			19	118.8	66 x 84	12 x 66	790
	72	4	20	107.8	66 x 84	12 x 66	790

of coal, which corresponds to an efficiency of about 60 per cent, and is about the average obtained in practice for heating boilers.

The areas of uptake and smoke-pipe are figured on a basis of 1 square foot to 7 square feet of grate surface, and the results given in round numbers. In the smaller sizes the relative size of smoke-pipe is greater. The rate of combustion runs from 6 pounds in the smaller sizes to $11\frac{1}{2}$ in the larger. Boilers of the proportions given in the table, correspond well with those used in actual practice, and may be relied upon to give good results under all ordinary conditions.

Water-tube boilers are often used for heating purposes, but more especially in connection with power plants. The method of computing the required H. P. is the same as for tubular boilers.

Sectional Boilers. Fig. 13 shows a common form of cast-iron boiler. It is made up of slabs or sections, each one of which is connected by nipples with headers at the sides and top. The top header acts as a steam drum, and the lower ones act as mud drums; they also receive the water of condensation from the radiators. The gases from the fire pass backward and forward through flues and are finally taken off at the rear of the boiler.

Another common form of sectional boiler is shown in Fig. 14. It is made up of sections which increase the length like the one just described. These boilers have no drum connecting with the sections; but instead, each section connects with the adjacent one through openings at the top and bottom, as shown.

The ratio of heating to grate surface in boilers of this type ranges from 15 to 25 in the best makes. They are provided with the usual attachments, such as pressure-gauge, water-glass, gauge-cocks, and safety-valve; a low-pressure damper regulator is furnished for operating the draft doors, thus keeping the steam pressure practically constant. A pressure of from 1 to 5 pounds is usually carried on these boilers, depending upon the outside temperature. The usual setting is simply a covering of some kind of non-conducting material like plastic magnesia or asbestos, although some forms are enclosed in light brickwork.

In computing the required size, we may proceed in the same manner as in the case of a furnace. For the best types of house-heating boilers, we may assume a combustion of 5 pounds of coal per square foot of grate per hour, and an average efficiency of 60 per cent, which corresponds to 8,000 B. T. U. per pound of coal, available for useful work.

In the case of direct-steam heating, we have only to supply heat to offset that lost by radiation and conduction; so that the grate area may be found by dividing the computed heat loss per hour by 8,000, which gives the number of pounds of coal; and this in turn, divided by 5, will give the area of grate required. The most efficient rate of

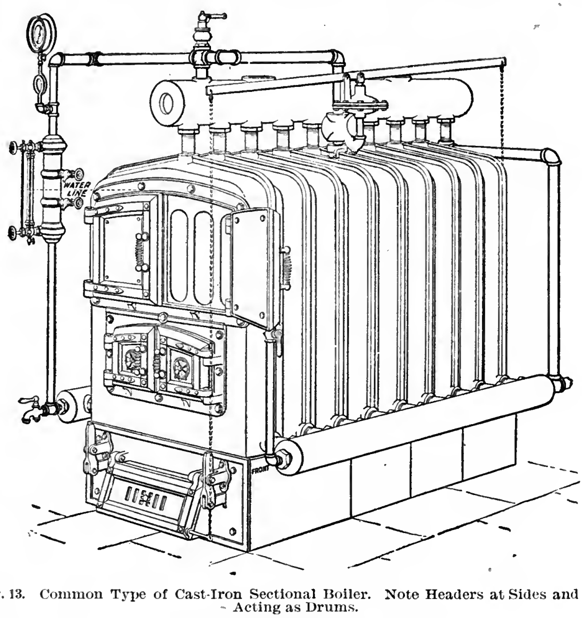


Fig. 13. Common Type of Cast-Iron Sectional Boiler. Note Headers at Sides and Top Acting as Drums.

combustion will depend somewhat upon the ratio between the grate and heating surface. It has been found by experience that about $\frac{1}{4}$ of a pound of coal per hour for each square foot of heating surface gives the best results; so that, by knowing the ratio of heating surface to grate area for any make of heater, we can easily compute the most efficient rate of combustion, and from it determine the necessary grate area.

For example, suppose the heat loss from a building to be 480,000 B. T. U. per hour, and that we wish to use a heater in which the ratio of heating surface to grate area is 24. What will be the most efficient rate of combustion and the required grate area? 480,000 ÷ 8,000 = 60 pounds of coal per hour, and 24 ÷ 4 = 6, which is the best rate of combustion to employ; therefore 60 ÷ 6 = 10, the grate area required.

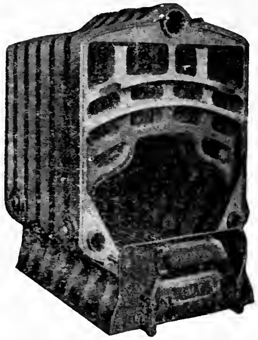


Fig. 14. Another Type of Sectional Boiler. Here there are no drums, the sections being directly connected through openings at top and bottom.
Courtesy of American Radiator Co.

There are many different designs of cast-iron boilers for low-pressure steam and hot-water heating. In general, boilers having a drum connected by nipples with each section give dryer steam and hold a steadier water-line than the second form, especially when forced above their normal capacity. The steam, in passing through the openings between successive sections in order to reach the outlet, is apt to carry with it more or less water, and to choke the openings, thus producing an uneven pressure in different parts of the boiler.

In the case of hot-water boilers this objection disappears.

In order to adapt this type of boiler to steam work, the opening between the sections should be of good size, with an ample steam space above the water-line; and the nozzles for the discharge of steam should be located at frequent intervals.

EXAMPLES FOR PRACTICE

1. The heat loss from a building is 240,000 B. T. U. per hour, and the ratio of heating to grate area in the heater to be used is 20. What will be the required grate area? Ans. 6 sq. ft.

2. The heat loss from a building is 168,000 B. T. U. per hour, and the chimney draft is such that not over 3 pounds of coal per hour can be burned per square foot of grate. What ratio of heating to grate area will be necessary, and what will be the required grate area? Ans. Ratio, 12. Grate area, 7 sq. ft.

Cast-iron sectional boilers are used for dwelling-houses, small schoolhouses, churches, etc., where low pressures are carried. They are increased in size by adding more slabs or sections. After a certain length is reached, the rear sections become less and less efficient, thus limiting the size and power.

Horse-Power for Ventilation. We already know that one B. T. U. will raise the temperature of 1 cubic foot of air 55 degrees, or it will raise 100 cubic feet $\frac{1}{100}$ of 55 degrees, or $\frac{55}{100}$ of 1 degree; therefore, to raise 100 cubic feet 1 degree, it will take $1 \div \frac{55}{100}$, or $\frac{100}{55}$ B. T. U.; and to raise 100 cubic feet through 100 degrees, it will take $\frac{100}{55} \times 100$ B. T. U. In other words, the B. T. U. required to raise any given volume of air through any number of degrees in temperature, is equal to

$$\frac{\text{Volume of air in cubic ft.} \times \text{Degrees raised}}{55}$$

Example. How many B. T. U. are required to raise 100,000 cubic feet of air 70 degrees?

$$\frac{100,000 \times 70}{55} = 127,272 +$$

To compute the H. P. required for the ventilation of a building, we multiply the total air-supply, in cubic feet per hour, by the number of degrees through which it is to be raised, and divide the result by 55. This gives the B. T. U. per hour, which, divided by 33,000, will give the H. P. required. In using this rule, always take the air-supply in cubic feet per *hour*.

EXAMPLES FOR PRACTICE

1. The heat loss from a building is 1,650,000 B. T. U. per hour. There is to be an air-supply of 1,500,000 cubic feet per hour, raised through 70 degrees. What is the total boiler H. P. required?

Ans. 108.

2. A high school has 10 classrooms, each occupied by 50 pupils. Air is to be delivered to the rooms at a temperature of 70 degrees. What will be the total H. P. required to heat and ventilate the building when it is 10 degrees below zero, if the heat loss through walls and windows is 1,320,000 B. T. U. per hour? Ans. 106+.

DIRECT-STEAM HEATING

A system of direct-steam heating consists (1) of a furnace and boiler for the combustion of fuel and the generation of steam; (2) a system of pipes for conveying the steam to the radiators and for returning the water of condensation to the boiler; and (3) radiators or coils placed in the rooms for diffusing the heat.

Various types of boilers are used, depending upon the size and kind of building to be warmed. Some form of cast-iron sectional boiler is commonly used for dwelling-houses, while the tubular or water-tube boiler is more usually employed in larger buildings. Where the boiler is used for heating purposes only, a low steam-pressure of from 2 to 10 pounds is carried, and the condensation flows back by gravity to the boiler, which is placed below the lowest radiator. When, for any reason, a higher pressure is required, the steam for the heating system is made to pass through a reducing valve, and the condensation is returned to the boiler by means of a pump or return trap.

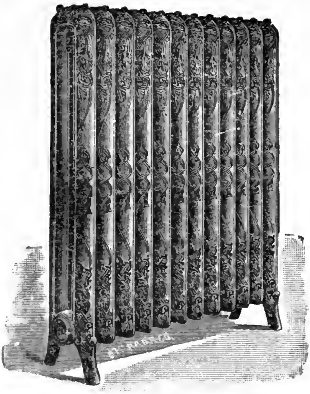


Fig. 15. Common Type of Cast-Iron Sectional Radiator.

Types of Radiating Surface. The radiation used indirect-steam heating is made up of cast-iron radiators of various forms, pipe radiators, and circulation coils.

Cast-Iron Radiators. The general form of a cast-iron sectional radiator is shown in Fig. 15. Radiators of this type are made up of sections, the number depending upon the amount of heating surface required. Fig. 16 shows an intermediate section of a radiator of this type. It is simply a loop with inlet and outlet at the bottom. The end sections are the same, except that they have legs, as shown in Fig. 17. These sections are connected at the bottom by special nipples, so that steam entering at the end fills the bottom of the radiator, and, being lighter than the air, rises through the loops and forces the air downward and toward the farther end, where it is discharged through an air-valve placed about midway of the last section. There are many different designs varying in height and width, to suit all conditions. The wall pattern shown in Fig. 18 is very convenient when it is desired to place the radiator above the floor, as in bathrooms, etc.; it is also a convenient form to place under the windows of halls and churches to counteract the effect of cold down drafts. It is adapted to nearly every place where the ordinary direct radiator can be used, and may be connected up in different ways to meet the various requirements.

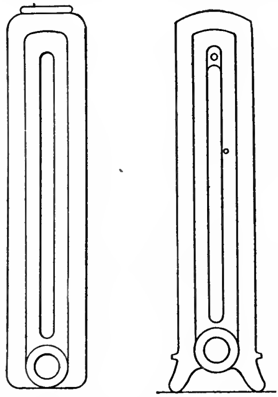


Fig. 16. Fig. 17.
Intermediate and End Sections of Radiator Shown in Fig. 15. The end sections (at right) have legs.

A low and moderately shallow radiator, with ample space for the circulation of air between the sections, is more efficient than a deep radiator with the sections closely packed together. One- and two-column radiators, so called, are preferable to three- and four-column, when there is sufficient space to use them.

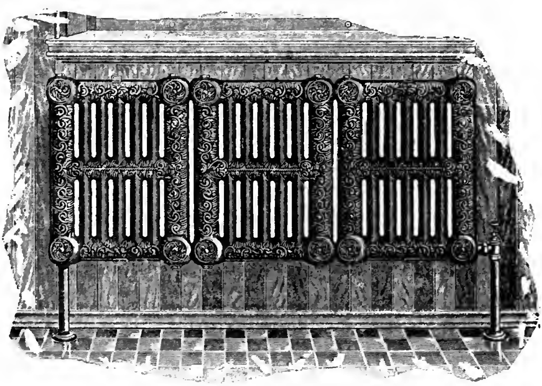


Fig. 18. Cast-Iron Sectional Radiator of Wall Pattern.

The standard height of a radiator is 36 or 38 inches, and, if possible, it is better not to exceed this.

For small radiators, it is better practice to use lower sections and increase the length; this makes the radiator slightly more efficient and gives a much better appearance.

To get the best results from wall radiators, they should be set out at least $1\frac{1}{2}$ inches from the wall to allow a free circulation of air back of them. Patterns having cross-bars should be placed, if possible, with the bars in a vertical position, as their efficiency is impaired somewhat when placed horizontally.

Pipe Radiators. This type of radiator (see Fig. 19) is made up of wrought-iron pipes screwed into a cast-iron base. The pipes are either connected in pairs at the top by return bends, or each separate tube has a thin metal diaphragm passing up the center nearly to the top. It is necessary that a loop be formed, else a "dead end" would occur. This would become filled with air and prevent steam from entering, thus causing portions of the radiator to remain cold.

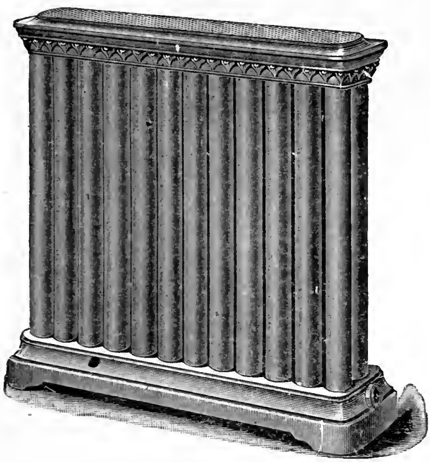


Fig. 19. Wrought-Iron Pipe Radiator.

Circulation Coils. These are usually made up of 1 or $1\frac{1}{4}$-inch wrought-iron pipe, and may be hung on the walls of a room by means of hook plates, or suspended overhead on hangers and rolls.

Fig. 20 shows a common form for schoolhouse and similar work; this coil is usually made of $1\frac{1}{4}$-inch pipe screwed into *headers* or *branch tees* at the ends, and is hung on the wall just below the windows. This is known as a *branch coil.* Fig. 21 shows a *trombone coil,* which is commonly used when the pipes cannot turn a corner, and where the entire coil must be placed upon one side of the room. Fig. 22

is called a *miter coil,* and is used under the same conditions as a trombone coil if there is room for the vertical portion. This form is not so pleasing in appearance as either of the other two, and is found only in factories or shops, where looks are of minor importance.

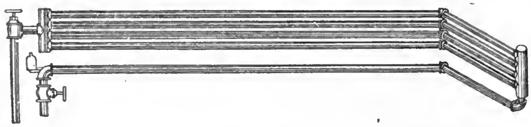


Fig. 20. Common Form of "Branch" Coil for Circulation of Direct Steam.

Overhead coils are usually of the miter form, laid on the side and suspended about a foot from the ceiling; they are less efficient than when placed nearer the floor, as the warm air stays at the ceiling and the lower part of the room is likely to remain cold. They are used

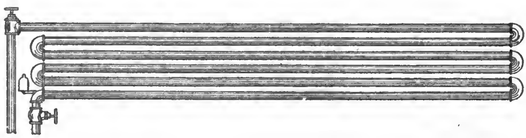


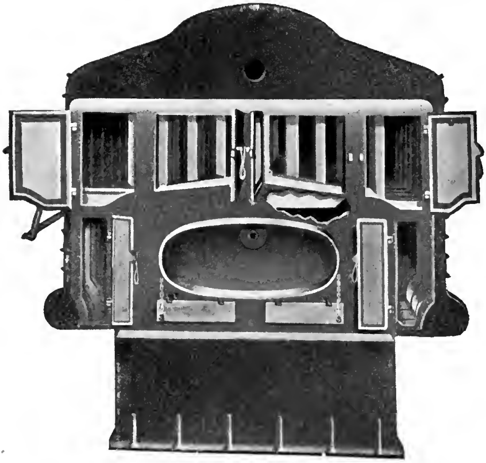
Fig. 21. "Trombone" Coil. Used where Entire Coil must be Placed on One Side of Room

only when wall coils or radiators would be in the way of fixtures, or when they would come below the water-line of the boiler if placed near the floor.

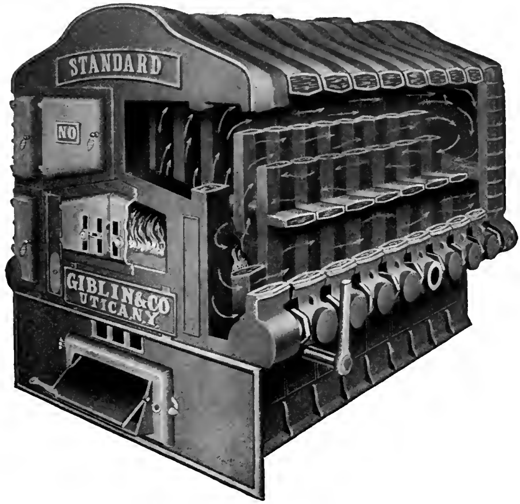
When steam is first turned on a coil, it usually passes through a

Fig. 22. "Miter" Coil. Adapted, like the "Trombone," Only to a Single Wall. Frequently Used in Factories and Shops.

portion of the pipes first and heats them while the others remain cold and full of air. Therefore the coil must always be made up in such a way that each pipe shall have a certain amount of spring and may expand independently without bringing undue strains upon the others. Circulation coils should incline about 1 inch in 20 feet toward the



FRONT VIEW OF SECTIONAL STEAM AND HOT-WATER BOILER
Giblin & Co., Utica, N. Y.



SECTIONAL STEAM AND HOT-WATER BOILER
Cut Open to Show Course Taken by Hot Gases and by Water

return end in order to secure proper drainage and quietness of operation.

Efficiency of Radiators. The efficiency of a radiator—that is, the B. T. U. which it gives off per square foot of surface per hour—depends upon the difference in temperature between the steam in the radiator and the surrounding air, the velocity of the air over the radiator, and the quality of the surface, whether smooth or rough. In ordinary low-pressure heating, the first condition is practically constant; but the second varies somewhat with the pattern of the radiator. An open design which allows the air to circulate freely over the radiating surfaces, is more efficient than a closed pattern, and for this reason a pipe coil is more efficient than a radiator.

In a large number of tests of cast-iron and pipe radiators, working under usual conditions, the heat given off per square foot of surface per hour for each degree difference in temperature between the steam and surrounding air was found to average about 1.7 B. T. U. The temperature of steam at 3 pounds' pressure is 220 degrees, and 220—70 =150, which may be taken as the average difference between the temperature of the steam and the air of the room, in ordinary low-pressure work. Taking the above results, we have $150 \times 1.7 = 255$ B. T. U. as the efficiency of an average cast-iron or pipe radiator. This, for convenient use, may be taken as 250. A circulation coil made up of pipes from 1 to 2 inches in diameter, will easily give off 300 B. T. U. under the same conditions; and a cast-iron wall radiator with ample space back of it should have an efficiency equal to that of a wall coil. While overhead coils have a higher efficiency than cast-iron radiators, their position near the ceiling reduces their effectiveness, so that in practice the efficiency should not be taken over 250 B. T. U. per hour at the most. Tabulating the above we have:

TABLE XIII

Efficiency of Radiators, Coils, etc.

Type of Radiating Surface	Radiation per Square Foot of Surface per Hour
Cast-Iron Sectional and Pipe Radiators	250 B. T. U.
Wall Radiators	300 "
Ceiling Coils	200 to 250 "
Wall Coils	300 "

If the radiator is for warming a room which is to be kept at a temperature above or below 70 degrees, or if the steam pressure is greater than 3 pounds, the radiating surface may be changed in the same proportion as the difference in temperature between the steam and the air.

For example, if a room is to be kept at a temperature of 60°, the efficiency of the radiator becomes $\frac{150}{140} \times 250 = 268$; that is, the efficiency varies directly as the difference in temperature between the steam and the air of the room. It is not customary to consider this unless the steam pressure should be raised to 10 or 15 pounds or the temperature of the rooms changed 15 or 20 degrees from the normal.

From the above it is easy to compute the size of radiator for any given room. First compute the heat loss per hour by conduction and leakage in the coldest weather; then divide the result by the efficiency of the type of radiator to be used. It is customary to make the radiators of such size that they will warm the rooms to 70 degrees in the coldest weather. As the low-temperature limit varies a good deal in different localities, even in the same State, the lowest temperature for which we wish to provide must be settled upon before any calculations are made. In New England and through the Middle and Western States, it is usual to figure on warming a building to 70 degrees when the outside temperature is from zero to 10 degrees below.

The different makers of radiators publish in their catalogues, tables giving the square feet of heating surface for different styles and heights, and these can be used in determining the number of sections required for all special cases.

If pipe coils are to be used, it becomes necessary to reduce square feet of heating surface to linear feet of pipe; this can be done by means of the factors given below.

Square feet of heating surface ×	3 =	linear	ft. of	1 -in.	pipe
	2.3 =	"	"	1¼-in.	"
	2 =	"	"	1½-in.	"
	1.6 =	"	"	2 -in.	"

The size of radiator is made only sufficient to keep the room warm after it is once heated; and no allowance is made for *warming up*; that is, the heat given off by the radiator is just equal to that lost through walls and windows. This condition is offset in two ways—

first, when the room is cold, the difference in temperature between the steam and the air of the room is greater, and the radiator is more efficient; and *second,* the radiator is proportioned for the coldest weather, so that for a greater part of the time it is larger than necessary.

EXAMPLES FOR PRACTICE

1. The heat loss from a room is 25,000 B. T. U. per hour in the coldest weather. What size of direct radiator will be required?
Ans. 100 square feet.

2. A schoolroom is to be warmed with circulation coils of $1\frac{1}{4}$-inch pipe. The heat loss is 30,000 B. T. U. per hour. What length of pipe will be required? Ans. 230 linear feet.

Location of Radiators. Radiators should, if possible, be placed in the coldest part of the room, as under windows or near outside doors. In living rooms it is often desirable to keep the windows free, in which case the radiators may be placed at one side. Circulation coils are run along the outside walls of a room under the windows. Sometimes the position of the radiators is decided by the necessary location of the pipe risers, so that a certain amount of judgment must be used in each special case as to the best arrangement to suit all requirements.

Systems of Piping. There are three distinct systems of piping, known as the *two-pipe system,* the *one-pipe relief system,* and the *one-pipe circuit system,* with various modifications of each and combinations of the different systems.

Fig. 23 shows the arrangement of piping and radiators in the two-pipe system. The steam main leads from the top of the boiler, and the branches are carried along near the basement ceiling. Risers are taken from the supply branches, and carried up to the radiators on the different floors; and return pipes are brought down to the return mains, which should be placed near the basement floor below the water-line of the boiler. Where the building is more than two stories high, radiators in similar positions on different floors are connected with the same riser, which may run to the highest floor; and a corresponding return drop connecting with each radiator is carried down beside the riser to the basement. A system in which the main horizontal returns are below the water-line of the boiler is said to have a *wet* or *sealed* return. If the returns are overhead and above the water-line, it is called a *dry* return. Where the steam is exposed to extended surfaces of water, as in overhead returns, where the condensation partially fills the pipes, there is likely to be cracking or *water-hammer*, due to the sudden condensation of the steam as it comes in contact with the cooler water. This is especially noticeable when steam is first turned into cold pipes and radiators, and the condensation is excessive. When dry returns are used, the pipes should be large and have a good pitch toward the boiler.

In the case of sealed returns, the only contact between the steam

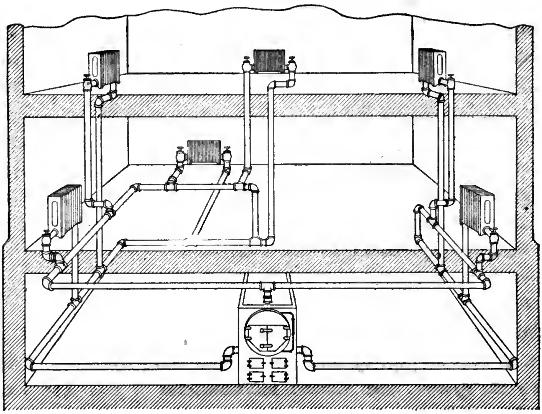


Fig. 23. Arrangement of Piping and Radiators in "Two-Pipe" System.

and standing water is in the vertical returns, where the exposed surfaces are very small (being equal to the sectional area of the pipes), and trouble from water-hammer is practically done away with. Dry returns should be given an incline of at least 1 inch in 10 feet, while for wet returns 1 inch in 20 or even 40 feet is ample. The ends of all steam mains and branches should be dripped into the returns. If the return is sealed, the drip may be directly connected as shown in Fig. 24; but if it is dry, the connection should be provided with a siphon loop as indicated in Fig. 25. The loop becomes filled with water, and prevents steam from flowing directly into the return. As the condensation collects in the loop, it overflows into the return pipe and is carried away. The return pipes in this case are of course filled with steam above the water; but it is steam which has passed through the radiators and their return connections, and is therefore at a slightly lower pressure; so that, if steam were admitted directly from the main, it would tend to hold back the water in more distant returns and cause surging and cracking in the pipes. Sometimes the boiler is at a lower level than the basement in which the returns are run, and it then becomes necessary to establish a *false* water-line. This is done by making connections as shown in Fig. 26.

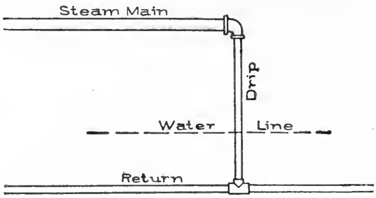


Fig. 24. Drip from Steam Main Connected Directly to Sealed Return.

It is readily seen that the return water, in order to reach the boiler, must flow through the trap, which raises the water-line or seal to the level shown by the dotted line. The balance pipe is to equalize the pressure above and below the water in the trap, and prevent siphonic action, which would tend to drain the water out of the return mains after a flow was once started.

The balance pipe, when possible, should be 15 or 20 feet in length, with a throttle-valve placed near its connection with the main. This valve should be opened just enough to allow the steam-pressure to act upon the air which occupies the space above the water in the trap; but it should not be opened sufficiently to allow the steam to enter in large volume and drive the air out. The success of this arrangement depends upon keeping a layer or cushion of cool air next to the surface of the water in the trap, and this is easily done by following the method here described.

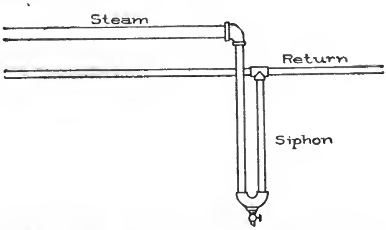


Fig. 25. Use of Siphon in Connecting Drip from Steam Main to a "Dry" Return.

One-Pipe Relief System. In this system of piping, the radiators have but a single connection, the steam flowing in and the condensation draining out through the same pipe. Fig. 27 shows the method of running the pipes for this system. The steam main, as before, leads from the top of the boiler, and is carried to as high a point as the basement ceiling will allow; it then slopes downward with a grade of about 1 inch in 10 feet, and makes a circuit of the building or a portion of it.

Risers are taken from the top and carried to the radiators above, as in the two-pipe system; but in this case, the condensation flows back through the same pipe, and drains into the return main near the floor through drip connections which are made at frequent intervals. In a two-story building, the bottom of each riser to the second floor is dripped; and in larger buildings, it is customary to drip each riser that has more than one radiator connected with it. If the radiators are large and at a considerable distance from the next riser, it is better to make a drip connection for each radiator. When the return main is overhead, the risers should be dripped through siphon loops; but the ends of the branches should make direct connection with the returns. This is the reverse of the two-pipe system. In this case the lowest pressure is at the ends of the mains, so that steam introduced into the returns at these points will cause no trouble in the pipes connecting between these and the boiler.

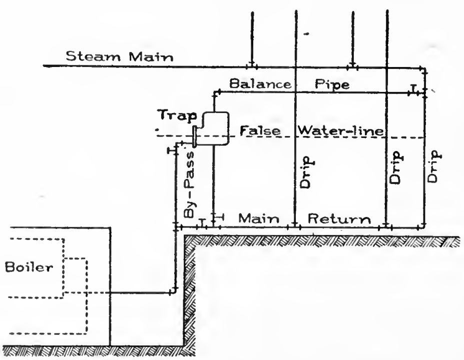


Fig. 26. Connections Made to Establish "False" Water-Line when Boiler is below Basement Level.

If no steam is allowed to enter the returns, a vacuum will be formed, and there will be no pressure to force the water back to the boiler. A check-valve should always be placed in the main return

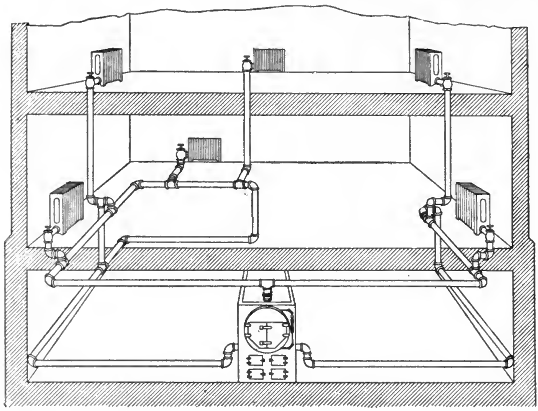


Fig. 27. Arrangement of Piping and Radiators in "One-Pipe Relief" System.

near the boiler, to prevent the water from flowing out in case of a vacuum being formed suddenly in the pipes.

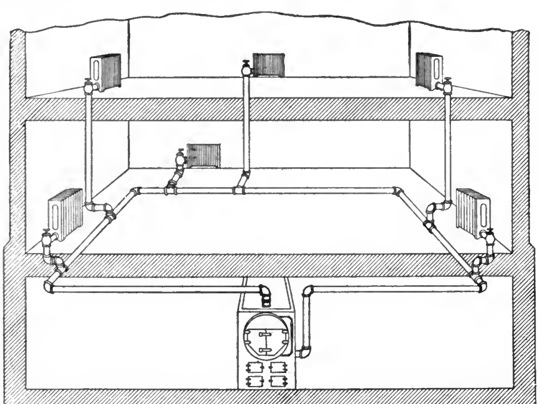


Fig. 28. Arrangement of Piping and Radiators in "One-Pipe Circuit" System.

There is but little difference in the cost of the two systems, as larger pipes and valves are required for the single-pipe method

With radiators of medium size and properly proportioned connections, the single-pipe system in preferable, there being but one valve to operate and only one-half the number of risers passing through the lower rooms.

One-Pipe Circuit System. In this case, illustrated in Fig. 28, the steam main rises to the highest point of the basement, as before; and then, with a considerable pitch, makes an entire circuit of the building, and again connects with the boiler below the water-line. Single risers are taken from the top; and the condensation drains back through the same pipes, and is carried along with the flow of steam to the extreme end of the main, where it is returned to the boiler. The main is made large, and of the same size throughout its entire length. It must be given a good pitch to insure satisfactory results.

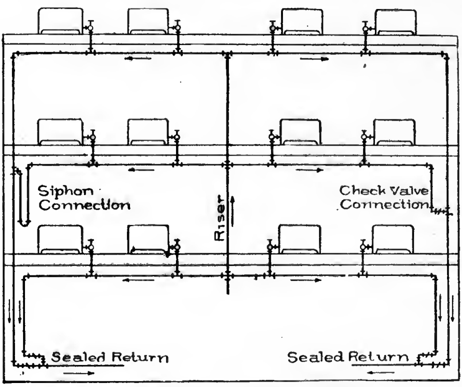


Fig. 29. "One-Pipe Circuit" System. Adapted to a Large Building.

One objection to a single-pipe system is that the steam and return water are flowing in opposite directions, and the risers must be made of extra large size to prevent any interference. This is overcome in large buildings by carrying a single riser to the attic, large enough to supply the entire building; then branching and running "drops" to the basement. In this system the flow of steam is downward, as well as that of water. This method of piping may be used with good results in two-pipe systems as well. Care must always be taken that no pockets or low points occur in any of the lines of pipe; but if for any reason they cannot be avoided, they should be carefully drained.

A modification of this system, adapting it to large buildings, is shown in diagram in Fig. 29. The riser shown in this case is one of several, the number depending upon the size of the building; and may be supplied at either bottom or top as most desirable. If steam is supplied at the bottom of the riser, as shown in the cut, all of the drip connections with the return drop, except the upper one, should

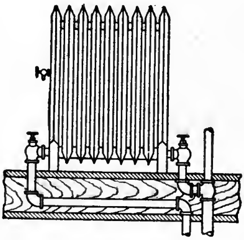


Fig. 30. "Two-Pipe" Connection of Radiator to Riser and Return.

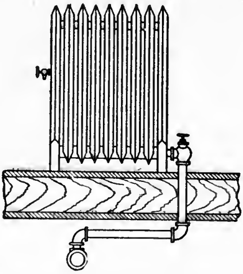


Fig. 31. "One-Pipe" Connection of Radiator to Basement Main.

be sealed with either a siphon loop or a check-valve, to prevent the steam from short-circuiting and holding back the condensation in the returns above. If an overhead supply is used, the arrangement should be the reverse; that is, all return connections should be sealed except the lowest.

Sometimes a separate drip is carried down from each set of radiators, as shown on the lower story, being connected with the main return below the water-line of the boiler. In case this is done, it is well to provide a check-valve in each drip below the water-line.

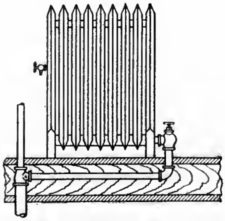


Fig. 32. "One-Pipe" Connection of Radiator to Riser.

In buildings of any considerable size, it is well to divide the piping system into sections by means of valves placed in the corresponding supply and return branches. These are for use in case of a break in any part of the system, so that it will be necessary to shut off only a small part of the heating system during repairs. In tall buildings, it is customary to place valves at the top and bottom of each riser, for the same purpose.

Radiator Connections. Figs. 30, 31, and 32 show the common methods of making connections between supply pipes and radiators. Fig. 30 shows a two-pipe connection with a riser; the return is carried down to the main below. Fig. 31 shows a single-pipe connection with a basement main; and Fig. 32, a single connection with a riser.

Care must always be taken to make the horizontal part of the piping between the radiator and riser as short as possible, and to give it a good pitch toward the riser. There are various ways of making these connections, especially suited to different conditions; but the examples given serve to show the general principle to be followed.

Figs. 20, 21, and 22 show the common methods of making steam and return connections with circulation coils. The position of the air-valve is shown in each case.

Expansion of Pipes. Cold steam pipes expand approximately

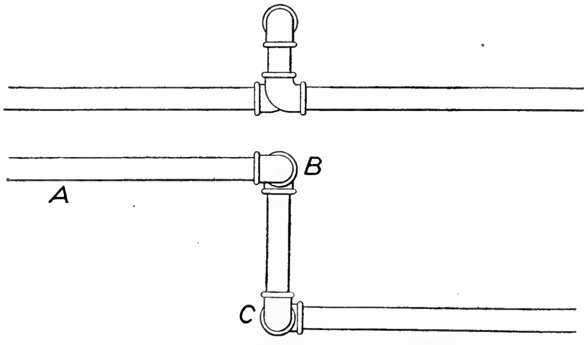


Fig. 33. Elevation and Plan of Swivel-Joint to Counteract Effects of Expansion and Contraction in Pipes.

1 inch in each 100 feet in length when low-pressure steam is turned into them; so that, in laying out a system of piping, we must arrange it in such a manner that there will be sufficient "spring" or "give" to the pipes to prevent injurious strains. This is done by means of offsets and bends. In the case of larger pipes this simple method will not be sufficient, and swivel or slip joints must be used to take up the expansion.

The method of making up a swivel-joint is shown in Fig. 33. Any lengthening of the pipe *A* will be taken up by slight turning or swivel movements at the points *B* and *C*. A slip-joint is shown in

Fig. 34. The part *c* slides inside the shell *d*, and is made steam-tight by a stuffing-box, as shown. The pipes are connected at the flanges *A* and *B*.

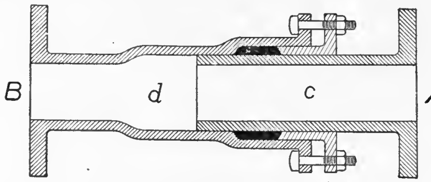


Fig. 34. "Slip-Joint" Connection to Take Care of Expansion and Contraction of Pipes.

When pipes pass through floors or partitions, the woodwork should be protected by galvanized-iron sleeves having a diameter from $\frac{3}{4}$ to 1 inch greater than the pipe. Fig. 35 shows a form of adjustable floor-sleeve which may be lengthened or shortened to conform to the thickness of floor or partition. If plain sleeves are used, a plate should be placed around the pipe where it passes through the floor or partition. These are made in two parts so that they may be put in place after the pipe is hung. A plate of this kind is shown in Fig. 36.

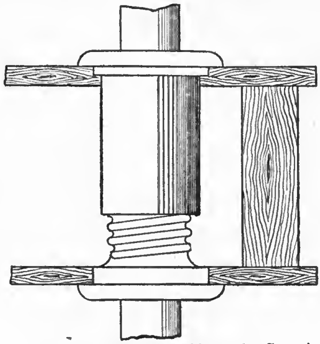


Fig. 35. Adjustable Metal Sleeve for Carrying Pipe through Floor or Partition.

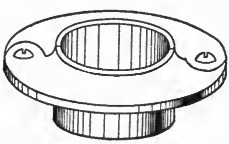


Fig. 36. Floor-Plate Adjusted to Plain Sleeve for Carrying Pipe through Floor or Partition.


Fig. 37. Angle Valve.


Fig. 38. Offset Valve.


Fig. 39. Corner Valve.

Valves for Radiator Connections.

Valves. The different styles commonly used for radiator connections are shown in Figs. 37, 38, and 39, and are known as *angle, offset,* and *corner* valves, respectively. The first is used when the radiator is at the top of a riser or when the connections are like those shown in Figs. 30, 31, and 32; the second is used when the connection

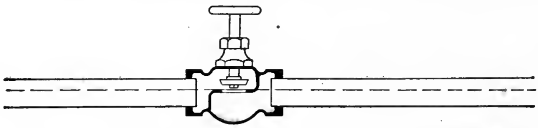


Fig. 40. Indicating Effect of Using Globe Valve on Horizontal Steam Supply Pipe or Dry Return.

between the riser and radiator is above the floor; and the third, when the radiator has to be set close in the corner of a room and there is not space for the usual connection.

A *globe* valve should never be used in a horizontal steam supply or dry return. The reason for this is plainly shown in Fig. 40. In order for water to flow through the valve, it must rise to a height shown by the dotted line, which would half fill the pipes, and cause serious trouble from water-hammer. The gate valve shown in Fig. 41 does not have this undesirable feature, as the opening is on a level with the bottom of the pipe.

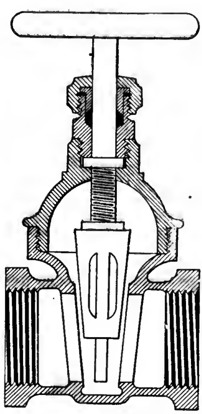


Fig. 41. Gate Valve.

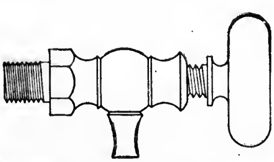


Fig. 42. Simplest Form of Air-Valve. Operated by Hand.

Air-Valves. Valves of various kinds are used for freeing the radiators from air when steam is turned on. Fig. 42 shows the simplest form, which is operated by hand. Fig. 43 is a type of automatic valve, consisting of a shell, which is attached to the radiator. *E* is a small opening which may be closed by the spindle *C*, which is provided with a conical end. *D* is a strip composed of a layer of iron or steel and one of brass soldered or brazed together. The action of the valve is as follows: when the radiator is cold and filled with air the valve stands as shown in the cut. When steam is turned on, the air is driven out through the opening *B*. As soon as this is expelled and steam strikes the strip *D*, the two prongs spring apart owing to the unequal expansion of the two metals due to the heat of the steam. This raises the spindle *C*, and closes the opening so that no steam can escape. If air should collect in the valve, and the metal strip become cool, it would contract, and the spindle would drop and allow the air to escape through *B* as before. *E* is an adjusting nut. *F* is a float attached to the spindle, and is supposed, in case of a sudden rush of water with the air, to rise and close the opening; this action, however, is somewhat uncertain, especially if the pressure of water continues for some time.

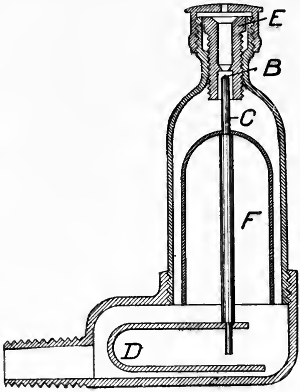


Fig. 43. Radiator Automatic Air-Valve. Operated by Metal Strip *D*, Consisting of Two Pieces of Metal of Unequal Expansive Power.

There are other types of valves acting on the same principle. The valve shown in Fig. 44 is closed by the expansion of a piece of vulcanite instead of a metal strip, and has no water float.

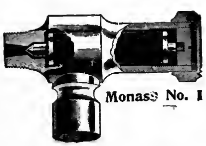


Fig. 44. Automatic Air-Valve. Closed by Expansion of a Piece of Vulcanite.

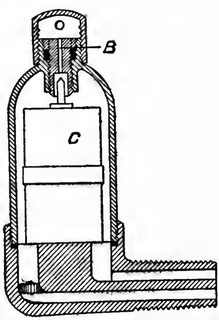


Fig. 45. Automatic Air-Valve. Operated by Expansion of Drum *C* Due to Vaporization of Alcohol with which it is Partly Filled.

The valve shown in Fig. 45 acts on a somewhat different principle. The float *C* is made of thin brass, closed at top and bottom, and is partially filled with wood alcohol. When steam strikes the float, the alcohol is vaporized, and creates a pressure sufficient to bulge out the ends slightly, which raises the spindle and closes the opening *B*.

Fig. 46 shows a form of so-called *vacuum valve*. It acts in a similar manner to those already described, but has in addition a ball check which prevents the air from being drawn into the radiator, should the steam go down and a vacuum be formed. If a partial vacuum exists in the boiler and radiators, the boiling point, and consequently the temperature of the steam, are lowered, and less heat is given off by the radiators. This method of operating a heating plant is sometimes advocated for spring and fall, when little heat is required, and when steam under pressure would overheat the rooms.

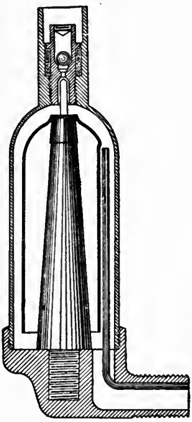


Fig. 46. Vacuum Valve.

Pipe Sizes. The proportioning of the steam pipes in a heating plant is of the greatest importance, and should be carefully worked out by methods which experience has proved to be correct. There are several ways of doing this; but for ordinary conditions, Tables XIV, XV, and XVI have given excellent results in actual practice. They have been computed from what is known as D'Arcy's formula, with suitable corrections made for actual working conditions. As the computations are somewhat complicated, only the results will be given here, with full directions for their proper use.

Table XIV gives the flow of steam in pounds per minute for pipes of different diameters and with varying drops in pressure between the supply and discharge ends of the pipe. These quantities are for pipes 100 feet in length; for other lengths the results must be corrected by the factors given in Table XVI. As the length of pipe increases, friction becomes greater, and the quantity of steam discharged in a given time is diminished.

Table XIV is computed on the assumption that the drop in

TABLE XIV

Flow of Steam in Pipes of Various Sizes, with Various Drops in Pressure between Supply and Discharge Ends

Calculated for 100-Foot Lengths of Pipe

Diam. of Pipe	Drop in Pressure (Pounds)								
	¼	½	¾	1	1½	2	3	4	5
1	.44	.63	.78	91	1.13	1.31	1.66	1.97	2.26
1¼	.81	1.16	1.43	1.66	2.05	2.39	3.02	3.59	4.12
1½	1.06	1.89	2.34	2.71	3.36	3.92	4.94	5.88	6.75
2	2.93	4.17	5.16	5.99	7.43	8.65	10.9	13.0	14.9
2½	5.29	7.52	9.32	10.8	13.4	15.6	19.7	23.4	26.9
3	8.61	12.3	15.2	17.6	21.8	25.4	32	31.8	43.7
3½	12.9	18.3	22.6	26.3	32.5	37.9	47.8	56.9	65.3
4	18 1	25.7	31.8	36.9	45.8	53.3	67.2	80.1	91.9
5	32.2	45.7	56.6	65.7	81.3	94.7	120	142	163
6	51.7	73.3	90.9	106	131	152	192	229	262
7	76.7	109	135	157	194	226	285	339	390
8	108	154	190	222	274	319	402	478	549
9	147	209	258	299	371	432	545	649	745
10	192	273	339	393	487	567	715	852	977
12	305	434	537	623	771	899	1,130	1,350	1,550
15	535	761	942	1,090	1,350	1,580	1,990	2,370	2,720

pressure between the two ends of the pipe equals the initial pressure. If the drop in pressure is less than the initial pressure, the actual discharge will be slightly greater than the quantities given in the table;

TABLE XV

Factors for Calculating Flow of Steam in Pipes under Initial Pressures above Five Pounds

To be used in connection with Table XIV

Drop in Pressure in Pounds	Initial Pressure (Pounds)					
	10	20	30	40	60	80
¼	1.27	1.49	1.68	1.84	2.13	2.38
½	1.26	1.48	1.66	1.83	2.11	2.36
1	1.24	1.46	1.64	1.80	2.08	2.32
2	1.21	1.41	1.59	1.75	2.02	2.26
3	1.17	1.37	1.55	1.70	1.97	2.20
4	1.14	1.34	1.51	1.66	1.92	2.14
5	1.12	1.31	1.47	1.62	1.87	2.09

but this difference will be small for pressures up to 5 pounds, and may be neglected, as it is on the side of safety. For higher initial pressures, Table XV has been prepared. This is to be used in connection with Table XIV as follows: First find from Table XIV the quantity of steam which will be discharged through the given diameter of pipe

TABLE XVI

Factors for Calculating Flow of Steam in Pipes of Other Lengths than 100 Feet

Feet	Factor	Feet	Factor	Feet	Factor	Feet	Factor
10	3.16	120	.91	275	.60	600	.40
20	2.24	130	.87	300	.57	650	.39
30	1.82	140	.84	325	.55	700	.37
40	1.58	150	.81	350	.53	750	.36
50	1.41	160	.79	375	.51	800	.35
60	1.29	170	.76	400	.50	850	.34
70	1.20	180	.74	425	.48	900	.33
80	1.12	190	.72	450	.47	950	.32
90	1.05	200	.70	475	.46	1,000	.31
100	1.00	225	.66	500	.45		
110	.95	250	.63	550	.42		

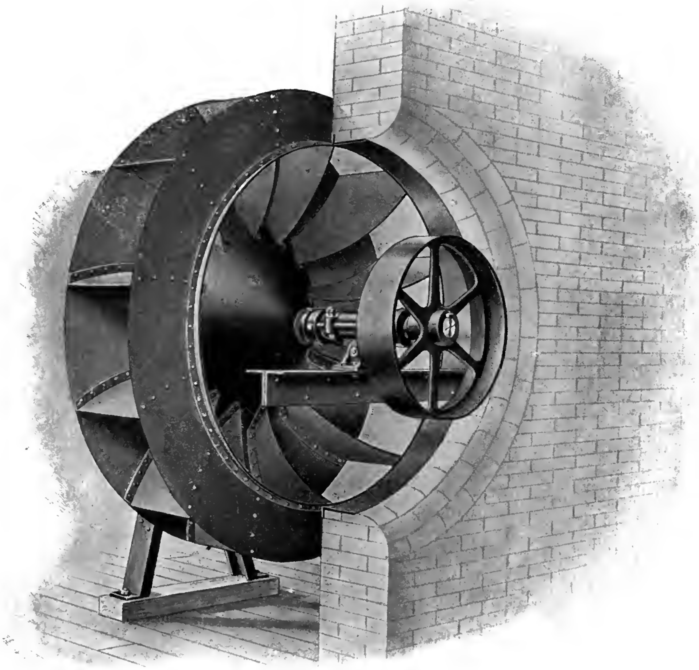
with the assumed drop in pressure; then look in Table XV for the factor corresponding with the assumed drop and the higher initial pressure to be used. The quantity given in Table XIV, *multiplied by* this factor, will give the actual capacity of the pipe under the given conditions.

Example—What weight of steam will be discharged through a 3-inch pipe 100 feet long, with an initial pressure of 60 pounds and a drop of 2 pounds?

Looking in Table XIV, we find that a 3-inch pipe will discharge 25.4 pounds of steam per minute with a 2-pound drop. Then looking in Table XV, we find the factor corresponding to 60 pounds initial pressure and a drop of 2 pounds to be 2.02. Then according to the rule given, $25.4 \times 2.02 = 51.3$ pounds, which is the capacity of a 3-inch pipe under the assumed conditions.

Sometimes the problem will be presented in the following way: What size of pipe will be required to deliver 80 pounds of steam a distance of 100 feet with an initial pressure of 40 pounds and a drop of 3 pounds?

We have seen that the higher the initial pressure with a given drop, the greater will be the quantity of steam discharged; therefore a smaller pipe will be required to deliver 80 pounds of steam at 40 pounds than at 3 pounds initial pressure From Table XV, we find that a given pipe will discharge 1.7 times as much steam per minute with a pressure of 40 pounds and a drop of 3 pounds, as it would with a pressure of 3 pounds, dropping to zero. From this it is evident that if we divide 80 by 1.7 and look in Table XIV under "3 pounds



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American Blower Co.

drop" for the result thus obtained, the size of pipe corresponding will be that required. Now, 80 ÷ 1.7 = 47. The nearest number in the table marked "3 pounds drop" is 47.8, which corresponds to a 3½-inch pipe, which is the size required.

These conditions will seldom be met with in low-pressure heating, but apply more particularly to combination power and heating plants, and will be taken up more fully under that head. For lengths of pipe other than 100 feet, multiply the quantities given in Table XIV by the factors found in Table XVI.

Example—What weight of steam will be discharged per minute through a 3½-inch pipe 450 feet long, with a pressure of 5 pounds and a drop of ½ pound?

Table XIV, which may be used for all pressures below 10 pounds, gives for a 3½-inch pipe 100 feet long, a capacity of 18.3 pounds for the above conditions. Looking in Table XVI, we find the correction factor for 450 feet to be .47. Then 18.3 × .47 = 8.6 pounds, the quantity of steam which will be discharged if the pipe is 450 feet long.

Examples involving the use of Tables XIV, XV, and XVI in combination, are quite common in practice. The following example will show the method of calculation:

What size of pipe will be required to deliver 90 pounds of steam per minute a distance of 800 feet, with an initial pressure of 80 pounds and a drop of 5 pounds?

Table XVI gives the factor for 800 feet as .35, and Table XV, that for 80 pounds pressure and 5 pounds drop, as 2.09. Then $\frac{90}{.35 \times 2.09} = 123$, which is the equivalent quantity we must look for in Table XIV. We find that a 4-inch pipe will discharge 91.9 pounds, and a 5-inch pipe 163 pounds. A 4½-inch pipe is not commonly carried in stock, and we should probably use a 5-inch in this case, unless it was decided to use a 4-inch and allow a slightly greater drop in pressure. In ordinary heating work, with pressures varying from 2 to 5 pounds, a drop of ¼ pound in 100 feet has been found to give satisfactory results.

In computing the pipe sizes for a heating system by the above methods, it would be a long process to work out the size of each branch separately. Accordingly Table XVII has been prepared for ready use in low-pressure work.

As most direct heating systems, and especially those in schoolhouses, are made up of both radiators and circulation coils, an efficiency of 300 B. T. U. has been taken for direct radiation of whatever variety, no distinction being made between the different kinds. This gives a slightly larger pipe than is necessary for cast-iron radiators; but it is probably offset by bends in the pipes, and in any case gives a slight factor of safety. We find from a steam table that the *latent heat* of steam at 20 pounds above a vacuum (which corresponds to 5 pounds' gauge-pressure) is 954 + B. T. U.—which means that, for every pound of steam condensed in a radiator, 954 B. T. U. are given off for warming the air of the room. If a radiator has an efficiency of 300 B. T. U., then each square foot of surface will condense 300 ÷ 954 = .314 pound of steam per hour; so that we may assume in round numbers a condensation of $\frac{1}{3}$ of a pound of steam per hour for each square foot of direct radiation, when computing the sizes of steam pipes in low-pressure heating. Table XVII has been calculated on this assumption, and gives the square feet of heating surface

TABLE XVII

Heating Surface Supplied by Pipes of Various Sizes

Length of Pipe, 100 Feet

Size of Pipe	Square Feet of Heating Surface	
	$\frac{1}{4}$ Pound Drop	$\frac{1}{2}$ Pound Drop
1	80	114
1¼	145	210
1½	190	340
2	525	750
2½	950	1,350
3	1,550	2,210
3½	2,320	3,290
4	3,250	4,620
5	5,800	8,220
6	9,320	13,200
7	13,800	19,620
8	19,440	27,720

which different sizes of pipe will supply, with drops in pressure of $\frac{1}{4}$ and $\frac{1}{2}$ pounds in each 100 feet of pipe. The former should be used for pressures from 1 to 5 pounds, and the latter may be used for pressures over 5 pounds, under ordinary conditions. The sizes of long mains and special pipes of large size should be proportioned directly from Tables XIV, XV, and XVI.

Where the two-pipe system is used and the radiators have separate supply and return pipes, the risers or vertical pipes may be taken from Table XVII; but if the single-pipe system is used, the risers must be increased in size, as the steam and water are flowing in opposite directions and must have plenty of room to pass each other. It is customary in this case to base the computation on the velocity of the steam in the pipes, rather than on the drop in pressure. Assuming, as before, a condensation of one-third of a pound of steam per hour per square foot of radiation, Tables XVIII and XIX have been prepared for velocities of 10 and 15 feet per second. The sizes given in Table XIX have been found sufficient in most cases; but the larger sizes, based on a flow of 10 feet per second, give greater safety and should be more generally used. The size of the largest riser should usually be limited to 2½ inches in school and dwelling-house work, unless it is a special pipe carried up in a concealed position. If the length of riser is short between the lowest radiator and the main, a higher velocity of 20 feet or more may be allowed through this portion, rather than make the pipe excessively large.

TABLE XVIII **TABLE XIX**

Radiating Surface Supplied by Steam Risers

10 Feet per Second Velocity		15 Feet per Second Velocity	
Size of Pipe	Sq. Feet of Radiation	Size of Pipe	Sq. Feet of Radiation
1 in.	30	1 in.	50
1¼ "	60	1¼ "	90
1½ "	80	1½ "	120
2 "	130	2 "	200
2½ "	190	2½ "	290
3 "	290	3 "	340
3½ "	390	3½ "	590

EXAMPLES FOR PRACTICE

1. How many pounds of steam will be delivered per minute, through a 3½-inch pipe 600 feet long, with an initial pressure of 5 pounds and a drop of ½ pound? Ans. 7.32 pounds.

2. What size pipe will be required to deliver 25.52 pounds of steam per minute with an initial pressure of 3 pounds and a drop of ¼ pound, the length of the pipe being 50 feet? Ans. 4-inch.

3. Compute the size of pipe required to supply 10,000 square feet of direct radiation (assume ⅓ of a pound of steam per square

foot per hour) where the distance to the boiler house is 300 feet, and the pressure carried is 10 pounds, allowing a drop in pressure of 4 pounds. Ans. 5-inch (this is slightly larger than is required, while a 4-inch is much too small).

TABLE XX

Sizes of Returns for Steam Pipes (in Inches)

Diameter of Steam Pipe	Diameter of Dry Return	Diameter of Sealed Return
1	1	3/4
1 1/4	1	1
1 1/2	1 1/4	1
2	1 1/2	1 1/4
2 1/2	2	1 1/2
3	2 1/2	2
3 1/2	2 1/2	2
4	3	2 1/2
5	3	2 1/2
6	3 1/2	3
7	3 1/2	3
8	4	3 1/2
9	5	3 1/2
10	5	4
12	6	5

Returns. The size of return pipes is usually a matter of custom and judgment rather than computation. It is a common rule among steamfitters to make the returns one size smaller than the corresponding steam pipes. This is a good rule for the smaller sizes, but gives a larger return than is necessary for the larger sizes of pipe. Table XX gives different sizes of steam pipes with the corresponding diameters for dry and sealed returns.

TABLE XXI

Pipe Sizes for Radiator Connections

Square Feet of Radiation		Steam	Return
Two-Pipe	10 to 30	3/4 inch	3/4 inch
	30 to 48	1 "	3/4 "
	48 to 96	1 1/4 "	1 "
	96 to 150	1 1/2 "	1 1/4 "
Single-Pipe	10 to 24	1 inch	
	24 to 60	1 1/4 "	
	60 to 80	1 1/2 "	
	80 to 130	2 "	

The length of run and number of turns in a return pipe should be noted, and any unusual conditions provided for. Where the condensation is discharged through a trap into a lower pressure, the sizes given may be slightly reduced, especially among the larger sizes, depending upon the differences in pressure.

Radiators are usually tapped for pipe connections as shown in Table XXI, and these sizes may be used for the connections with the mains or risers.

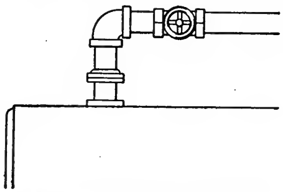


Fig 47. Good Position for Shut-Off Valve.

Boiler Connections. The steam main should be connected to the rear nozzle, if a tubular boiler is used, as the boiling of the water is less violent at this point and dryer steam will be obtained. The shut-off valve should be placed in such a position that pockets for the accumulation of condensation will be avoided. Fig. 47 shows a good position for the valve.

The size of steam connection may be computed by means of the methods already given, if desired. But for convenience the sizes given in Table XXII may be used with satisfactory results for the short runs between the boilers and main header.

TABLE XXII

Pipe Sizes from Boiler to Main Header

Diameter of Boiler	Size of Steam Pipe
36 inches	3 inches
42 "	4 "
48 "	4 "
54 "	5 "
60 "	5 "
66 "	6 "
72 "	6 "

The return connection is made through the blow-off pipe, and should be arranged so that the boiler can be blown off without draining the returns. A check-valve should be placed in the main return, and a plug-cock in the blow-off pipe. Fig. 48 shows in plan a good arrangement for these connections.

The feed connections, with the exception of that part exposed in the smoke-bonnet, are always made of brass in the best class of work. The small section referred to should be of extra heavy wrought

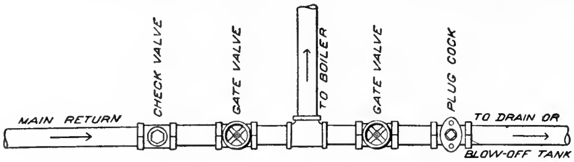


Fig. 48. A Good Arrangement of Return and Blow-Off Connections.

iron. The branch to each boiler should be provided with a gate or globe valve and a check-valve, the former being placed next to the boiler.

Table XXIII gives suitable sizes for return, blow-off, and feed pipes for boilers of different diameters.

TABLE XXIII

Sizes for Return, Blow-Off, and Feed Pipes

Diameter of Boiler	Size of Pipe for Gravity Return	Size of Blow-Off Pipe	Size of Feed Pipe
36 inches	1½ inches	1¼ inches	1 inch
42 "	2 "	1½ "	1 "
48 "	2 "	1½ "	1 "
54 "	2½ "	2 "	1¼ "
60 "	2½ "	2 "	1¼ "
66 "	3 "	2½ "	1½ "
72 "	3 "	2½ "	1½ "

Blow-Off Tank. Where the blow-off pipe connects with a sewer, some means must be provided for cooling the water, or the expansion and contraction caused by the hot water flowing through the drain-pipes will start the joints and cause leaks. For this reason it is customary to pass the water through a blow-off tank. A form of wrought-iron tank is shown in Fig. 49. It consists of a receiver supported on cast-iron cradles. The tank ordinarily stands nearly full of cold water.

The pipe from the boiler enters above the water-line, and the sewer connection leads from near the bottom, as shown. A vapor pipe is carried from the top of the tank above the roof of the building. When water from the boiler is blown into the tank, cold water from the bottom flows into the sewer, and the steam is carried off through the vapor pipe. The equalizing pipe is to prevent any siphon action which might draw the water out of the tank after a flow is once started. As only a part of the water is blown out of a boiler at one time, the blow-off tank can be of a comparatively small size. A tank 24 by 48 inches should be large enough for boilers up to 48 inches in diameter;

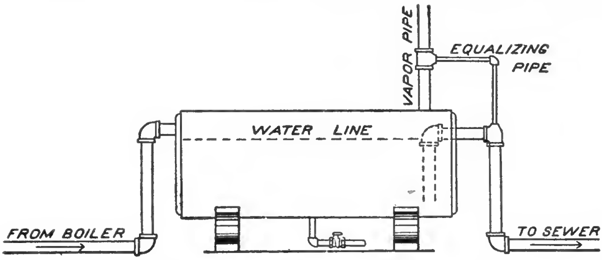
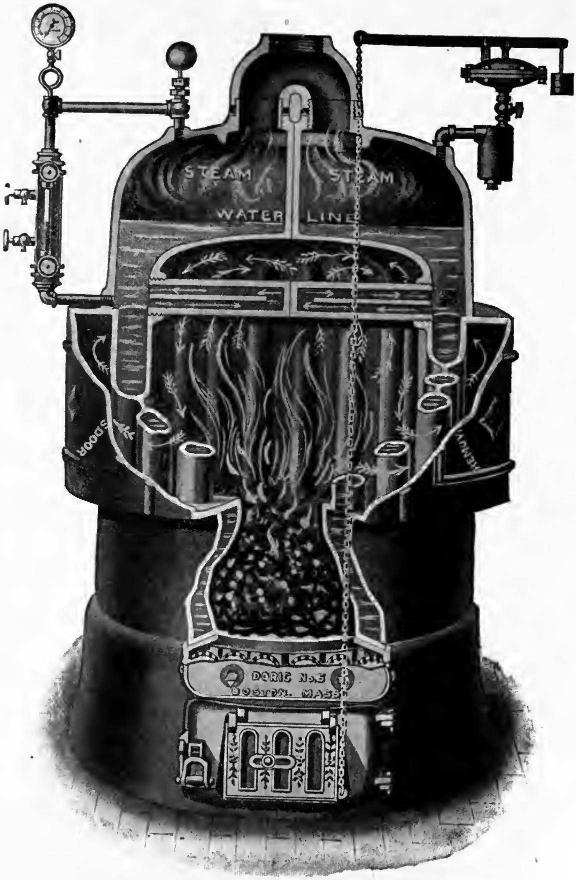


Fig. 49. Connections of Blow-Off Tank.

and one 36 by 72 inches should care for a boiler 72 inches in diameter. If smaller quantities of water are blown off at one time, smaller tanks can be used. The sizes given above are sufficient for batteries of 2 or more boilers, as one boiler can be blown off and the water allowed to cool before a second one is blown off. Cast-iron tanks are often used in place of wrought-iron, and these may be sunk in the ground if desired.



Cast Iron Seamless Tubular Steam Heater.

HEATING AND VENTILATION

PART II

INDIRECT STEAM HEATING

As already stated, in the indirect method of steam heating, a special form of heater is placed beneath the floor, and encased in galvanized iron or in brickwork. A cold-air box is connected with the space beneath the heater; and warm-air pipes at the top are connected with registers in the floors or walls as already described for furnaces. A separate heater may be provided for each register if the rooms are large, or two or more registers may be connected with the same heater if the horizontal runs of pipe are short. Fig. 50 shows a section through a heater arranged for introducing hot air into a room through a floor register; and Fig. 51 shows the same type of heater connected with a wall register. The cold-air box is seen at the bottom of the casing; and the air, in passing through the spaces between the sections of the heater, becomes warmed, and rises to the rooms above.

Different forms of indirect heaters are shown in Figs. 52 and 53. Several sections connected in a single group are called a *stack*. Sometimes the stacks are encased in brickwork built up from the basement floor, instead of in galvanized iron as shown in the cuts. This method of heating provides fresh air for ventilation, and for this reason is especially adapted for schoolhouses, hospitals, churches, etc. As compared with furnace heating, it has the advantage of being less affected by outside wind-pressure, as long runs of horizontal pipe

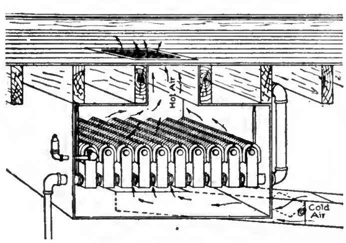


Fig. 50. Steam Heater Placed under Floor Register —Indirect System.

are avoided and the heaters can be placed near the registers. In a large building where several furnaces would be required, a single boiler can be used, and the number of stacks increased to suit the existing conditions, thus making it necessary to run but a single fire. Another advantage is the large ratio between the heating and grate surface as compared with a furnace; and as a result, a large quantity of air is warmed to a moderate temperature, in place of a smaller quantity heated to a much higher temperature. This gives a more agreeable quality to the air, and renders it less dry. Direct and indirect systems are often combined, thus providing the living rooms with ventilation, while the hallways, corridors, etc., have only direct radiators for warming.

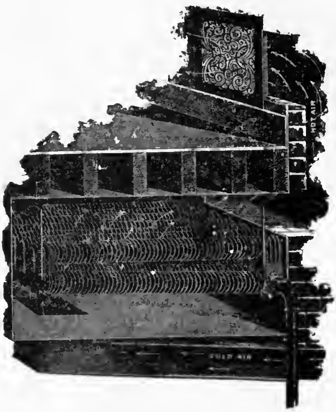


Fig. 51. Steam Heater Connected to Wall Register.—Indirect System.

Types of Heaters. Various forms of indirect radiators are shown in Figs. 52, 53, 54, and 56. A hot-water radiator may be used for steam; but a steam radiator cannot always be used for hot water, as

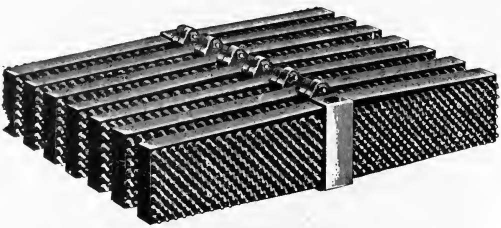


Fig. 52. One Form of Indirect Steam or Hot-Water Heater.

it must be especially designed to produce a continuous flow of water through it from top to bottom. Figs. 54 and 55 show the outside and the interior construction of a common pattern of indirect radiator designed especially for steam. The arrows in Fig. 55 indicate the path of the steam through the radiator, which is supplied at the right, while the return connection is at the left. The air-valve in this case should be connected in the end of the last section near the return.

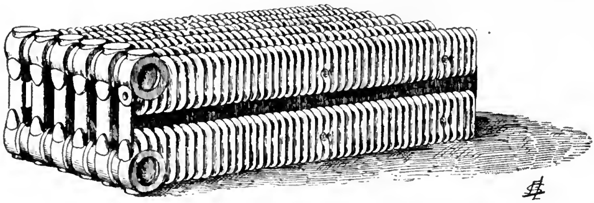


Fig. 53. Another Form of Indirect Steam or Hot-Water Heater.

A very efficient form of radiator, and one that is especially adapted to the warming of large volumes of air, as in schoolhouse work, is shown in Fig. 56, and is known as the *School pin* radiator. This can

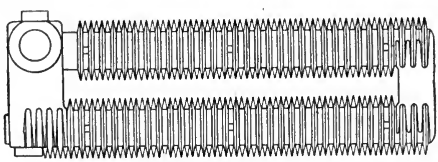


Fig. 54. Exterior View of a Common Type of Radiator for Indirect-Steam Heating.

be used for either steam or hot water, as there is a continuous passage downward from the supply connection at the top to the return at the bottom. These sections or slabs are made up in stacks after the

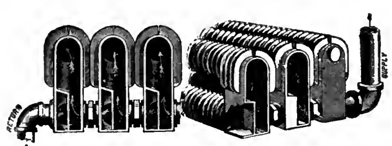


Fig. 55. Interior Mechanism of Radiator Shown in Fig. 54.

manner shown in Fig. 57, which represents an end view of several sections connected together with special nipples.

A very efficient form of indirect heater may be made up of wrought-iron pipe joined together with branch tees and return bends.

A heater like that shown in Fig. 58 is known as a *box coil.* Its efficiency is increased if the pipes are *staggered*—that is, if the pipes in alternate rows are placed over the spaces between those in the row below.

Efficiency of Heaters. The efficiency of an indirect heater

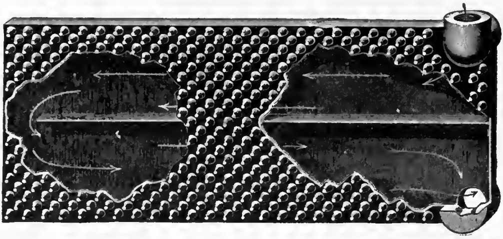


Fig. 56. "School Pin" Radiator, Especially Adapted for Warming Large Volumes of Air by Either Steam or Hot Water.

depends upon its form, the difference in temperature between the steam and the surrounding air, and the velocity with which the air passes over the heater. Under ordinary conditions in dwelling-house work, a good form of indirect radiator will give off about 2 B. T. U. per square foot per hour for each degree difference in temperature between the steam and the entering air. Assuming a steam pressure of 2 pounds and an outside temperature of zero, we should have a difference in temperature of about 220 degrees, which, under the conditions stated, would give an efficiency of $220 \times 2 = 440$ B. T. U. per hour for each square foot of radiation. By making a similar computation for 10 degrees below zero, we find the efficiency to be 460. In the same manner we may calculate the efficiency for varying conditions of steam pressure and outside temperature. In the case of schoolhouses and similar buildings where large volumes of air are warmed to a moderate tem-

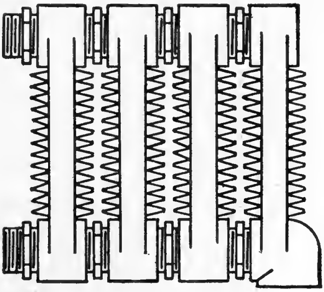


Fig. 57. End View of Several "School Pin" Radiator Sections Connected Together.

perature, a somewhat higher efficiency is obtained, owing to the increased velocity of the air over the heaters. Where efficiencies of 440 and 460 are used for dwellings, we may substitute 600 and 620 for schoolhouses. This corresponds approximately to 2.7 B. T. U. per square foot per hour for a difference of 1 degree between the air and steam.

The principles involved in indirect steam heating are similar to those already described in furnace heating. Part of the heat given off by the radiator must be used in warming up the air-supply to the temperature of the room, and part for offsetting the loss by conduction through walls and windows. The method of computing the heating surface required, depends upon the volume of air to be supplied to the room. In the case of a schoolroom or hall, where the air quantity

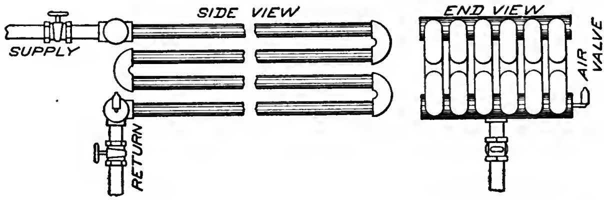


Fig. 58. "Box Coil," Built Up of Wrought-Iron Pipe, for Indirect-Steam Heating.

is large as compared with the exposed wall and window surface, we should proceed as follows:

First compute the B. T. U. required for loss by conduction through walls and windows; and to this, add the B. T. U. required for the necessary ventilation; and divide the sum by the efficiency of the radiators. An example will make this clear.

Example. How many square feet of indirect radiation will be required to warm and ventilate a schoolroom in zero weather, where the heat loss by conduction through walls and windows is 36,000 B. T. U., and the air-supply is 100,000 cubic feet per hour?

By the methods given under "Heat for Ventilation," we have

$$\frac{100{,}000 \times 70}{55} \times 127{,}272 = \text{B. T. U. required for ventilation.}$$

$$36{,}000 + 127{,}272 = 163{,}272 \text{ B. T. U.} = \text{Total heat required.}$$

This in turn divided by 600 (the efficiency of indirect radiators under these conditions) gives 272 square feet of surface required.

In the case of a dwelling-house the conditions are somewhat changed, for a room having a comparatively large exposure will have perhaps only 2 or 3 occupants, so that, if the small air-quantity necessary in this case were used to convey the required amount of heat to the room, it would have to be raised to an excessively high temperature. It has been found by experience that the radiating surface necessary for indirect heating is about 50 per cent greater than that required for direct heating. So for this work we may compute the surface required for direct radiation, and multiply the result by 1.5.

Buildings like hospitals are in a class between dwellings and schoolhouses. The air-supply is based on the number of occupants, as in schools, but other conditions conform more nearly to dwelling-houses.

To obtain the radiating surface for buildings of this class, we compute the total heat required for warming and ventilation as in the case of schoolhouses, and divide the sum by the efficiencies given for dwellings—that is, 440 for zero weather, and 460 for 10 degrees below.

Example. A hospital ward requires 50,000 cubic feet of air per hour for ventilation; and the heat loss by conduction through walls, etc., is 100,000 B. T. U. per hour. How many square feet of indirect radiation will be required to warm the ward in zero weather?

$50{,}000 \times 70 \div 55 = 63{,}636$ B. T. U. for ventilation; then,

$$\frac{63{,}636 + 100{,}000}{440} = 372 + \text{ square feet.}$$

EXAMPLES FOR PRACTICE

1. A schoolroom having 40 pupils is to be warmed and ventilated when it is 10 degrees below zero. If the heat loss by conduction is 30,000 B. T. U. per hour, and the air supply is to be 40 cubic feet per minute per pupil, how many square feet of indirect radiation will be required? Ans. 273.

2. A contagious ward in a hospital has 10 beds, requiring 6,000 cubic feet of air each, per hour. The heat loss by conduction in zero weather is 80,000 B. T. U. How many square feet of indirect radiation will be required? Ans. 355.

3. The heat loss from a sitting room is 11,250 B. T. U. per hour in zero weather. How many square feet of indirect radiation will be required to warm it? Ans. 75.

Stacks and Casings. It has already been stated that a group of sections connected together is called a stack, and examples of these with their casings are shown in Figs. 50 and 51. The casings are usually made of galvanized iron, and are made up in sections by means of small bolts so that they may be taken apart in case it is necessary to make repairs. Large stacks are often enclosed in brickwork, the sides consisting of 8-inch walls, and the top being covered over with a layer of brick and mortar supported on light wrought-iron tee-bars. Blocks of asbestos are sometimes used for covering, instead of brick, the whole being covered over with plastic material of the same kind.

Where a single stack supplies several flues or registers, the connections between these and the warm-air chamber are made in the same manner as already described for furnace heating. When galvanized-iron casings are used, the heater is supported by hangers from the floor above. Fig. 59 shows the method of hanging a heater from a wooden floor. If the floor is of fireproof construction, the hangers may pass up through the brickwork, and the ends be provided with nuts and large washers or plates; or they may be clamped to the iron beams which carry the floor. Where brick casings are used, the heaters are supported upon pieces of pipe or light I-beams built into the walls.

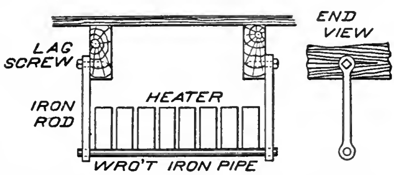


Fig. 59. Method of Hanging a Heater below a Wooden Floor.

The warm-air space above the heater should never be less than 8 inches, while 12 inches is preferable for heaters of large size. The cold-air space may be an inch or two less; but if there is plenty of room, it is good practice to make it the same as the space above.

Dampers. The general arrangement of a galvanized-iron casing and mixing damper is shown in Fig. 60. The cold-air duct is brought along the basement ceiling from the inlet window, and connects with the cold-air chamber beneath the heater. The entering air passes up between the sections, and rises through the register above, as shown by the arrows. When the mixing damper is in its lowest position, all air reaching the register must pass through the heater; but if the damper is raised to the position shown, part of the air will pass by without going through the heater, and the mixture entering through the register will be at a lower temperature than before. By changing

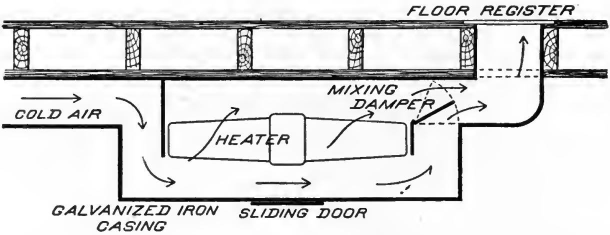


Fig. 60. General Arrangement of a Galvanized-Iron Casing and Mixing Damper Damper between Heater and Register.

the position of the damper, the proportions of warm and cold air delivered to the room can be varied, thus regulating the temperature without diminishing to any great extent the quantity of air delivered

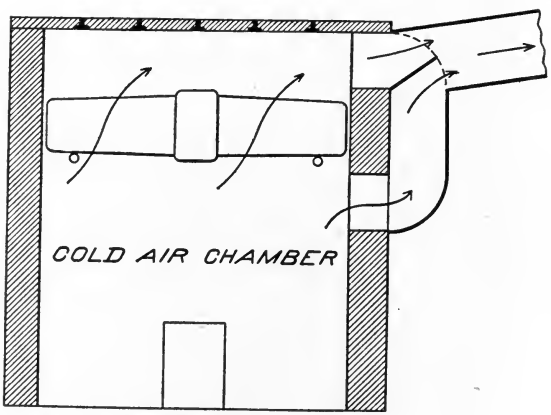
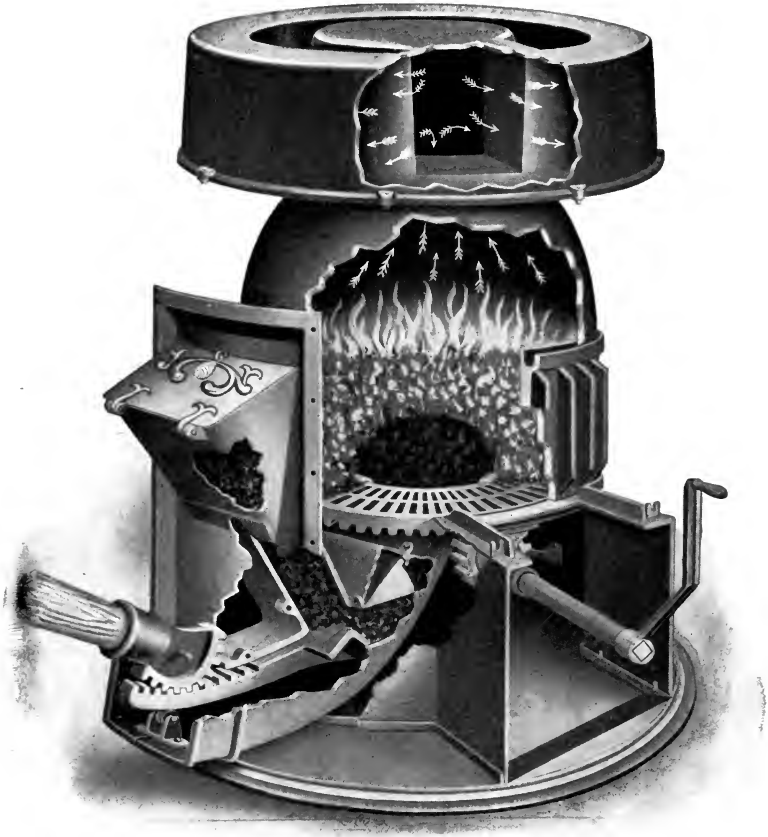


Fig. 61. Heater and Mixing Damper with Brick Casing. Damper between Heater and Register.

The objection to this form of damper is that there is a tendency for the air to enter the room before it is thoroughly mixed; that is, a stream of warm air will rise through one half of the register while



INTERIOR VIEW OF PECK-WILLIAMSON UNDERFEED FURNACE

cold air enters through the other. This is especially true if the connection between the damper and register is short. Fig. 61 shows a similar heater and mixing damper, with brick casing. Cold air is admitted to the large chamber below the heater, and rises through the sections to the register as before. The action of the mixing damper is the same as already described. Several flues or registers may be connected with a stack of this form, each connection having, in addition to its mixing damper, an adjusting damper for regulating the flow of air to the different rooms.

Another way of proportioning the air-flow in cases of this kind is to divide the hot-air chamber above the heater into sections, by means of galvanized-iron partitions, giving to each room its proper share of heating surface. If the cold-air supply is made sufficiently large, this arrangement is preferable to using adjusting dampers as

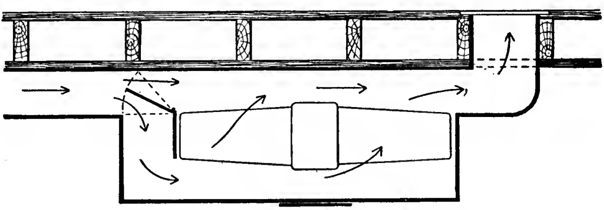


Fig. 62. Another Arrangement of Mixing Damper and Heater in Galvanized-Iron Casing. Heater between Damper and Register.

described above. The partitions should be carried down the full depth of the heater between the sections, to secure the best results.

The arrangement shown in Fig. 62 is somewhat different, and overcomes the objection noted in connection with Fig. 60, by substituting another. The mixing damper in this case is placed at the other end of the heater. When it is in its highest position, all of the air must pass through the heater before reaching the register; but when partially lowered, a part of the air passes over the heater, and the result is a mixture of cold and warm air, in proportions depending upon the position of the damper. As the layer of warm air in this case is below the cold air, it tends to rise through it, and a more thorough mixture is obtained than is possible with the damper shown in Fig. 60. One quite serious objection, however, to this form of damper, is illustrated in Fig. 63. When the damper is nearly closed so that the greater part of the air enters above the heater, it has a tendency to fall between the sections, as shown by the arrows, and, becoming heated, rises again, so that it is impossible to deliver air to a room below a certain temperature. This peculiar action increases as the quantity of air admitted below the heater is diminished. When the inlet register is placed in the wall at some distance above the floor, as in schoolhouse work, a thorough mixture of air can be obtained by placing the heater so that the current of warm air will pass up the front of the flue and be discharged into the room through the lower part of the register. This is shown quite clearly in Fig. 64, where the current of warm air is represented by crooked arrows, and the cold air by straight arrows. The two currents pass up the flue separately; but as soon as they are discharged through the register the warm air tends to rise, and the cold air to fall, with the result of a more or less complete mixture, as shown.

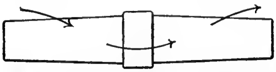


Fig. 63. Showing Difficulty of Regulating Temperature with Arrangement in Fig. 62.

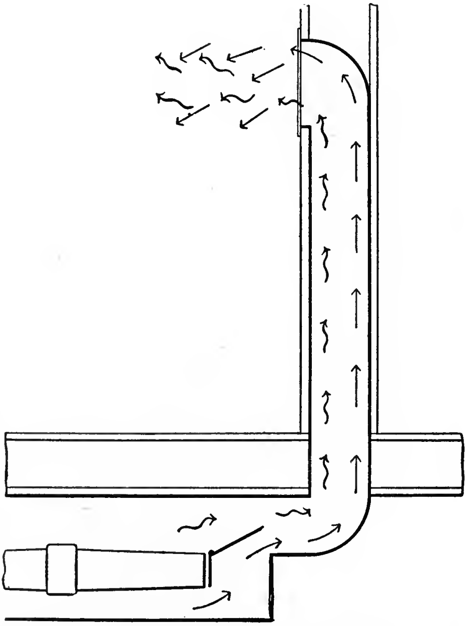


Fig. 64. Arrangement of Heater and Damper Causing Warm Air to Enter Room through Lower Part of Register, thus Securing Thorough Mixing

It is often desirable to warm a room at times when ventilation is not necessary, as in the case of living rooms during the night, or for quick warming in the morning. A register and damper for air rotation should be provided in this case. Fig. 65 shows an arrangement for this purpose. When the damper is in the position shown, air will be taken from the room above and be warmed over and over; but, by raising the damper, the supply will be taken from outside. Special care should be taken to make all mixing dampers tight against air-leakage, else their advantages will be lost. They should work easily and close tightly against flanges covered with felt. They may be operated from the rooms above by means of chains passing over

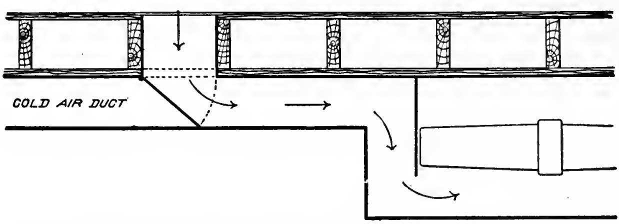


Fig. 65. Arrangement for Quick Heating without Ventilation. Damper Shuts off Fresh Air, and Air of Room Heated by Rotating Forth and Back through Register and Heater.

guide-pulleys; special attachments should be provided for holding in any desired position.

Warm-Air Flues. The required size of the warm-air flue between the heater and the register, depends first upon the difference in temperature between the air in the flue and that of the room, and second, upon the height of the flue. In dwelling-houses, where the conditions are practically constant, it is customary to allow 2 square inches area for each square foot of radiation when the room is on the first floor, and $1\frac{1}{2}$ square inches for the second and third floors. In the case of hospitals, where a greater volume of air is required, these figures may be increased to 3 square inches for the first floor wards, and 2 square inches for those on the upper floors.

In schoolhouse work, it is more usual to calculate the size of flue from an assumed velocity of air-flow through it. This will vary greatly according to the outside temperature and the prevailing wind conditions. The following figures may be taken as average velocities obtained in practice, and may be used as a basis for calculating the required flue areas for the different stories of a school building:

1st floor, 280 feet per minute.
2nd " , 340 " " "
3rd " , 400 " " "

These velocities will be increased somewhat in cold and windy weather and will be reduced when the atmosphere is mild and damp.

Having assumed these velocities, and knowing the number of cubic feet of air to be delivered to the room per minute, we have only to divide this quanity by the assumed velocity, to obtain the required flue area in square feet.

Example. A schoolroom on the second floor is to have an air-supply of 2,000 cubic feet per minute. What will be the required flue area?

ANS. $2000 \div 340 = 5.8 +$ sq. feet.

The velocities would be higher in the coldest weather, and dampers should be placed in the flues for throttling the air-supply when necessary.

Cold-Air Ducts. The cold-air ducts supplying heaters should be planned in a manner similar to that described for furnace heating. The air-inlet should be on the north or west side of the building; but this of course is not always possible. The method of having a large trunk line or duct with inlets on two or more sides of the building, should be carried out when possible. A cold-air room with large inlet windows, and ducts connecting with the heaters, makes a good arrangement for schoolhouse work. The inlet windows in this case should be provided with check-valves to prevent any outward flow of air. A detail of this arrangement is shown in Fig. 66.

This consists of a boxing around the window, extending from the floor to the ceiling. The front is sloped as shown, and is closed from the ceiling to a point below the bottom of the window. The remainder is open, and covered with a wire netting of about ½-inch mesh; to this are fastened flaps or checks of gossamer cloth about 6 inches in width. These are hemmed on both edges and a stout wire is run through the upper hem which is fastened to the netting by means of small copper or soft iron wire. The checks allow the air to flow inward but close when there is any tendency for the current to reverse.

The area of the cold-air duct for any heater should be about three-fourths the total area of the warm-air ducts leading from it.

If the duct is of any considerable length or contains sharp bends, it should be made the full size of all the warm-air ducts. Adjusting dampers should be placed in the supply duct to each separate stack. If a trunk with two inlets is used, each inlet should be of sufficient size to furnish the full amount of air required, and should be provided with cloth checks for preventing an outward flow of air, as already described. The inlet windows should be provided with some form of damper or slide, outside of which should be placed a wire grating, backed by a netting of about ⅜-inch mesh.

Vent Flues. In dwelling-houses, vent flues are often omitted, and the frequent opening of doors and leakage are depended upon to carry away the impure air. A well-designed system of warming should provide some means for discharge ventilation, especially for bathrooms and toilet-rooms, and also for living rooms where lights are burned in the evening. Fireplaces are usually provided in the more important rooms of a well-built house, and these are made to serve as vent flues. In rooms having no fireplaces, special flues of tin or galvanized iron may be carried up in the partitions in the same manner as the warm-air flues. These should be gathered together in the attic, and connected with a brick flue running up beside the boiler or range chimney.

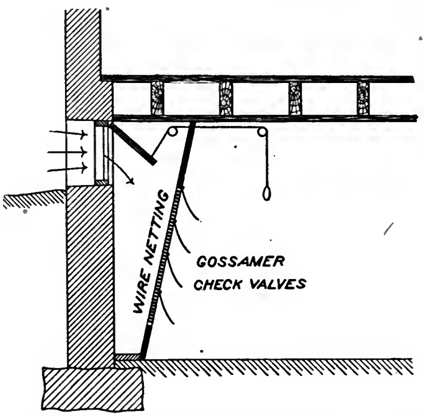


Fig. 66. Air-Inlet Provided with Check-Valves to Prevent Outward Flow of Air.

Very fair results may be obtained by simply letting the flues open into an unfinished attic, and depending upon leakage through the roof to carry away the foul air.

The sizes of flues may be made the reverse of the warm-air flues —that is, $1\frac{1}{2}$ square inches area per square foot of indirect radiation for rooms on the first floor, and 2 square inches for those on the second. This is because the velocity of flow will depend upon the height of flue, and will therefore be greater from the first floor. The flow of air through the vents will be slow at best, unless some means is provided for warming the air in the flue to a temperature above that of the room with which it connects.

The method of carrying up the outboard discharge beside a warm chimney is usually sufficient in dwelling-houses; but when it is desired to move larger quantities of air, a loop of steam pipe should be run inside the flue. This should be connected for drainage and air-venting as shown in Fig. 67. When vents are carried through the roof independently, some form of protecting hood should be provided for keeping out the snow and rain. A simple form is shown in Fig. 68. Flues carried outboard in this way should always be extended well above the ridges of adjacent roofs to prevent down drafts in windy weather.

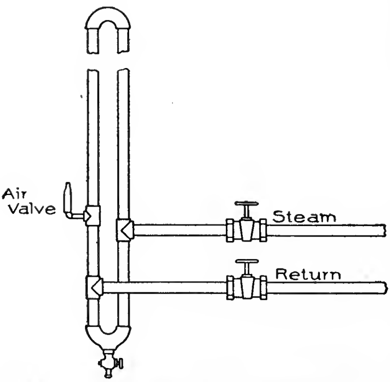


Fig. 67. Loop of Steam Pipe to be Run Inside Flue. Connected for Drainage and Air-Venting.

For schoolhouse work we may assume average velocities through the vent flues, as follows:

1st floor, 340 feet per minute.
2nd " , 280 " " "
3rd " , 220 " " "

Where flue sizes are based on these velocities, it is well to guard against down drafts by placing an aspirating coil in the flue. A single row of pipes across the flue as shown in Fig. 69, is usually sufficient for this purpose when the flues are large and straight;

otherwise, two rows should be provided. The slant height of the heater should be about twice the depth of the flue, so that the area between the pipes shall equal the free area of the flue.

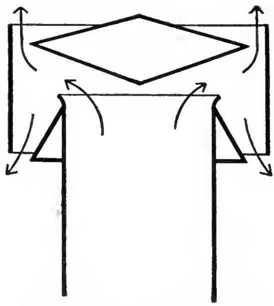


Fig. 68. Section Showing Simple Form of Protecting Hood for Vent Carried through Roof.

Large vent flues of this kind should always be provided with dampers for closing at night, and for regulation during strong winds.

Sometimes it is desired to move a given quantity of air through a flue which is already in place. Table XXIV shows what velocities may be obtained through flues of different heights, for varying differences in temperature between the outside air and that in the flue.

Example.—It is desired to discharge 1,300 cubic feet of air per minute through a flue having an area of 4 square feet and a height of 30 feet. If the efficiency of an aspirating coil is 400 B. T. U., how many square feet of surface will be required to move this amount of air when the temperature of the room is 70° and the outside temperature is 60°?

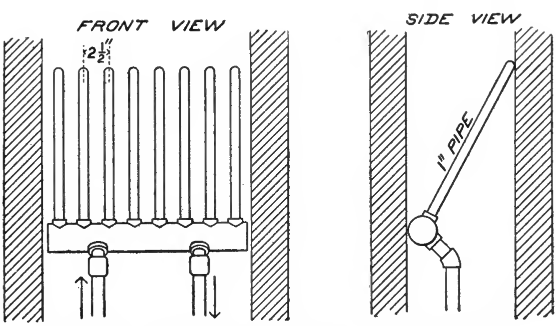


Fig. 69. Aspirating Coil Placed in Flue to Prevent Down Drafts.

1,300 ÷ 4 = 325 feet per minute = Velocity through the flue. Looking in Table XXIV, and following along the line opposite a 30-foot flue, we find that to obtain this velocity there must be a difference of 30 degrees between the air in the flue and the external air.

If the outside temperature is 60 degrees, then the air in the flue must be raised to 60 + 30 = 90 degrees. The air of the room being at 70 degrees, a rise of 20 degrees is necessary. So the problem resolves itself into the following: What amount of heating surface having an

TABLE XXIV

Air-Flow through Flues of Various Heights under Varying Conditions of Temperature

(Volumes given in cubic feet per square foot of sectional area of flue)

Height of Flue in Feet	Excess of Temperature of Air in Flue Above that of External Air					
	5°	10°	15°	20°	30°	50°
5	55	76	94	109	134	167
10	77	108	133	153	188	242
15	94	133	162	188	230	297
20	108	153	188	217	265	342
25	121	171	210	242	297	383
30	133	188	230	265	325	419
35	143	203	248	286	351	453
40	153	217	265	306	375	484
45	162	230	282	325	398	514
50	171	242	297	342	419	541
60	188	264	325	373	461	594

efficiency of 400 B. T. U. is necessary to raise 1,300 cubic feet of air per minute through 20 degrees?

1,300 cubic feet per minute = 1,300 × 60 = 78,000 per hour; and making use of our formula for "heat for ventilation," we have

$$\frac{78{,}000 \times 20}{55} = 28{,}363 \text{ B. T. U.};$$

and this divided by 400 = 71 square feet of heating surface required.

EXAMPLES FOR PRACTICE

1. A schoolroom on the third floor has 50 pupils, who are to be furnished with 30 cubic feet of air per minute each. What will be the required areas in square feet of the supply and vent flues?

Ans. Supply, 3.7 +. Vent, 6.8 +.

2. What size of heater will be required in a vent flue 40 feet high and with an area of 5 square feet, to enable it to discharge 1,530 cubic feet per minute, when the outside temperature is 60°? (Assume an efficiency of 400 B. T. U. for the heater.) Ans. 41.7 square feet.

Registers. Registers are made of cast iron and bronze, in a great variety of sizes and patterns. The almost universal finish for cast-iron registers is black "Japan;" but they are also finished in colors and electroplated with copper and nickel. Fig. 70 shows a section through a floor register, in which *A* represents the valves, which may be turned in a vertical or horizontal position, thus opening or closing the register; *B* is the iron border; *C*, the register box of tin or galvanized iron; and *D*, the warm-air pipe. Floor registers are usually set in cast-iron borders, one of which is shown in Fig. 71; while wall registers may be screwed directly to wooden borders or frames to correspond with the finish of the room. Wall registers should be provided with pull-cords for opening and closing from the floor; these are shown in Fig. 72. The plain lattice pattern shown in Fig. 73 is the best for schoolhouse work, as it has a comparatively free opening for air-flow and is pleasing and simple in design. More elaborate patterns are used for fine dwelling-house work. Registers with shut-off valves are used for air-inlets, while the plain register faces without the valves are placed in the vent openings. The vent flues are usually gathered together in the attic, and a single damper may be used to shut off the whole number at once. Flat or round wire gratings of open pattern are often used in place of

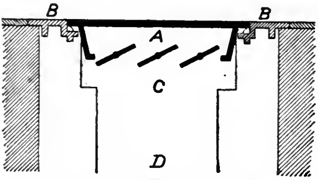


Fig. 70. Section through a Floor Register.

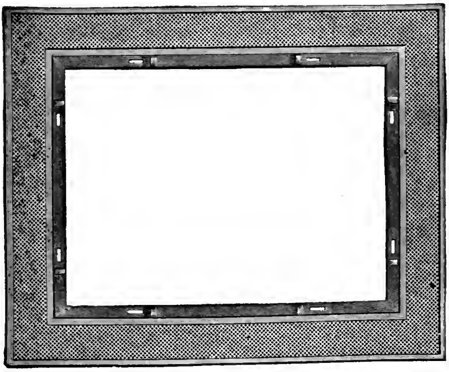


Fig. 71. Cast-Iron Border for a Floor Register.

register faces. The grill or solid part of a register face usually takes up about $\frac{1}{3}$ of the area; hence in computing the size, we must allow for this by multiplying the required "net area" by 1.5, to obtain the "total" or "over-all" area.

Example. Suppose we have a flue 10 inches in width and wish to use a register having a free area of 200 square inches. What will be the required height of the register?

$200 \times 1.5 = 300$ square inches, which is the total area required; then $300 \div 10 = 30$, which is the required height, and we should use a 10 by 30-inch register. When a register is spoken of as a 10 by

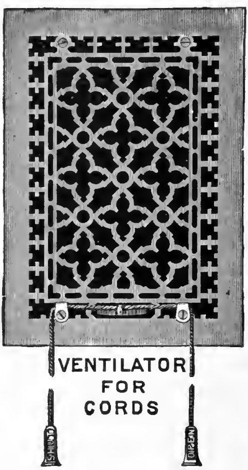


Fig. 72. Wall Register with Pull Cords for Opening and Closing.

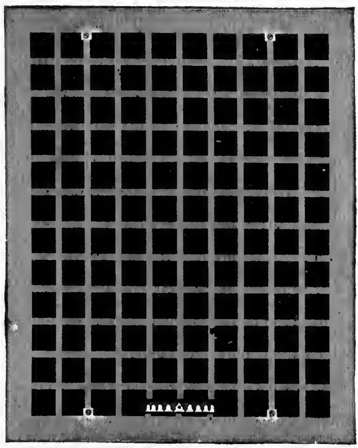


Fig. 73. Plain Lattice Pattern Register. Best for Schoolhouse Work.

30-inch or a 10 by 20-inch, etc., the dimensions of the latticed opening are meant, and not the outside dimensions of the whole register. The free opening should have the same area as the flue with which it connects. In designing new work, one should provide himself with a trade catalogue, and use only standard sizes, as special patterns and sizes are costly. Fig. 74 shows the method of placing gossamer check-valves back of the vent register faces to prevent down drafts, the same as described for fresh-air inlets.

Inlet registers in dwelling-house and similar work are placed either in the floor or in the baseboard; sometimes they are located under the windows, just above the baseboard. The object in view is to place them where the currents of air entering the room will not be objectionable to persons sitting near windows. A long, narrow floor-register placed close to the wall in front of a window, sends up a shallow current of warm air, which is not especially noticeable

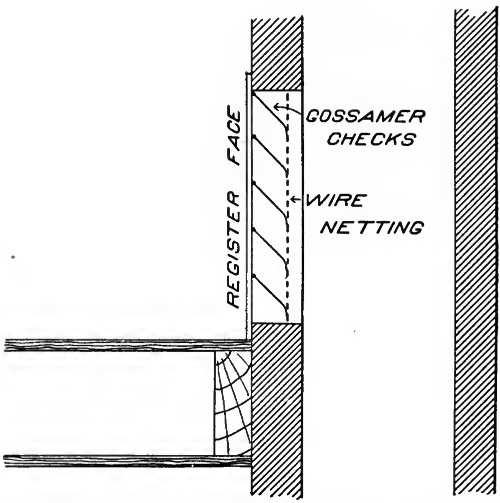


Fig. 74. Method of Placing Gossamer Check-Valves back of Vent Register Face to Prevent Down Drafts.

to one sitting near it. Inlet registers are preferably placed near outside walls, especially in large rooms. Vent registers should be placed in inside walls, near the floor.

Pipe Connections. The two-pipe system with dry or sealed returns is used in indirect heating. The conditions to be met are practically the same as in direct heating, the only difference being that the radiators are at the basement ceiling instead of on the floors above. The exact method of making the pipe connections will depend somewhat upon existing conditions; but the general method shown in Fig. 75 may be used as a guide, with modifications to suit any special case. The ends of all supply mains should be dripped, and the horizontal returns should be sealed if possible.

Pipe Sizes. The tables already given for the proportioning of pipe sizes can be used for indirect systems. The following table has been computed for an efficiency of 640 B. T. U. per square foot of surface per hour, which corresponds to a condensation of $\frac{2}{3}$ of a pound of steam. This is twice that allowed for direct radiation in Table

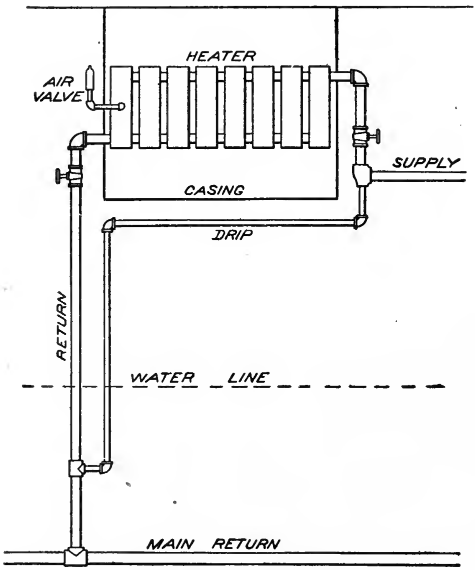


Fig. 75. General Method of Making Pipe and Radiator Connections, in Basement, in Indirect Heating.

XVII; so that we can consider 1 square foot of indirect surface as equal to 2 of direct in computing pipe sizes.

As the indirect heaters are placed in the basement, care must be taken that the bottom of the radiator does not come too near the water-line of the boiler, or the condensation will not flow back properly; this distance, under ordinary conditions, should not be less than 2 feet. If much less than this, the pipes should be made extra large, so that there may be little or no drop in pressure between the boiler

TABLE XXV

Indirect Radiating Surface Supplied by Pipes of Various Sizes

Size of Pipe	Square Feet of Indirect Radiation which will be Supplied with		
	¼ Pound Drop in 200 Feet	¼ Pound Drop in 100 Feet	½ Pound Drop in 100 Feet
1 in.	28	40	57
1¼ "	51	72	105
1½ "	67	95	170
2 "	185	262	375
2½ "	335	475	675
3 "	540	775	1,105
3½ "	812	1,160	1,645
4 "	1,140	1,625	2,310
5 "	2,030	2,900	4,110
6 "	3,260	4,660	6,600
7 "	4,830	6,900	9,810
8 "	6,800	9,720	13,860

and the heater. A drop in pressure of 1 pound would raise the water-line at the heater 2.4 feet.

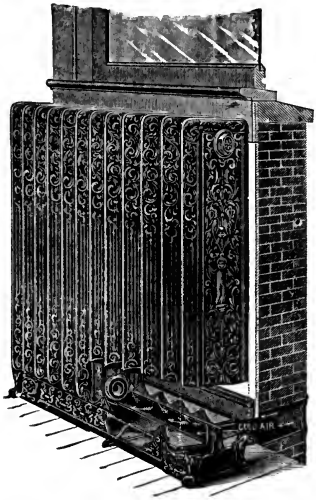


Fig. 76. General Form of Direct-Indirect Radiator.

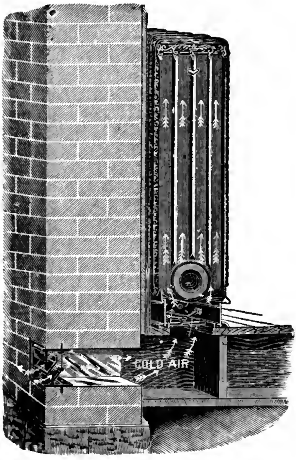


Fig. 77. Section through Radiator Shown in Fig. 76.

Direct-Indirect Radiators. A direct-indirect radiator is similar in form to a direct radiator, and is placed in a room in the same manner. Fig. 76 shows the general form of this type of radiator; and Fig. 77 shows a section through the same. The shape of the sections is such, that when in place, small flues are formed between them. Air is admitted through an opening in the outside wall; and, in passing upward through these flues, becomes heated before entering the room. A switch-damper is placed in the duct at the base of the radiator, so that the air may be taken from the room itself instead of from out of doors, if so desired. This is shown more particularly in Fig. 76.

Fig. 78 shows the wall box provided with louvre slats and netting, through which the air is drawn. A damper door is placed at either end of the radiator base; and, if desired, when the cold-air supply is shut off by means of the register in the air-duct, the radiator can be converted into the ordinary type by opening both damper doors, thus taking the air from the room instead of from the outside. It is customary to increase the size of a direct-indirect radiator 30 per cent above that called for in the case of direct heating.

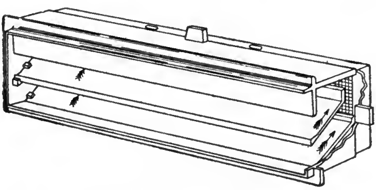


Fig. 78. Wall Box with Louvre Slats and Netting, Direct-Indirect System.

CARE AND MANAGEMENT OF STEAM-HEATING BOILERS

Special directions are usually supplied by the maker for each kind of boiler, or for those which are to be managed in any peculiar way. The following general directions apply to all makes, and may be used regardless of the type of boiler employed:

Before starting the fire, see that the boiler contains sufficient water. The water-line should be at about the center of the gauge-glass.

The smoke-pipe and chimney flue should be clean, and the draft good.

Build the fire in the usual way, using a quality of coal which is best adapted to the heater. In operating the fire, keep the firepot full of coal, and shake down and remove all ashes and cinders as often as the state of the fire requires it.

Hot ashes or cinders must not be allowed to remain in the ashpit under the grate-bars, but must be removed at regular intervals to prevent burning out the grate.

To control the fire, see that the damper regulator is properly attached to the draft doors and the damper; then regulate the draft by weighting the automatic lever as may be required to obtain the necessary steam pressure for warming. Should the water in the boiler escape by means of a broken gauge-glass, or from any other cause, the fire should be dumped, and the boiler allowed to cool before adding cold water.

An empty boiler should never be filled when hot. If the water gets low at any time, but still shows in the gauge-glass, more water should be added by the means provided for this purpose.

The safety-valve should be lifted occasionally to see that it is in working order.

If the boiler is used in connection with a gravity system, it should be cleaned each year by filling with pure water and emptying through the blow-off. If it should become foul or dirty, it can be thoroughly cleansed by adding a few pounds of caustic soda, and allowing it to stand for a day, and then emptying and thoroughly rinsing.

During the summer months, it is recommended that the water be drawn off from the system, and that air-valves and safety-valves be opened to permit the heater to dry out and to remain so. Good results, however, are obtained by filling the heater full of water, driving off the air by boiling slowly, and allowing it to remain in this condition until needed in the fall. The water should then be drawn off and fresh water added.

The heating surface of the boiler should be kept clean and free from ashes and soot by means of a brush made especially for this purpose.

Should any of the rooms fail to heat, examine the steam valves in the radiators. If a two-pipe system, both valves at each radiator must be opened or closed at the same time, as required. See that the air-valves are in working condition.

If the building is to be unoccupied in cold weather, draw all the water out of the system by opening the blow-off pipe at the boiler and all steam valves and air-valves at the radiators.

HOT-WATER HEATERS

Types. Hot-water heaters differ from steam boilers principally in the omission of the reservoir or space for steam above the heating surface. The steam boiler might answer as a heater for hot water; but the large capacity left for the steam would tend to make its operation slow and rather unsatisfactory, although the same type of boiler is sometimes used for both steam and hot water. The passages in a hot-water heater need not extend so directly from bottom to top as in a steam boiler, since the problem of providing for the free liberation of the steam bubbles does not have to be considered. In general, the heat from the furnace should strike the surfaces in such a manner as to increase the natural circulation; this may be accomplished to a certain extent by arranging the heating surface so that a large proportion of the direct heat will be absorbed near the top of the heater.

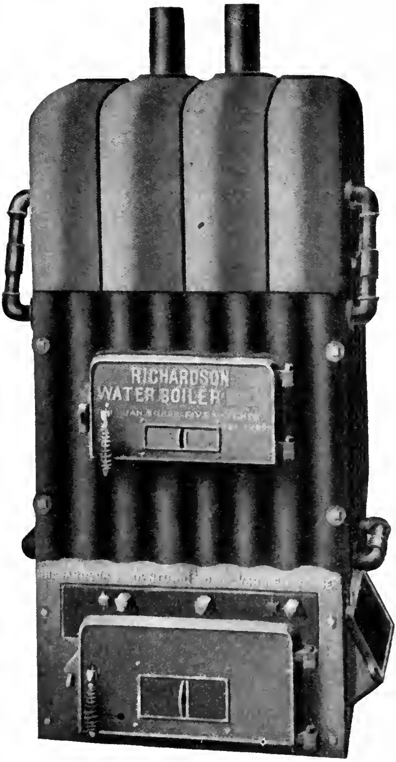
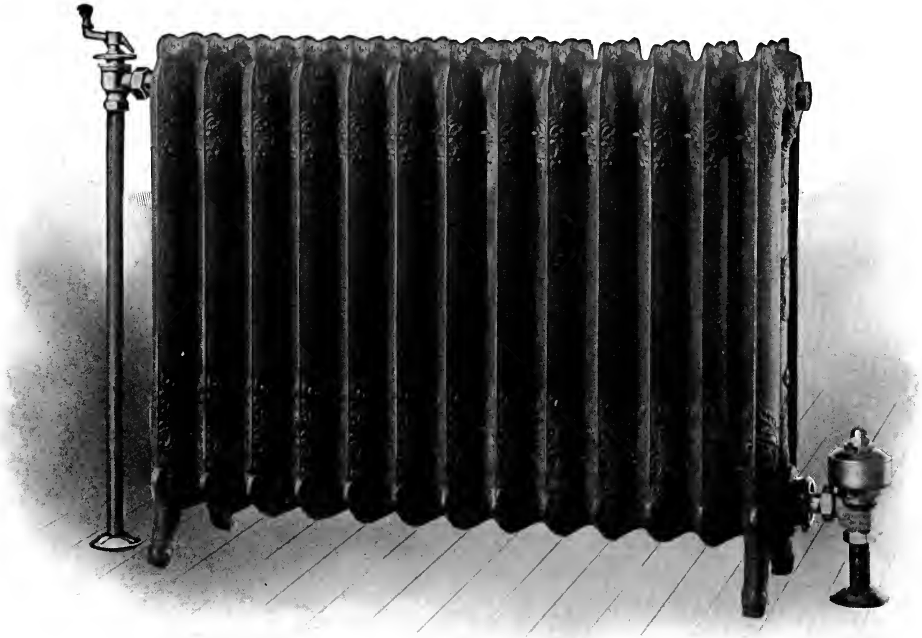


Fig. 79. Richardson Sectional Hot-Water Heater.

Practically the boilers for low-pressure steam and for hot water differ from each other very little as to the character of the heating surface, so that the methods already given for computing the size of grate surface, horse-power, etc., under the head of "Steam Boilers," can be



THE THERMOGRADE SEMI-AUTOMATIC SYSTEM OF HEATING
Showing a Thermograde Valve as Applied to Radiator

used with satisfactory results in the case of hot-water heaters.

It is sometimes stated that, owing to the greater difference in temperature between the furnace gases and the water in a hot-water heater, as compared with steam, the heating surface will be more efficient and a smaller heater can be used. While this is true to a certain extent, different authorities agree that this advantage is so small that no account should be taken of it, and the general proportions of the heater should be calculated in the same manner as for steam. Fig. 79 shows a form of hot-water heater made up of slabs or sections similar to the sectional steam boiler shown in Part I. The size can be increased in a similar manner, by adding more sections. In this case, however, the boiler is increased in width instead of in length. This has an advantage in the larger sizes, as a second fire door can be added, and all parts of the grate can be reached as well in the large sizes as in the small.

Fig. 80 shows a different form of sectional boiler, in which the sections are placed one above another. These boilers are circular in form and well adapted to dwelling-houses and similar work.

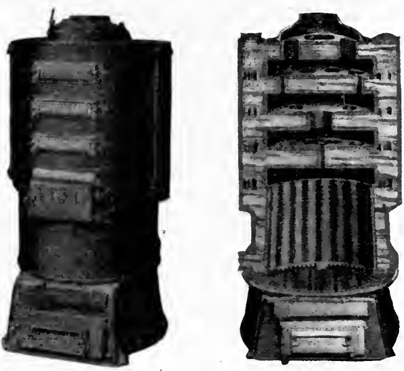


Fig. 80. "Invincible" Boiler, with Sections Superposed.
Courtesy of American Radiator Co.

Fig. 81 shows another type of cast-iron heater which is not made in sections. The space between the outer and inner shells surrounding the furnace is filled with water, and also the cross-pipes directly over the fire and the drum at the top. The supply to the radiators is taken off from the top of the heater, and the return connects at the lowest point.

The ordinary horizontal and vertical tubular boilers, with various modifications, are used to a considerable extent for hot-water heating, and are well adapted to this class of work, especially in the case of large buildings.

Automatic regulators are often used for the purpose of maintaining a constant temperature of the water. They are constructed in different ways—some depend upon the expansion of a metal pipe or rod at different temperatures, and others upon the vaporization and consequent pressure of certain volatile liquids. These means are usually employed to open small valves which admit water-pressure under rubber diaphragms; and these in turn are connected by means of chains with the draft doors of the furnace, and so regulate the draft as required to maintain an even temperature of the water in the heater. Fig. 82 shows one of the first kind. *A* is a metal rod placed in the flow pipe from the heater, and is so connected with the valve *B* that when the water reaches a certain temperature the expansion of the rod opens the valve and admits water from the street pressure through the pipes *C* and *D* into the chamber *E*. The bottom of *E* consists of a rubber diaphragm, which is forced down by the water-pressure and carries with it the lever which operates the dampers as shown, and checks the fire. When the temperature of the water drops, the rod contracts and valve *B* closes, shutting off the pressure from the chamber *E*. A spring is provided to throw the lever back to its original position.

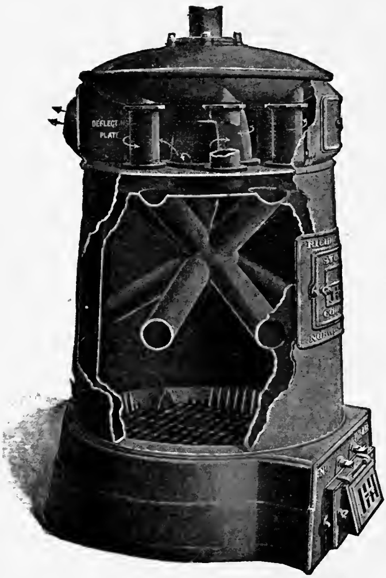


Fig. 81. Cast-Iron Heater Not Made in Sections. Water Fills Cross-Pipes and Space between Outer and Inner Shells.

and the water above the diaphragm is forced out through the pet-cock *G*, which is kept slightly open all the time.

DIRECT HOT-WATER HEATING

A hot-water system is similar in construction and operation to one designed for steam, except that *hot water* flows through the pipes and radiators instead.

The circulation through the pipes is produced solely by the difference in weight of the water in the supply and return, due to the difference in temperature. When water is heated it expands, and thus a given volume becomes lighter and tends to rise, and the cooler water flows in to take its place; if the application of heat is kept up, the circulation thus produced is continuous. The velocity of flow depends upon the difference in temperature between the supply and return, and the height of the radiator above the boiler. The horizontal distance of the radiator from the boiler is also an important factor affecting the velocity of flow.

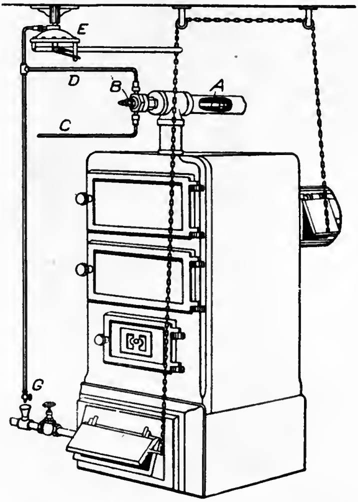


Fig. 82. Hot-Water Heater with Automatic Regulator Operated through Expansion and Contraction of Metal Rod in Flow Pipe.

This action is best shown by means of a diagram, as in Fig. 83. If a glass tube of the form shown in the figure is filled with water and held in a vertical position, no movement of the water will be noticed, because the two columns *A* and *B* are of the same weight, and therefore in equilibrium. Now, if a lamp flame be held near the tube *A*, the small bubbles of steam which are formed will show the water to be in motion, with a current flowing in the direction indicated by the arrows. The reason for this is, that, as the water in *A* is heated it expands and becomes lighter for a given volume, and is forced upward by the heavier water in *B* falling to the bottom of the tube. The heated water flows from *A* through the connecting tube at the top, into *B*, where it takes the place of the cooler water which is settling to the bottom. If, now, the lamp be replaced by a furnace, and the columns *A* and *B* be connected at the top by inserting a radiator, the illustration will assume the practical form as utilized in hot-water heating (see Fig. 84).

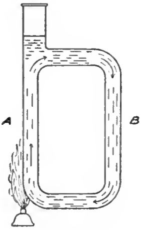


Fig. 83. Illustrating How the Heating of Water Causes Circulation.

The heat given off by the radiator always insures a difference in temperature between the columns of water in the supply and return pipes, so that as long as heat is supplied by the furnace the flow of water will continue. The greater the difference in temperature of the water in the two pipes, the greater the difference in weight, and consequently the faster the flow. The greater the height of the radiator above the heater, the more rapid will be the circulation, because the total difference in weight between the water in the supply and return risers will vary directly with their height. From the above it is evident that the rapidity of flow depends chiefly upon the *temperature* difference between the supply and return, and upon the *height of the radiator* above the heater. Another factor which must be considered in long runs of horizontal pipe is the *frictional resistance*.

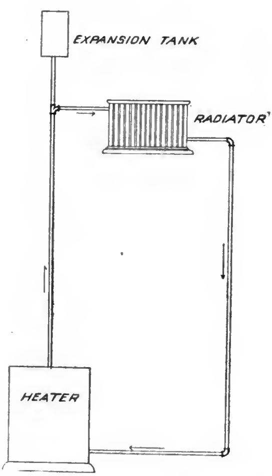


Fig. 84. Illustrating Simple Circulation in a Heating System.

Systems of Circulation. There are two distinct systems of circulation employed—one depending on the difference in temperature of the water in the supply and return pipes, called *gravity circulation*;

and another where a pump is used to force the water through the mains, called *forced circulation*. The former is used for dwellings and other buildings of ordinary size, and the latter for large buildings, and especially where there are long horizontal runs of pipe.

For gravity circulation some form of sectional cast-iron boiler is commonly used, although wrought-iron tubular boilers may be employed if desired. In the case of forced circulation, a heater designed to warm the water by means of live or exhaust steam is often used. A centrifugal or rotary pump is best adapted to this purpose, and may be driven by an electric motor or a steam engine, as most convenient.

Types of Radiating Surface. Cast-iron radiators and circulation coils are used for hot water as well as for steam. Hot-water radiators differ from steam radiators principally in having a horizontal passage at the top as well as at the bottom. This construction is necessary in order to draw off the air which gathers at the top of each loop or section. Otherwise they are the same as steam radiators, and are well adapted for the circulation of steam, and in some respects are superior to the ordinary pattern of steam radiator.

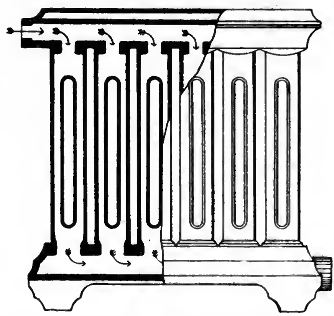


Fig. 85. Showing Construction of Radiator for Hot Water or Steam. Note Horizontal Passage along Top.

The form shown in Fig. 85 is made with an opening at the top for the entrance of water, and at the bottom for its discharge, thus insuring a supply of hot water at the top and of colder water at the bottom.

Some hot-water radiators are made with a cross-partition so arranged that all water entering passes at once to the top, from which it may take any passage toward the outlet. Fig. 86 is the more common form of radiator, and is made with continuous passages at top and bottom, the hot water being supplied at one side and drawn off at the other. The action of gravity is depended upon for making the hot and lighter water pass to the top, and the colder water sink to the bottom and flow off through the return. Hot-water radiators are usually tapped and plugged so that the pipe connections can be made either at the top or at the bottom. This is shown in Fig. 87.

Wall radiators are adapted to hot-water as well as steam heating.

Efficiency of Radiators. The efficiency of a hot-water radiator depends entirely upon the temperature at which the water is circulated. The best practical results are obtained with the water leaving the boiler at a maximum temperature of about 180 degrees in zero weather and returning at about 160 degrees; this gives an average

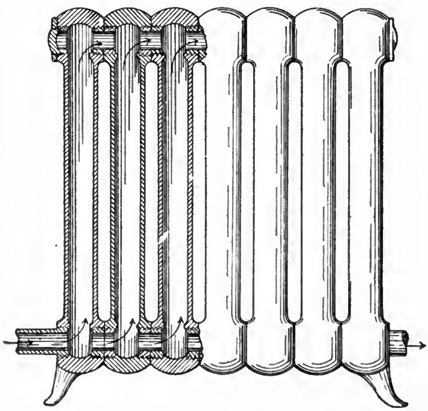


Fig. 86. Common Form of Hot-Water Radiator. Circulation Produced Wholly through Action of Gravity, Hot Water Rising to Top.

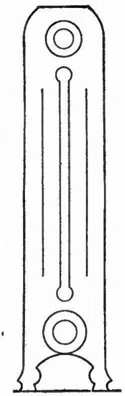


Fig. 87. End Elevation of Radiator Showing Taps at Top and Bottom for Pipe Connections.

temperature of 170 degrees in the radiators. Variations may be made, however, to suit the existing conditions of outside temperature. We have seen that an average cast-iron radiator gives off about 1.7 B.T.U. per hour per square foot of surface per degree difference in temperature between the radiator and the surrounding air, when working under ordinary conditions; and this holds true whether it is filled with steam or water.

If we assume an average temperature of 170 degrees for the water. then the difference in temperature between the radiator and the air will be 170 — 70 = 100 degrees; and this multiplied by 1.7 =

170, which may be taken as the efficiency of a hot-water radiator under the above average conditions.

This calls for a water radiator about 1.5 times as large as a steam radiator to heat a given room under the same conditions. This is common practice although some engineers multiply by the factor 1.6, which allows for a lower temperature of the water. Water leaving the boiler at 170 degrees should return at about 150; the drop in temperature should not ordinarily exceed 20 degrees.

Systems of Piping. A system of hot-water heating should produce a perfect circulation of water from the heater to the radiating

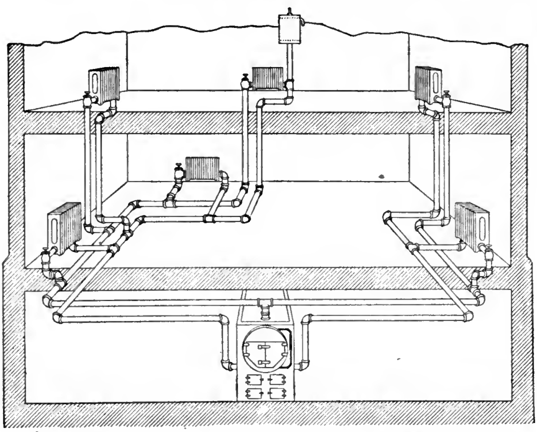


Fig. 88. System of Piping Usually Employed for Hot-Water Heating.

surface, and thence back to the heater through the returns. The system of piping usually employed for hot-water heating is shown in Fig. 88. In this arrangement the main and branches have an inclination upward from the heater; the returns are parallel to the mains, and have an inclination downward toward the heater, connecting with it at the lowest point. The flow pipes or risers are taken from the tops of the mains, and may supply one or more radiators as required. The return risers or drops are connected with the return mains in a similar manner. In this system great care must be taken to produce a nearly equal resistance to flow in all of the branches, so that each radiator may receive its full supply of water. It will always be found that the principal current of heated water will take the path of least resistance, and that a small obstruction or irregularity in the piping is sufficient to interfere greatly with the amount of heat received in the different parts of the same system.

Some engineers prefer to carry a single supply main around the building, of sufficient size to supply all the radiators, bringing back a single return of the same size. Practice has shown that in general it is not well to use pipes over 8 or 10 inches in diameter; if larger pipes are required, it is better to run two or more branches.

The boiler, if possible, should be centrally located, and branches carried to different parts of the building. This insures a more even circulation than if all the radiators are supplied from a single long main, in which case the circulation is liable to be sluggish at the farther end.

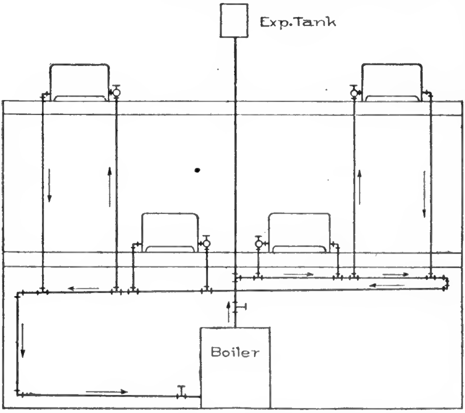


Fig. 89. System of Hot-Water Piping Especially Adapted to Apartment Buildings where Each Flat Has a Separate Heater.

The arrangement shown in Fig. 89 is similar to the circuit system for steam, except that the radiators have two connections instead of one. This method is especially adapted to apartment houses, where each flat has its separate heater, as it eliminates a separate return main, and thus reduces, by practically one-half, the amount of piping in the basement. The supply risers are taken from the top of the main; while the returns should connect into the side a short distance beyond, and in a direction *away* from the boiler. When this system is used, it is necessary to enlarge the radiators slightly as the distance from the boiler increases.

In flats of eight or ten rooms, the size of the last radiator may be increased from 10 to 15 per cent, and the intermediate ones proportionally, at the same time keeping the main of a large and uniform size for the entire circuit.

Overhead Distribution. This system of piping is shown in Fig. 90. A single riser is carried directly to the expansion tank, from which branches are taken to supply the various drops to which the radiators are connected. An important advantage in connection with this system is that the air rises at once to the expansion tank, and escapes through the vent, so that air-valves are not required on the radiators.

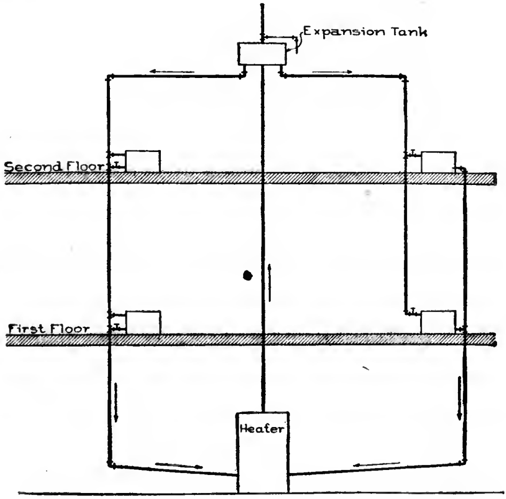


Fig. 90. "Overhead" Distribution System of Hot-Water Piping.

At the same time, it has the disadvantage that the water in the tank is under less pressure than in the heater; hence it will boil at a lower temperature. No trouble will be experienced from this, however, unless the temperature of the water is raised above 212 degrees.

Expansion Tank. Every system for hot-water heating should be connected with an expansion tank placed at a point somewhat above the highest radiator. The tank must in every case be connected to a line of piping which cannot by any possible means be shut off from the boiler. When water is heated, it expands a certain amount, depending upon the temperature to which it is raised; and a tank or reservoir should always be provided to care for this increase in volume.

Expansion tanks are usually made of heavy galvanized iron of one of the forms shown in Figs. 91 and 92, the latter form being used where the headroom is limited. The connection from the heating system enters the bottom of the tank, and an open vent pipe is taken from the top. An overflow connected with a sink or drain-pipe should be provided. Connections should be made with the water supply both at the boiler and at the expansion tank, the former to be used when first filling the system, as by this means all air is driven from the bottom upward and is discharged through the vent at the expansion tank. Water that is added afterward may be supplied directly to the expansion tank, where the water-line can be noted in the gauge-glass. A ball-cock is sometimes arranged to keep the water-line in the tank at a constant level.

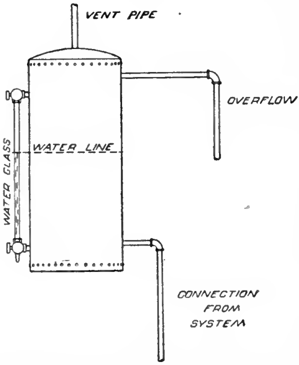


Fig. 91. A Common Form of Galvanized-Iron Expansion Tank.

An *altitude gauge* is often placed in the basement with the colored hand or pointer set to indicate the normal water-line in the expansion tank. When the movable hand falls below the fixed one, more water may be added, as required, through the supply pipe at the boiler. When the tank is placed in an attic or roof space where there is danger of freezing, the expansion pipe may be connected into the side of the

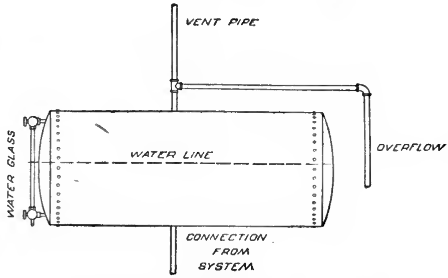


Fig. 92. Form of Expansion Tank Used where Headroom is Limited.

tank, 6 or 8 inches from the bottom, and a circulation pipe taken from the lower part and connected with the return from an upper-floor radiator. This produces a slow circulation through the tank, and keeps the water warm.

The size of the expansion tank depends upon the volume of water contained in the system, and on the temperature to which it is heated. The following rule for computing the capacity of the tank may be used with satisfactory results:

Square feet of radiation, *divided by* 40, equals required capacity of tank in gallons.

Air-Venting. One very important point to be kept in mind in the design of a hot-water system, is the removal of air from the pipes and radiators. When the water in the boiler is heated, the air it contains forms into small bubbles which rise to the highest points of the system.

In the arrangement shown in Fig. 88, the main and branches grade upward from the boiler, so that the air finds its way into the radiators, from which it may be drawn off by means of the air-valves.

A better plan is that shown in Fig. 89. In this case the expansion pipe is taken directly off the top of the main over the boiler, so that the larger part of the air rises directly to the expansion tank and escapes through the vent pipe. The same action takes place in the overhead system shown in Fig. 90, where the top of the main riser is connected with the tank. Every high point in the system and every radiator, except in the downward system with top supply connection, should be provided with an air-valve.

Pipe Connections. There are various methods of connecting the radiators with the mains and risers. Fig. 93 shows a radiator connected with the horizontal flow and return mains, which are located below the floor. The manner of connecting with a vertical riser and return drop is shown in Fig. 94. As the water tends to flow to the highest point, the radiators on the lower floors should be favored by making the connection at the top of the riser and taking the pipe for the upper floors from the side as shown. Fig. 95 illustrates the manner of connecting with a radiator on an upper floor where the supply is connected at the top of the radiator.

The connections shown in Figs. 96 and 97 are used with the overhead system shown in Fig. 90.

Where the connection is of the form shown at the left in Fig. 90, the cooler water from the radiators is discharged into the supply pipe again, so that the water furnished to the radiators on the lower floors is at a lower temperature, and the amount of heating surface must be correspondingly increased to make up for this loss, as already described for the circuit system.

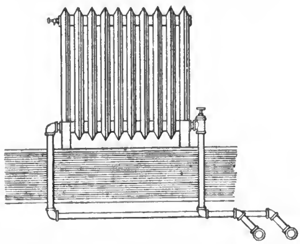


Fig. 93. Radiator Connected with Horizontal Flow and Return Mains Located below Floor.

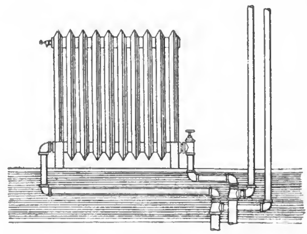


Fig. 94. Radiator Connected to Vertical Riser and Return Drop.

For example, if in the case of Fig. 90 we assume the water to leave at 180 degrees and return at 160, we shall have a drop in temperature of 10 degrees on each floor; that is, the water will enter the radiator on the second floor at 180 degrees and leave it at 170, and will enter the radiator on the first floor at 170 and leave it at 160.

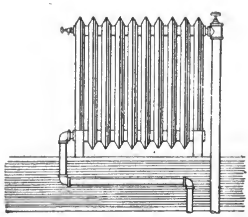


Fig. 95. Upper-Floor Radiator with Supply Connected at Top.

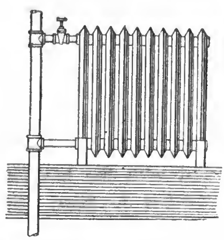


Fig 96. Radiator Connections, Overhead Distribution System.

The average temperatures will be 175 and 165, respectively. The efficiency in the first case will be 175 — 70 = 105; and 105 × 1.5 = 157. In the second case, 165 — 70 = 95; and 95 × 1.5 = 142; so that the radiator on the first floor will have to be larger than that on the second floor in the ratio of 157 to 142, in order to do the same work.

This is approximately an increase of 10 per cent for each story downward to offset the cooling effect; but in practice the supply drops are made of such size that only a part of the water is by-passed through the radiators. For this reason an increase of 5 per cent for each story downward is probably sufficient in ordinary cases.

Where the radiators discharge into a separate return as in the case of Fig. 88, or those at the right in Fig. 90, we may assume the temperature of the water to be the same on all floors, and give the radiators an equal efficiency.

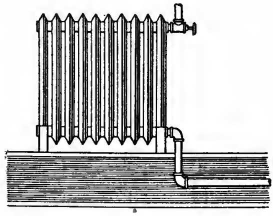


Fig. 97. Another Form of Radiator Connection, Overhead Distribution System.

In a dwelling-house of two stories, no difference would be made in the sizes of radiators on the two floors; but in the case of a tall office building, corrections would necessarily be made as above described.

Where circulation coils are used, they should be of a form which will tend to produce a flow of water through them. Figs. 98, 99, and 100 show different ways of making up and connecting these coils. In Figs. 98 and 100, supply pipes may be either drops or risers; and

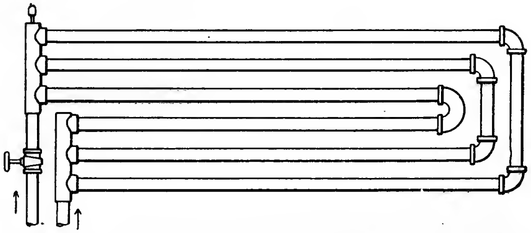


Fig. 98. Circulation Coil, One Method of Construction. Supply Pipes may be Either Drops or Risers.

in the former case the return in Fig. 100 may be carried back, if desired, into the supply drop, as shown by the dotted lines.

Combination Systems. Sometimes the boiler and piping are arranged for either steam or hot water, since the demand for a higher or lower temperature of the radiators might change.

The object of this arrangement is to secure the advantages of a hot-water system for moderate temperatures, and of steam heating for extremely cold weather.

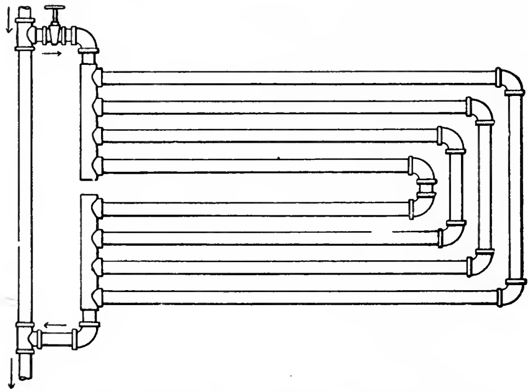


Fig. 99. Another Method of Building Up a Circulation Coil.

As less radiating surface is required for steam heating, there is an advantage due to the reduction in first cost. This is of considerable importance, as a heating system must be designed of such dimensions as to be capable of warming a building in the coldest weather;

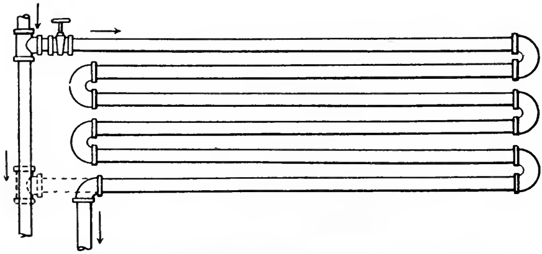


Fig. 100. Circulation Coil with Either Drop or Riser Supply. In former case, return may be carried into Supply Drop as shown by Dotted Lines.

and this involves the expenditure of a considerable amount for radiating surfaces, which are needed only at rare intervals. A combination system of hot-water and steam heating requires, *first,* a heater or boiler which will answer for either purpose; *second,* a system of piping which will permit the circulation of either steam or hot water; and *third,* the use of radiators which are adapted to both kinds of heating. These requirements will be met by using a steam boiler provided with all the fittings required for steam heating, but so arranged that the damper regulator may be closed by means of valves when the system is to be used for hot-water heating. The addition of an expansion tank is required, which must be so arranged that it can be shut off when the system is used for steam heating. The system of piping shown in Fig. 88 is best adapted for a combination system, although an overhead distribution as shown in Fig. 90 may be used by shutting off the vent and overflow pipes, and placing air-valves on the radiators.

While this system has many advantages in the way of cost over the complete hot-water system, the labor of changing from steam to hot water will in some cases be troublesome; and should the connections to the expansion tank not be opened, serious results would follow.

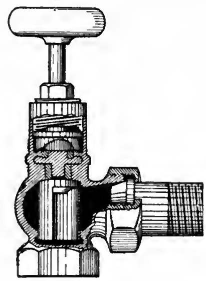


Fig. 101. Radiator Valve for Hot-Water Work.

Valves and Fittings. Gate-valves should always be used in connection with hot-water piping, although angle-valves may be used at the radiators. There are several patterns of radiator valves made especially for hot-water work; their chief advantage lies in a device for quick closing, usually a quarter-turn or half-turn being sufficient to open or close the valve. Two different designs are shown in Figs. 101 and 102.

It is customary to place a valve in only one connection, as that is sufficient to stop the flow of water through the radiator; a fitting known as a *union elbow* is often employed in place of the second valve. (See Fig. 103.)

Air-Valves. The ordinary pet-cock air-valve is the most reliable for hot-water radiators, although there are several forms of automatic valves which are claimed to give satisfaction. One of these is shown in Fig. 104. This is similar in construction to a steam trap. As air collects in the chamber, and the water-line is lowered, the float drops, and in so doing opens a small valve at the top of the chamber, which allows the air to escape. As the water flows in to take its place, the float is forced upward and the valve is closed.

All radiators which are supplied by risers from below, should be provided with air-valves placed in the top of the last section at the return end. If they are supplied by drops from an over-

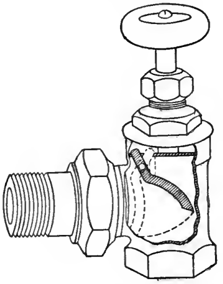


Fig. 102. Another Type of Hot-Water Radiator Valve.

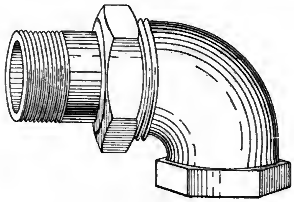


Fig. 103. Union Elbow.

head system, the air will be discharged at the expansion tank, and air-valves will not be necessary at the radiators.

Fittings. All fittings, such as elbows, tees, etc., should be of the *long-turn* pattern. If the common form is used, they should be a size larger than the pipe, bushed down to the proper size. The long-turn fittings, however, are preferable, and give a much better appearance. Connections between the radiators and risers may be made with the ordinary short-pattern fittings, as those of the other form are not well adapted to the close connections necessary for this work.

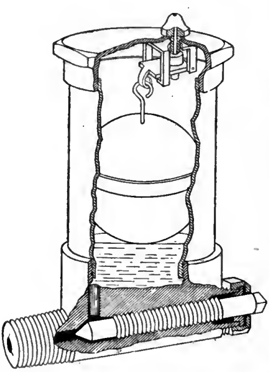
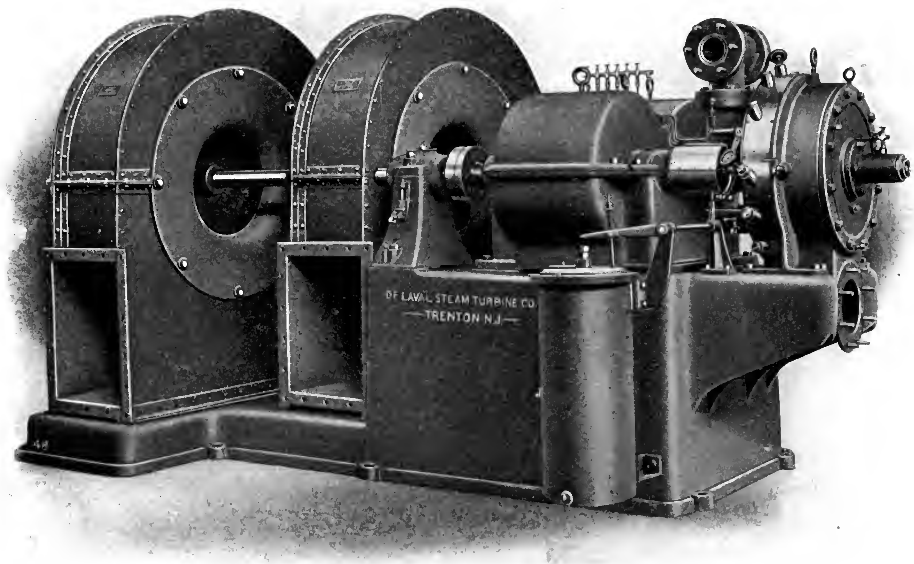


Fig. 104. Automatic Air-Valve for Hot-Water Radiator. Operated by a Float.

Pipe Sizes. The size of pipe required to supply any given radiator depends upon four conditions; *first*, the size of the radiator; *second*, its elevation above the boiler; *third*, the length of pipe required to connect it with the boiler; and *fourth*, the difference in temperature between the supply and the return



150 H.P. DE LAVAL TURBINE BLOWER.

As it would be a long and rather complicated process to work out the required size of each pipe for a heating system, Tables XXVI and XXVII have been prepared, covering the usual conditions to be met with in practice.

TABLE XXVI

Direct Radiating Surface Supplied by Mains of Different Sizes and Lengths of Run

Size of Pipe	Square Feet of Radiating Surface								
	100 ft. Run	200 ft. Run	300 ft. Run	400 ft. Run	500 ft. Run	600 ft Run	700 ft. Run	800 ft. Run	1,000 ft. Run
1 in.	30								
1¼ "	60	50							
1½ "	100	75	50						
2 "	200	150	125	100	75				
2½ "	350	250	200	175	150	125			
3 "	550	400	300	275	250	225	200	175	150
3½ "	850	600	450	400	350	325	300	250	225
4 "	1,200	850	700	600	525	475	450	400	350
5 "		1,400	1,150	1,000	700	850	775	725	650
6 "				1,600	1,400	1,300	1,200	1,150	1,000
7 "							1,706	1,600	1,500

These quantities have been calculated on a basis of 10 feet difference in elevation between the center of the heater and the radiators, and a difference in temperature of 17 degrees between the supply and the return.

TABLE XXVII

Radiating Surface on Different Floors Supplied by Pipes of Different Sizes

Size of Riser	Square Feet of Radiating Surface					
	1st Story	2d Story	3d Story	4th Story	5th Story	6th Story
1 in.	30	55	65	75	85	95
1¼ "	60	90	110	125	140	160
1½ "	100	140	165	185	210	240
2 "	200	275	375	425	500	
2½ "	350	475				
3 "	550					
3½ "	850					

Table XXVI gives the number of square feet of direct radiation which different sizes of mains and branches will supply for varying lengths of run.

Table XXVI may be used for all horizontal mains. For vertical risers or drops, Table XXVII may be used. This has been computed for the same difference in temperature as in the case of Table XXVI (17 degrees), and gives the square feet of surface which different sizes of pipe will supply on the different floors of a building, assuming the height of the stories to be 10 feet. Where a single riser is carried to the top of a building to supply the radiators on the floors below, by drop pipes, we must first get what is called the *average elevation of the system* before taking its size from the table. This may be illustrated by means of a diagram (see Fig. 105).

In *A* we have a riser carried to the third story, and from there a drop brought down to supply a radiator on the first floor. The elevation available for producing a flow in the riser is only 10 feet, the same as though it extended only to the radiator. The water in the two pipes above the radiator is practically at the same temperature, and therefore in equilibrium, and has no effect on the flow of the water in the riser. (Actually there would be some radiation from the pipes, and the return, above the radiator, would be slightly cooler, but for purposes of illustration this may be neglected). If the radiator was on the second floor the elevation of the system would be 20 feet (see *B*); and on the third floor, 30 feet; and so on. The distance which the pipe is carried above the first radiator which it supplies has but little effect in producing a flow, especially if covered, as it should be in practice. Having seen that the flow in the main riser depends upon the elevation of the radiators, it is easy to see that the way in which it is distributed on the different floors must be considered. For example, in *B*, Fig. 105, there will be a more rapid flow through the riser with the radiators as shown, than there would be if they were reversed and the largest one were placed upon the first floor.

We get the average elevation of the system by multiplying the square feet of radiation on each floor by the elevation above the heater, then adding these products together and dividing the same by the total radiation in the whole system. In the case shown in *B*, the average elevation of the system would be

$$\frac{(100 \times 30) + (50 \times 20) + (25 \times 10)}{100 + 50 + 25} = 24 \text{ feet;}$$

and we must proportion the main riser the same as though the whole radiation were on the second floor. Looking in Table XXVII, we find, for the second story, that a $1\frac{1}{2}$-inch pipe will supply 140 square feet; and a 2-inch pipe, 275 feet. Probably a 1½-inch pipe would be sufficient.

Although the height of stories varies in different buildings, 10 feet will be found sufficiently accurate for ordinary practice.

INDIRECT HOT-WATER HEATING

This is used under the same conditions as indirect steam, and the heaters used are similar to those already described. Special

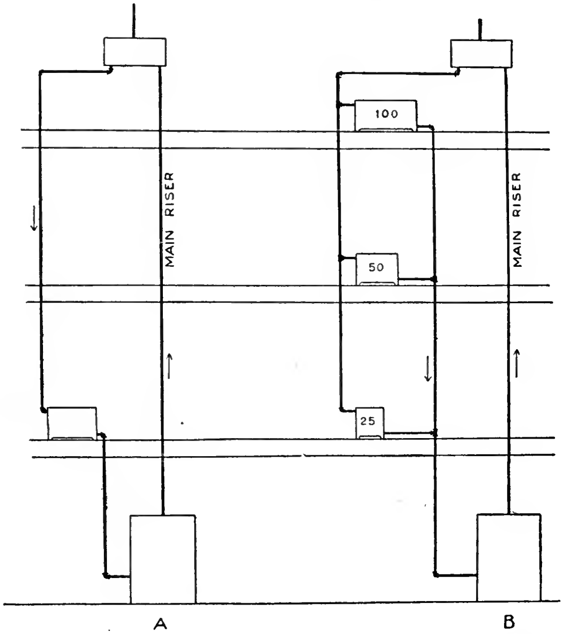


Fig. 105. Diagram to Illustrate Finding of Average Elevation of Heating System.

attention is given to the form of the sections, in order that there may be an even distribution of water through all parts of them. As the stacks are placed in the basement of a building, and only a short distance above the boiler, extra large pipes must be used to secure a proper circulation, for the *head* producing flow is small. The stack casings, cold-air and warm-air pipes, and registers are the same as in steam heating.

Types of Radiators. The radiators for indirect hot-water heating are of the same general form as those used for steam. Those shown in Figs. 52, 53, 56, 106, and 107 are common patterns. The *drum pin*, Fig. 106, is an excellent form, as the method of making the connections insures a uniform distribution of water through the stack.

Fig. 107 shows a radiator of good form for water circulation, and also of good depth, which is a necessary point in the design of hot-water radiators. They should be not less than 12 or 15 inches deep for good results. Box coils of the form given for steam may also be

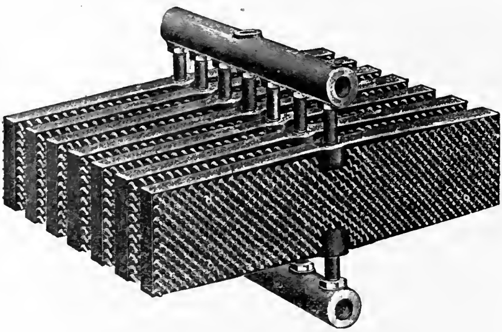


Fig. 106. "Drum Pin" Indirect Hot-Water Radiator.

used, provided the connections for supply and return are made of good size.

Size of Stacks. As indirect hot-water heaters are used principally in the warming of dwelling-houses, and in combination with direct radiation, the easiest method is to compute the surfaces required for direct radiation, and multiply these results by 1.5 for pin radiators of good depth. For other forms the factor should vary from 1.5 to 2, depending upon the depth and proportion of free area for air-flow between the sections.

If it is desired to calculate the required surface directly by the thermal unit method, we may allow an efficiency of from 360 to 400 for good types in zero weather.

In schoolhouse and hospital work, where larger volumes of air are warmed to lower temperatures, an efficiency as high as 500 B. T. U. may be allowed for radiators of good form.

Flues and Casings. For cleanliness, as well as for obtaining the best results, indirect stacks should be hung at one side of the register or flue receiving the warm air, and the cold-air duct should enter beneath the heater at the other side. A space of at least 10 inches, and preferably 12, should be allowed for the warm air above the stack. The top of the casing should pitch upward toward the warm-air outlet at least an inch in its length. A space of from 8 to 10 inches should be allowed for cold air below the stack.

As the amount of air warmed per square foot of heating surface is less than in the case of steam, we may make the flues somewhat smaller as compared with the size of heater. The following proportions may be used under usual conditions for dwelling-houses: $1\frac{1}{2}$ square inches per square foot of radiation for the first floor, $1\frac{1}{4}$ square inches for the second floor, and $1\frac{1}{4}$ square inches for the cold-air duct.

Fig. 107. Indirect Hot-Water Radiator.

Pipe Connections. In indirect hot-water work, it is not desirable to supply more than 80 to 100 square feet of radiation from a single connection. When the requirements call for larger stacks, they should be divided into two or more groups according to size.

It is customary to carry up the main from the boiler to a point near the basement ceiling, where it is air-vented through a small pipe leading to the expansion tank. The various branches should grade downward and connect with the tops of the stacks. In this way, all air, both from the boiler and from the stacks, will find its way to the highest point in the main, and be carried off automatically.

As an additional precaution, a pet-cock air-valve should be placed in the last section of each stack, and brought out through the casing by means of a short pipe.

TABLE XXVIII

Radiating Surface Supplied by Pipes of Various Sizes—Indirect Hot-Water System

Diameter of Pipe	Square Feet of Radiating Surface			
	100 Ft. Run	200 Ft. Run	300 Ft. Run	400 Ft. Run
1 in.	15			
1¼ "	30	25		
1½ "	50	40	25	
2 "	100	75	60	50
2½ "	175	125	100	90
3 "	275	200	150	140
3½ "	425	300	225	200
4 "	600	425	350	300
5 "		700	575	500
6 "				800
7 "				1,200

Some engineers make a practice of carrying the main to the ceiling of the first story, and then dropping to the basement before branching to the stacks, the idea being to accelerate the flow of water through the main, which is liable to be sluggish on account of the small difference in elevation between the boiler and stacks. If the return leg of the loop is left uncovered, there will be a slight drop in temperature, tending to produce this result; but in any case it will be exceedingly small. With supply and return mains of suitable size and properly graded, there should be no difficulty in securing a good circulation in basements of average height.

Pipe Sizes. As the difference in elevation between the stacks and the heater is necessarily small, the pipes should be of ample size to offset the slow velocity of flow through them. The sizes mentioned in Table XXVIII, for runs up to 400 feet, will be found to supply ample radiating surface for ordinary conditions. Some engineers make a practice of using somewhat smaller pipes, but the larger sizes will in general be found more satisfactory.

CARE AND MANAGEMENT OF HOT-WATER HEATERS

The directions given for the care of steam-heating boilers apply in a general way to hot-water heaters, as to the methods of caring for the fires and for cleaning and filling the heater. Only the special points of difference need be considered. Before building the fire, all the pipes and radiators must be full of water, and the expansion tank should be partially filled as indicated by the gauge-glass. Should the water in any of the radiators fail to circulate, see that the valves are wide open and that the radiator is free from air. Water must always be added at the expansion tank when for any reason it is drawn from the system.

The required temperature of the water will depend upon the outside conditions, and only enough fire should be carried to keep the rooms comfortably warm. Thermometers should be placed in the flow and return pipes near the heater, as a guide. Special forms are made for this purpose, in which the bulb is immersed in a bath of oil or mercury (see Fig. 108).

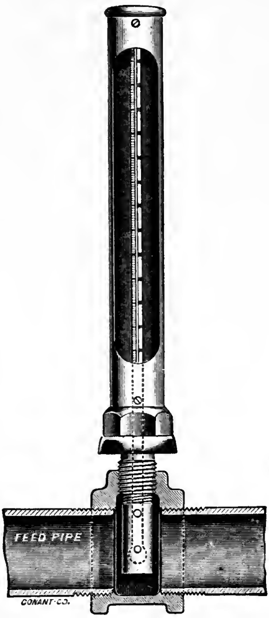


Fig. 108. Thermometer Attached to Feed-Pipe near Heater, to Determine Temperature of Water.

FORCED HOT-WATER CIRCULATION

While the gravity system of hot-water heating is well adapted to buildings of small and medium size, there is a limit to which it can be carried economically. This is due to the slow movement of the water, which calls for pipes of excessive size. To overcome this difficulty, pumps are used to force the water through the mains at a comparatively high velocity.

The water may be heated in a boiler in the same manner as for gravity circulation, or exhaust steam may be utilized in a feed-water heater of large size. Sometimes part of the heat is derived from an economizer placed in the smoke passage from the boilers.

Systems of Piping. The mains for forced circulation are usually run in one of two ways. In the *two-pipe system,* shown in Fig. 109, the supply and return are carried side by side, the former reducing in size, and the latter increasing as the branches are taken off.

The flow through the risers is produced by the difference in pressure in the supply and return mains; and as this is greatest nearest the pump, it is necessary to place throttle-valves in the risers to prevent short-circuiting and to secure an even distribution through all parts of the system.

Fig. 110 shows the *single-pipe* or *circuit system.* This is similar to the one already described for gravity circulation, except that it can be used on a much larger scale.

A single main is carried entirely around the building in this case, the ends being connected with the suction and discharge of the pump as shown.

As the pressure or head in the main drops constantly throughout the circuit, from the discharge of the pump back to the suction, it is

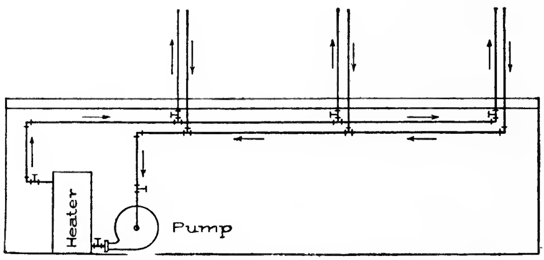


Fig. 109. "Two-Pipe" System for Forced Hot-Water Circulation.

evident that if a supply riser be taken off at any point, and the return be connected into the main a short distance along the line, there will be a sufficient difference in pressure between the two points to produce a circulation through the two risers and the connecting radiators. A distance of 8 or 10 feet between the connections is usually ample to produce the necessary circulation, and even less if the supply is taken from the top of the main and the return connected into the side.

Sizes of Mains and Branches. As the velocity of flow is independent of the temperature and elevation when a pump is used, it is necessary to consider only the volume of water to be moved and the length of run.

The volume is found by the equation

$$Q = \frac{R\ E}{500\ T},$$

in which

Q = Gallons of water required per minute;
R = Square feet of radiating surface to be supplied;
E = Efficiency of radiating surface in B. T. U. per sq. foot per hour;
T = Drop in temperature of the water in passing through the heating system.

In systems of this kind, where the circulation is comparatively rapid, it is customary to assume a drop in temperature of 30° to 40°, between the supply and return.

Having determined the gallons of water to be moved, the required size of main can be found by assuming the velocity of flow, which for pipes from 5 to 8 inches in diameter may be taken at 400 to 500

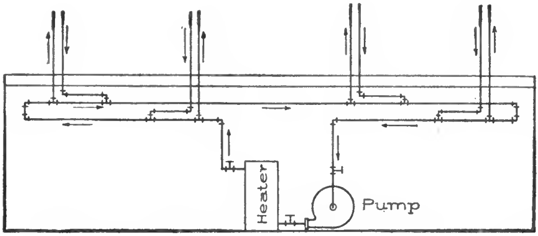


Fig. 110. "Single-Pipe" or "Circuit" System for Forced Hot-Water Circulation.

feet per minute. A velocity as high as 600 feet is sometimes allowed for pipes of large size, while the velocity in those of smaller diameter should be proportionally reduced to 250 or 300 feet for a 3-inch pipe. The next step is to find the pressure or head necessary to force the water through the main at the given velocity. This in general should not exceed 50 or 60 feet, and much better pump efficiencies will be obtained with heads not exceeding 35 or 40 feet.

As the water in a heating system is in a state of equilibrium, the only power necessary to produce a circulation is that required to overcome the friction in the pipes and radiators; and, as the area of the passageways through the latter is usually large in comparison with the former, it is customary to consider only the head necessary to force the water through the mains, taking into consideration the additional friction produced by valves and fittings.

Each long-turn elbow may be taken as adding about 4 feet to the length of pipe; a short-turn fitting, about 9 feet; 6-inch and 4-inch swing check-valves, 50 feet and 25 feet, respectively; and 6-inch and 4-inch globe check-valves, 200 feet and 130 feet, respectively.

Table XXIX is prepared especially for determining the size of mains for different conditions, and is used as follows:

Example. Suppose that a heating system requires the circulation of 480 gallons of water per minute through a circuit main 600 feet in length. The pipe contains 12 long-turn elbows and 1 swing check-valve. What diameter of main should be used?

Assuming a velocity of 480 feet per minute as a trial velocity, we follow along the line corresponding to that velocity, and find that a 5-inch pipe will deliver the required volume of water under a head of 4.9 feet for each 100 feet length of run.

The actual length of the main, including the equivalent of the fittings as additional length, is

$$600 + (12 \times 9) + 50 = 758 \text{ feet};$$

hence the total head required is $4.9 \times 7.58 = 37$ feet. As both the assumed velocity and the necessary head come within practicable limits, this is the size of pipe which would probably be used. If it were desired to reduce the power for running the pump, the size of main could be increased. That is, Table XXIX shows that a 6-inch pipe would deliver the same volume of water with a friction head of only about 2 feet per 100 feet in length, or a total head of $2 \times 7.58 = 15$ feet.

The risers in the circuit system are usually made the same size as for gravity work. With double mains, as shown in Fig. 109, they may be somewhat smaller, a reduction of one size for diameters over $1\frac{1}{4}$ inches being common

The branches connecting the risers with the mains may be proportioned from the combined areas of the risers. When the branches are of considerable size, the diameter may be computed from the available head and volume of water to be moved.

Pumps. Centrifugal pumps are usually employed in connection with forced hot-water circulation, in preference to pumps of the piston or plunger type. They are simple in construction, having no valves, produce a continuous flow of water, and, for the low heads

TABLE XXIX

Capacity in Gallons per Minute Discharged at Velocities of 300 to 540 Feet per Minute—Also Friction Head in Feet, per 100 Feet Length of Pipe

	DIAMETER OF PIPE											
	3-INCH		4-INCH		5-INCH		6-INCH		7-INCH		8-INCH	
Velocity	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction
300	110	3.41	195	2.56	306	2.05	440	1.70	600	1.46	783	1.28
480	176	8.16	314	6.12	490	4.9	705	4.08	959	3.49	1,253	3.06
540	198	10.1	352	7.64	550	6.11	794	5.09	1,079	4.36	1,410	3.82

against which they are operated, have a good efficiency. A pump of this type, with a direct-connected engine, is shown in Fig. 111.

Under ordinary conditions the efficiency of a centrifugal pump falls off considerably for heads above 30 or 35 feet; but special high-speed pumps are constructed which work with a good efficiency against 500 feet or more.

Under favorable conditions an efficiency of 60 to 70 per cent is often obtained; but for hot-water circulation it is more common to assume an efficiency of about 50 per cent for the average case.

The horse-power required for driving a pump is given by the following formula:

$$\text{H. P.} = \frac{H \times V \times 8.3}{33{,}000 \times E},$$

in which

H = Friction head in feet;
V = Gallons of water delivered per minute;
E = Efficiency of pump.

Centrifugal pumps are made in many sizes and with varying proportions, to meet the different requirements of capacity and head.

Heaters. If the water is heated in a boiler, any good form may be used, the same as for gravity work. In case tubular boilers are used, the entire shell may be filled with tubes, as no steam space is required.

In order to prevent the water from passing in a direct line from the inlet to the outlet, a series of baffle-plates should be used to bring it in contact with all parts of the heating surface.

When steam is used for heating the water, it is customary to employ a closed feed-water heater with the steam on the inside of the tubes and the water on the outside.

Any good form of heater can be used for this purpose by providing it with steam connections of sufficient size. In the ordinary form of heater, the feed-water flows through the tubes, and the connections are therefore small, making it necessary to substitute special nozzles of large size when used in the manner here described.

When computing the required amount of heating surface in the tubes of a heater, it is customary to assume an efficiency of about 200 B. T. U. per square foot of surface per hour, per degree difference in temperature between the water and steam.

It is usual to circulate the water at a somewhat higher temperature in systems of this kind, and a maximum initial temperature of 200 degrees, with a drop of 40 degrees in the heating system, may be used in computing the size of heater. If exhaust steam is used at atmospheric pressure, there will be a difference of 212 − 180 = 32 degrees, between the *average* temperature of the water and the steam, giving an efficiency of 200 × 32 = 6,400 B. T. U. per square foot of heating surface.

From this it is evident that 6,400 ÷ 170 = 38 square feet of direct radiating surface, or 6,400 ÷ 400 = 16 square feet of indirect, may be supplied from each square foot of tube surface in the heater.

Example. A building having 6,000 square feet of direct, and 2,000 square feet of indirect radiation, is to be warmed by hot water under forced circulation. Steam at atmospheric pressure is to be used for heating the water. How many square feet of heating surface should the heater contain?

6,000 ÷ 38 = 158; and 2,000 ÷ 16 = 125; therefore, 158 + 125 = 283 square feet, the area of heating surface called for.

When the exhaust steam is not sufficient for the requirements, an auxiliary live steam heater is used in connection with it.

Fig. 111. Centrifugal Pump Direct-Connected to Engine, for Forced Hot-Water Circulation.

EXAMPLES FOR PRACTICE

1. A building contains 10,000 square feet of direct radiation and 4,000 square feet of indirect radiation. How many gallons of water must be circulated through the mains per minute, allowing a drop in temperature of 40 degrees? Ans. 165 gal.

2. In the above example, what size of main should be used, assuming the circuit to be 300 feet in length and to contain ten long-turn elbows? The friction head is not to exceed 10 ft., and the velocity of flow not to exceed 300 feet per minute. Ans. 4-inch.

3. What horse-power will be required to drive a centrifugal pump delivering 400 gallons per minute against a friction head of 40 feet, assuming an efficiency of 50 per cent for the pump?
Ans. 8 H. P.

4. A building contains 10,000 square feet of direct radiation and 5,000 square feet of indirect radiation. Steam at atmospheric pressure is to be used. The initial temperature of the water is to be 200°; and the final, 160°. How many square feet of heating surface should the heater contain? ANS. 575 sq. ft.

5. How many square feet would be required in the above heater (Example 4) if the initial temperature of the water were 180° and the final temperature 150°? ANS. 399 sq. ft.

EXHAUST-STEAM HEATING

Steam, after being used in an engine, contains the greater part of its heat; and if not condensed or used for other purposes, it can usually be employed for heating without affecting to any great extent the power of the engine. In general, we may say that it is a matter of economy to use the exhaust for heating, although various factors must be considered in each case to determine to what extent this is true. The more important considerations bearing upon the matter are: the relative quantities of steam required for power and for heating; the length of the heating season; the type of engine used; the pressure carried; and, finally, whether the plant under consideration is entirely new, or whether, on the other hand, it involves the adapting of an old heating system to a new plant.

The first use to be made of the exhaust steam is the heating of the feed-water, as this effects a constant saving both summer and winter, and can be done without materially increasing the back-pressure on the engine. Under ordinary conditions, about one-sixth of the steam supplied to the engine can be used in this way, or more nearly one-fifth of the exhaust *discharged* from the engine.

We may assume in average practice that about 80 per cent of the steam supplied to an engine is discharged in the form of steam at a lower pressure, the remaining 20 per cent being partly converted into work and partly lost through cylinder condensation. Taking this into account, there remains, after deducting the steam used for feed-water heating, $.8 \times \frac{4}{5} = .64$ of the entire quantity of steam supplied to the engine, available for heating purposes.

When the quantity of steam required for heating is small compared with the total amount supplied to the engine, or where the heating season is short, it is often more economical to run the engine condensing and use the live steam for heating. This can be determined in any particular case by computing the saving in fuel by the use of a condenser, taking into account the interest and depreciation on the first cost of the condensing apparatus, and the cost of water, if it must be purchased, and comparing it with the cost of heating with live steam.

Usually, however, in the case of office buildings and institutions, and commonly in the case of shops and factories, especially in northerly latitudes, it is advantageous to use the exhaust for heating, even if a condenser is installed for summer use only. The principal objection raised to the use of exhaust steam has been the higher back-pressure required on the engines, resulting in a loss of power nearly proportional to the ratio of the back-pressure to the mean effective pressure. There are two ways of offsetting this loss—one, by raising the initial or boiler pressure; and the other, by increasing the cut-off of the engine. Engines are usually designed to work most economically at a given cut-off, so that in most cases it is undesirable to change it to any extent. Raising the boiler pressure, on the other hand, is not so objectionable if the increase amounts to only a few pounds.

Under ordinary conditions in the case of a simple engine, a rise of 3 pounds in the back-pressure calls for an increase of about 5 pounds in the boiler pressure, to maintain the same power at the engine.

The indicator card shows a back-pressure of about 2 pounds when an engine is exhausting into the atmosphere, so that an increase of 3 pounds would bring the pressure up to a total of 5 pounds which should be more than sufficient to circulate the steam through any well-designed heating system.

If it is desired to reduce rather than increase the back-pressure, one of the so-called *vacuum systems*, described later, can be used.

The systems of steam heating which have been described are those in which the water of condensation flows back into the boiler by gravity. Where exhaust steam is used, the pressure is much below that of the boiler, and it must be returned either by a pump or by a return trap. The exhaust steam is often insufficient to supply the entire heating system, and must be supplemented by live steam taken directly from the boiler. This must first pass through a reducing valve in order to reduce the pressure to correspond with that carried in the heating system.

An engine does not deliver steam continuously, but at regular intervals, at the end of each stroke; and the amount is likely to vary with the work done, since the governor is adjusted to admit steam in such a quantity as is required to maintain a uniform speed. If the work is light, very little steam will be admitted to the engine; and for this reason, the supply available for heating may vary somewhat, depending upon the use made of the power delivered by the engine. In mills the amount of exhaust steam is practically constant; in office buildings where power is used for lighting, the variation is greater, especially if power is also required for the running of elevators.

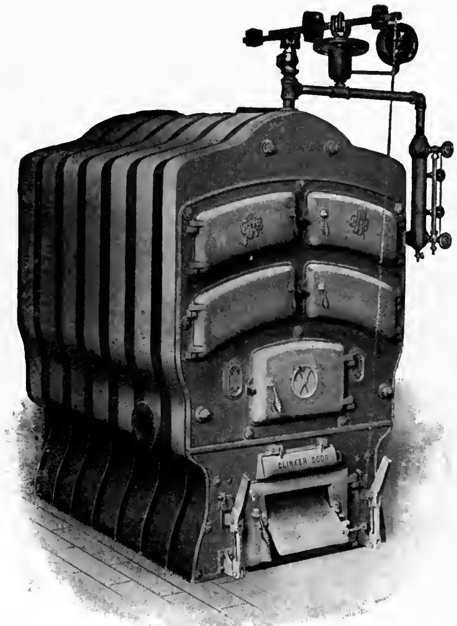
The general requirements for a successful system of exhaust steam heating include a system of piping of such proportions that only a slight increase in back-pressure will be thrown upon the engine; a connection which shall automatically supply live steam at a reduced pressure as needed; provision for removing the oil from the exhaust steam; a relief or back-pressure valve arranged to prevent any sudden increase in back pressure on the engine; and a return system of some kind for returning the water of condensation to the boiler against a higher pressure. These requirements may be met in various ways, depending upon actual conditions found in different cases.

To prevent sudden changes in the back-pressure, due to irregular supply of steam, the exhaust pipe from the engine is often carried to a closed tank having a capacity from 30 to 40 times that of the engine cylinder. This tank may be provided with baffle-plates or other arrangements and may serve as a separator for removing the oil from the steam as it passes through.

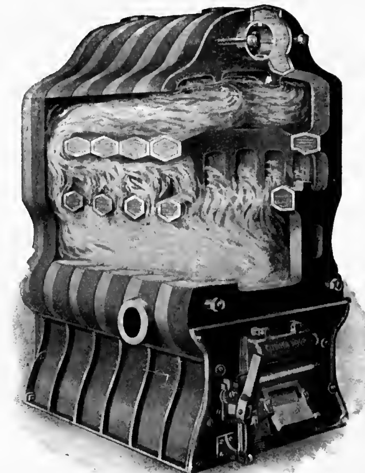
Any system of piping may be used; but great care should be taken that as little resistance as possible is introduced at bends and fittings; and the mains and branches should be of ample size. Usually the best results are obtained from the system in which the main steam pipe is carried directly to the top of the building, the distributing pipes being run from that point, and the radiating surfaces supplied by a down-flowing current of steam.

Before taking up the matter of piping in detail a few of the more important pieces of apparatus will be described in a brief way.

Reducing Valves. The action of pressure-reducing valves has



SECTIONAL STEAM BOILER.



SECTIONAL WATER BOILER.

Made by American Radiator Company.

been taken up quite fully in "Boiler Accessories," and need not be repeated here. When the reduction in pressure is large, as in the case of a combined power and heating plant, the valve may be one or two sizes smaller than the low-pressure main into which it discharges. For example, a 5-inch valve will supply an 8-inch main, a 4-inch a 6-inch main, a 3-inch a 5-inch main, a $2\frac{1}{2}$-inch a 4-inch main, etc.

For the smaller sizes, the difference should not be more than one size. All reducing valves should be provided with a valved by-pass for cutting out the valve in case of repairs. This connection is usually made as shown in plan by Fig. 112.

Grease Extractor. When exhaust steam is used for heating purposes, it must first be passed through some form of separator for removing the oil; and as an additional precaution it is well to pass the

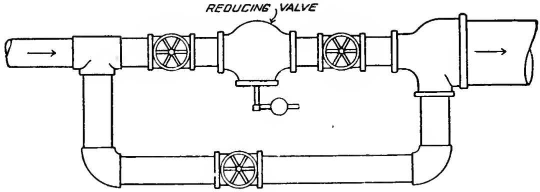


Fig. 112. Connections of Reducing Valve in Exhaust-Steam Heating System.

water of condensation through a separating tank before returning it to the boilers.

Such an arrangement is shown in Fig. 113. As the oil collects on the surface of the water in the tank, it can be made to overflow into the sewer by closing the valve in the connection with the receiving tank, for a short time.

As much of the oil as possible should be removed before the steam enters the pipes and radiators, else a coating will be formed on their inner surfaces, which will reduce their heating efficiency. The separation of the oil is usually effected by introducing a series of baffling plates in the path of the steam; the particles of oil striking these are stopped, and thus separated from the steam. The oil drops into a receiver provided for this purpose and is discharged through a trap to the sewer.

In the separator, or extractor, shown in Fig. 114, the separation is accomplished by a series of plates placed in a vertical position in the body of the separator, through which the steam must pass. These plates consist of upright hollow columns, with openings at regular intervals for the admission of water and oil, which drain downward to the receiver below. The steam takes a zigzag course, and all of it comes in contact with the intercepting plates, which insures a thorough separation of the oil and other solid matter from the steam. Another form, shown in Fig. 115, gives excellent results, and has the advantage of providing an equalizing chamber for overcoming, to some extent, the unequal pressure due to the varying load on the engine. It consists of a tank or receiver about 4 feet in diameter, with heavy boiler-iron heads slightly crowned to give stiffness.

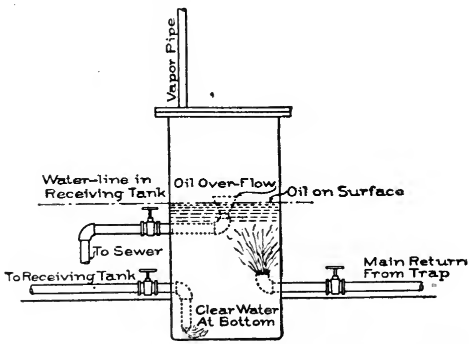


Fig. 113. Separator for Removing Oil from Exhaust Steam and Water Condensation.

Through the center is a layer of excelsior (wooden shavings of long fibre) about 12 inches in thickness, supported on an iron grating, with a similar grating laid over the top to hold it in place. The steam enters the space below the excelsior and passes upward, as shown by the arrows. The oil is caught by the excelsior, which can be renewed from time to time as it becomes saturated. The oil and water which fall to the bottom of the receiver are carried off through a trap. Live steam may be admitted through a reducing valve, for supplementing the exhaust when necessary.

Back-Pressure Valve. This is a form of relief valve which is placed in the outboard exhaust pipe to prevent the pressure in the heating system from rising above a given point. Its office is the reverse of the reducing valve, which supplies more steam when the pressure becomes too low. The form shown in Fig. 116 is designed for a vertical pipe. The valve proper consists of two discs of unequal area, the combined area of which equals that of the pipe. The force tending to open the valve is that due to the steam pressure acting on an area equal to the difference in area between the two discs; it is clear from the cut that the pressure acting on the larger disc tends to open the valve while the pressure on the smaller acts in the opposite direction. The valve-stem is connected by a link and crank arm with a spindle upon which is a lever and weight outside. As the valve opens, the weight is raised, so that, by placing it in different positions on the lever arm, the valve will open at any desired pressure.

Fig. 117 shows a different type, in which a spring is used instead of a weight. This valve has a single disc moving in a vertical direction. The valve stem is in the form of a piston or dash-pot which prevents a too sudden movement and makes it more quiet in its action. The disc is held on its seat against the steam pressure by a lever attached to the spring as shown. When the pressure of the steam on the underside becomes greater than the tension of the spring, the valve lifts and allows the steam to escape. The tension of the spring can be varied by means of the adjusting screw at its upper end.

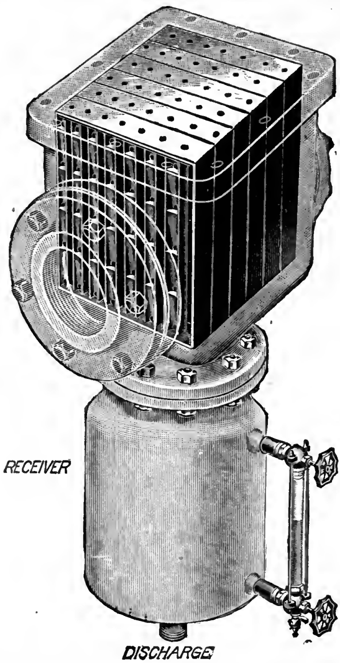


Fig. 114. Oil Separator Consisting of Vertical Plates with Openings Giving Steam a Zigzag Course.

A back-pressure valve is simply a low-pressure safety-valve designed with a specially large opening for the passage of steam through it. These valves are made for horizontal as well as for vertical pipes.

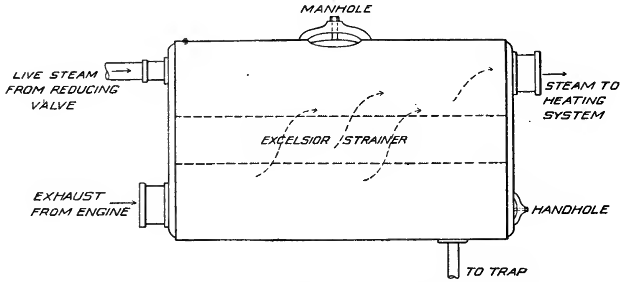


Fig. 115. Oil Separator Consisting of a Tank in which Steam is Filtered by Passing Upward through a Layer of Excelsior.

Exhaust Head. This is a form of separator placed at the top of an outboard exhaust pipe to prevent the water carried up in the steam from falling upon the roofs of buildings or in the street below. Fig. 118 is known as a centrifugal exhaust head. The steam, on entering at the bottom, is given a whirling or rotary motion by the spiral deflectors; and the water is thrown outward by centrifugal force against the sides of the chamber, from which it flows into the shallow trough at the base, and is carried away through the drip-pipe, which is brought down and connected with a drain-pipe inside the building. The passage of the steam outboard is shown by the arrows. Other forms are used in which the water is separated from the steam by deflectors which change the direction of the currents.

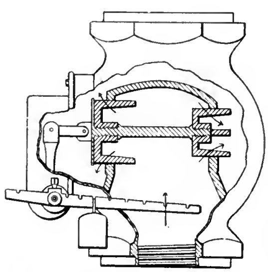


Fig. 116. Automatically Acting Back-Pressure Valve Attached to Vertical Pipe. For Preventing Rise of Pressure in System above any Desired Point.

Automatic Return-Pumps. In exhaust heating plants, the condensation is returned to the boilers by means of some form of return-pump. A combined pump and receiver of the form illustrated in Fig. 119 is generally used. This consists of a cast-iron or wrought-iron tank mounted on a base in connection with a boiler feed-pump. Inside the tank is a ball-float connected by means of levers with a valve in the steam pipe which is connected with the pump. When the water-line in the tank rises above a certain level, the float is raised and opens the steam valve, which starts the pump. When the water is lowered to its normal level, the valve closes and the pump stops. By this arrangement, a constant water-line is maintained in the receiver, and the pump runs only as needed to care for the condensation as it returns from the heating system. If dry returns are used, they may be brought together and connected with the top of the receiver. If it is desired to seal the horizontal runs, as

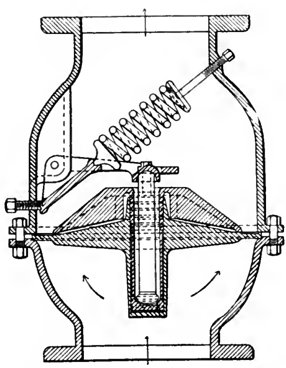


Fig. 117. Back-Pressure Valve Automatically Operated by a Spring.

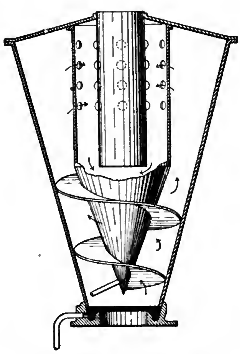


Fig. 118. Centrifugal Exhaust Head.

is usually the case, the receiver may be raised to a height sufficient to give the required elevation and the returns connected near the bottom below the water-line.

A *balance-pipe*, so called, should connect the heating main with the top of the tank, for equalizing the pressure; otherwise the steam above the water would condense, and the vacuum thus formed would draw all the water into the tank, leaving the returns practically empty and thus destroying the condition sought. Sometimes an independent regulator or pump governor is used in place of a receiver. One type is shown in Fig. 120. The return main is connected at the upper opening, and the pump suction at the lower. A float inside the chamber operates the steam valve shown at the top, and the pump works automatically as in the case just described.

If it is desired to raise the water-line, the regulator may be elevated to the desired height and connections made as shown in Fig. 121.

Return Traps. The principle of the return trap has been described in "Boiler Accessories," but its practical form and application

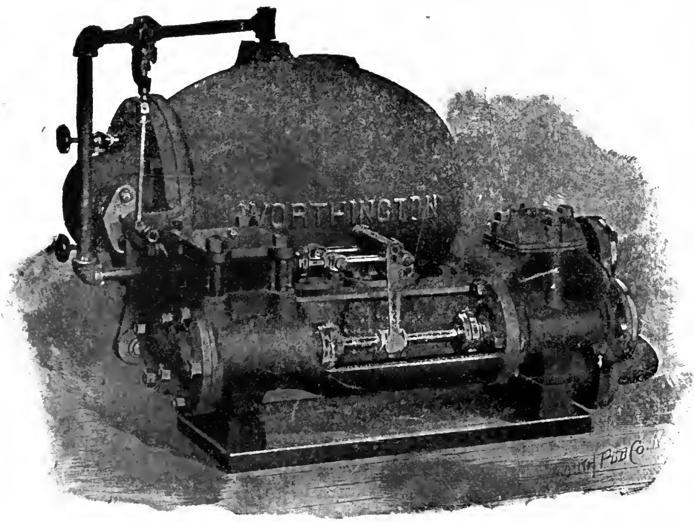


Fig. 119. Combined Receiver and Automatic Pump for Returning Water of Condensation to Boiler.

will be taken up here. The type shown in Fig. 122 has all its working parts outside the trap. It consists of a cast-iron bowl pivoted at *G* and *H*. There is an opening through *G* connecting with the inside of the bowl. The pipe *K* connects through *C* with an interior pipe opening near the top (see Fig. 123). The pipe *D* connects with a receiver, into which all the returns are brought. *A* is a check-valve allowing water to pass through in the direction shown by the arrow. *E* is a pipe connecting with the boiler below the water-line. *B* is a check opening toward the boiler, and *K*, a pipe connected with the steam main or drum.

The action of the trap is as follows: As the bowl fills with water from the receiver, it overbalances the weighted lever and drops to the bottom of the ring. This opens the valve *C*, and admits steam at boiler pressure to the top of the trap. Being at a higher level the water flows by gravity into the boiler, through the pipe *E*. Water and steam are kept from passing out through *D* by the check *A*.

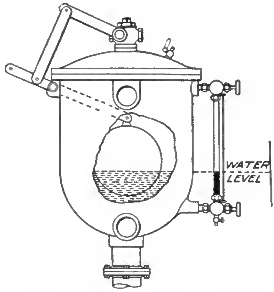


Fig. 120. Automatic Float-Operated Pump Governor Used instead of a Receiver.

When the trap has emptied itself, the weight of the ball raises it to the original position, which movement closes the valve *C* and opens the small vent *F*. The pressure in the bowl being relieved, water flows in from the receiver through *D*, until the trap is filled, when the

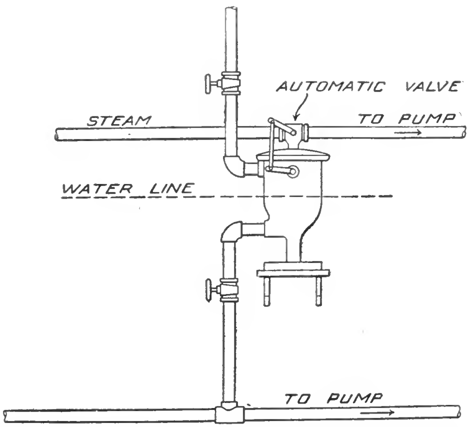


Fig. 121. Pump Regulator Placed at Sufficient Height to Raise Water-Line to Point Desired.

process is repeated. In order to work satisfactorily, the trap should be placed at least 3 feet above the water-level in the boiler, and the pressure in the returns must always be sufficient to raise the water from the receiver to the trap against atmospheric pressure, which is theoretically about 1 pound for every 2 feet in height. In practice there will be more or less friction to overcome, and suitable adjustments must be made for each particular case.

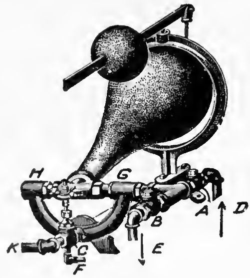


Fig. 122. Return Trap with Working Parts External.

Fig. 124 shows another form of trap acting upon the same principle, except that in this case the steam valve is operated by a bucket or float inside the trap. The pipe connections are practically the same as with the trap just described.

Return traps are more commonly used in smaller plants where it is desired to avoid the expense and care of a pump.

Damper-Regulators. Every heating and every power plant should be provided with automatic means for closing the dampers when the steam pressure reaches a certain point, and for opening them again when the pressure drops. There are various regulators designed for this purpose, a simple form of which is shown in Fig. 125.

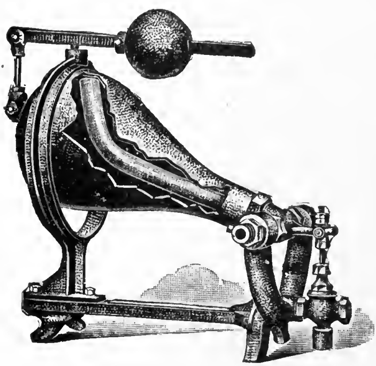


Fig. 123. Showing Interior Detail of Return Trap of Fig. 122.

Steam at boiler pressure is admitted beneath a diaphragm which is balanced by a weighted lever. When the pressure rises to a certain point, it raises the lever slightly and opens a valve which admits water under pressure above a diaphragm located near the smoke-pipe. This action forces down a lever connected by chains with the damper, and closes it. When the steam pressure drops, the water-valve is closed, and the different parts of the apparatus take their original positions.

Another form similar in principle is shown in Fig. 126. In this case a piston is operated by the water-pressure, instead of a diaphragm. In both types the pressures at which the damper shall open and close are regulated by suitable adjustments of the weights upon the levers.

Pipe Connections. The method of making the pipe connections in any particular case will depend upon the general arrangement of the apparatus and the various conditions. Fig. 127 illustrates

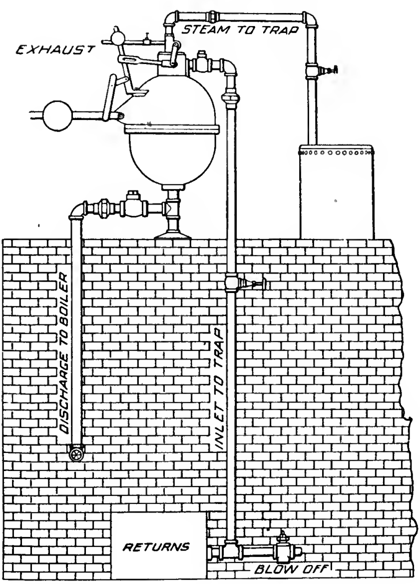


Fig. 124. Return Trap with Steam Valve Operated by Bucket or Float Inside.

the general principles to be followed, and by suitable changes may be used as a guide in the design of new systems.

Steam first passes from the boilers into a large drum or header. From this, a main, provided with a shut-off valve, is taken as shown; one branch is carried to the engines, while another is connected with the heating system through a reducing valve having a by-pass and cut-out valves. The exhaust from the engines connects with the large main over the boilers at a point just above the steam drum. The branch at the right is carried outboard through a back-pressure valve which may be set to carry any desired pressure on the system. The other branch at the left passes through an oil separator into the heating system. The connections between the mains and radiators are made in the usual way, and the main return is carried back to the return pump near the floor. A false water-line or seal is obtained by elevating the pump regulator as already described. An equalizing

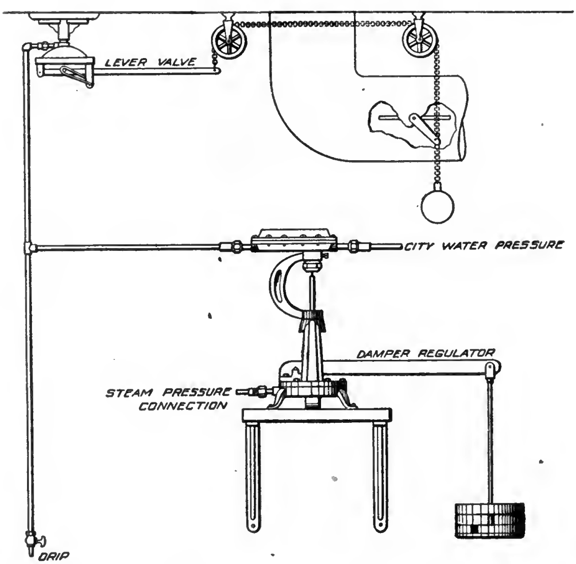


Fig. 125. Simple Form of Automatic Damper-Regulator, Operated by Lever Attached to Diaphragm, for Closing Dampers when Steam Pressure Reaches a Certain Point.

or balance pipe connects the top of the regulator with the low-pressure heating main, and high pressure is supplied to the pump as shown.

A sight-feed lubricator should be placed in this pipe above the automatic valve; and a valved by-pass should be placed around the regulator, for running the pump in case of accident or repairs. The oil separator should be drained through a special oil trap to a catch-basin or to the sewer; and the steam drum or any other low points or pockets in the high-pressure piping should be dripped to the return tank through suitable traps.

Means should be provided for draining all parts of the system to the sewer, and all traps and special apparatus should be by-passed. The return-pump should always be duplicated in a plant of any size, as a safeguard against accident; and the two pumps should be run alternately, to make sure that one is always in working order.

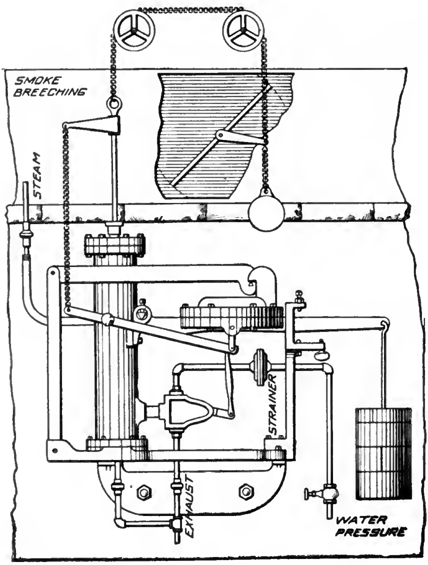


Fig. 126. Automatic Damper-Regulator Operated by Piston Actuated by Water-Pressure.

One piece of apparatus not shown in Fig. 127 is the feed-water heater. If all of the exhaust steam can be utilized for heating purposes, this is not necessary, as the cold water for feeding the boilers may be discharged into the return pipe and be pumped in with the condensation. In summertime, however, when the heating plant is not in use, a feed-water heater is necessary, as a large amount of heat

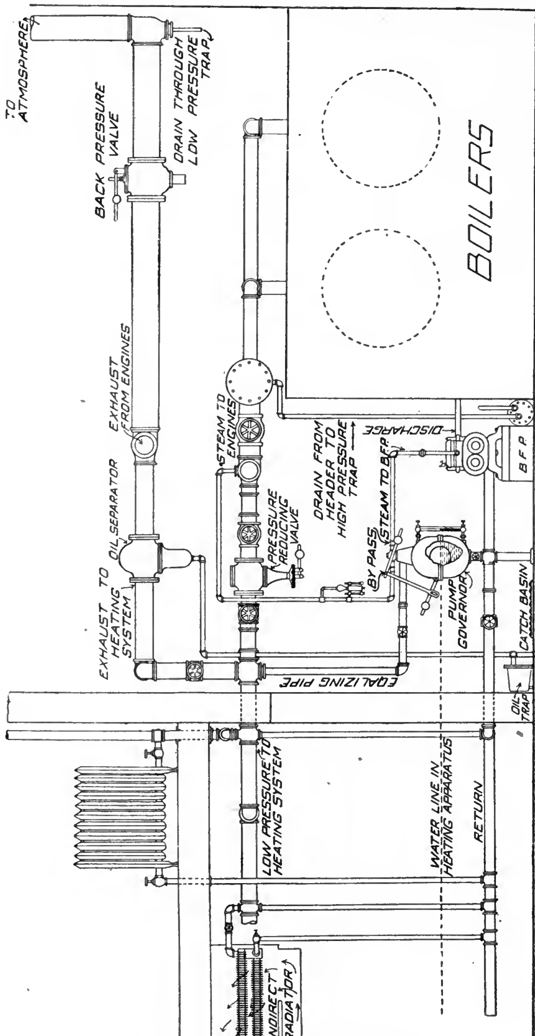
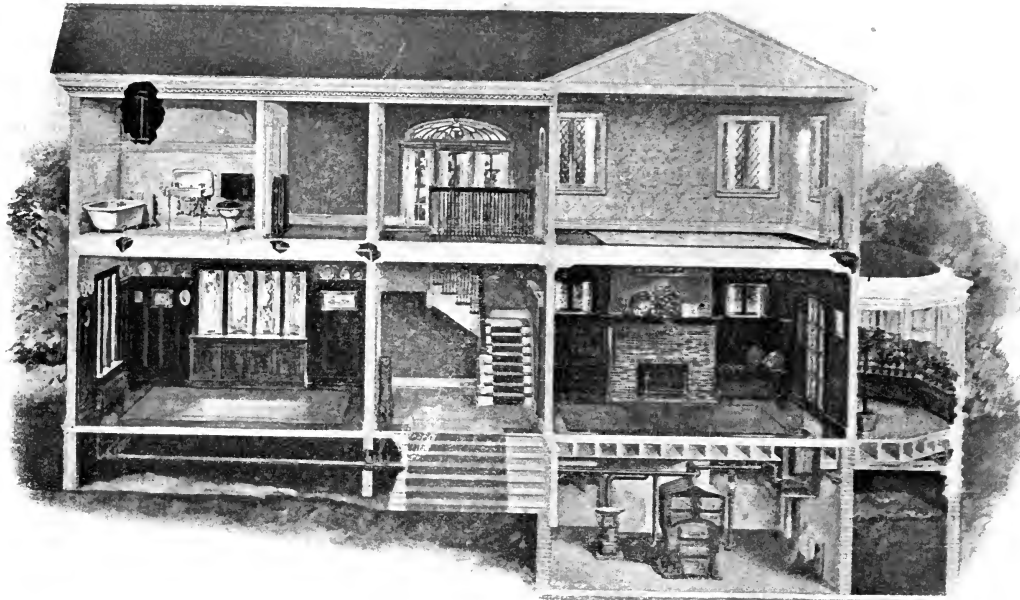


Fig. 127. General Method of Making Pipe Connections for Exhaust-Steam Heating.

which would otherwise be wasted may be saved in this way. The connections will depend somewhat upon the form of heater used; but in general a single connection with the heating main inside the back-pressure valve is all that is necessary. The condensation from the heater should be trapped to the sewer.



TRANSVERSE SECTIONAL VIEW OF COLONIAL MODEL HOUSE, SHOWING INSTALLATION OF HEATING PLANT.
Exhibited by the American Radiator Company at the St. Louis World's Fair, in 1904.

STEAM AND HOT WATER FITTING

STEAM BOILERS AND CONNECTIONS

Small Cast-Iron Boilers. For small low-pressure steam heating jobs, boilers made up of very few sections are used. Two types are illustrated in Figs. 1 and 2. The ratings of such boilers range, as a rule, from about 200 square feet to 800 square feet. These figures and those following are intended to give merely a general idea of the capacities of boilers of various types. There is no hard and fast rule governing the matter, manufacturers varying greatly in their practice. The ratings mentioned are given in the number of square feet of direct radiation the boiler is rated to supply, with steam at from 3 to 5 pounds' pressure when the radiators are surrounded by air at 70° F.

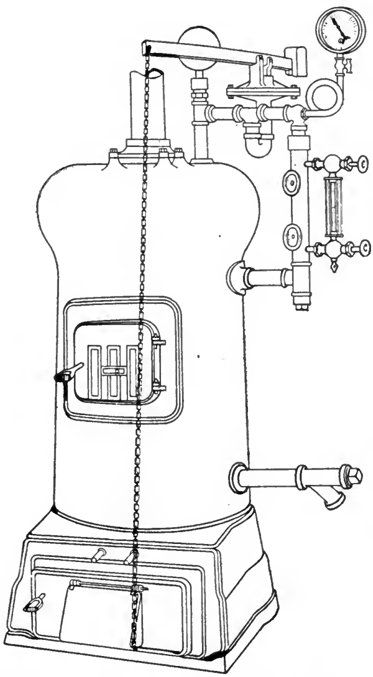


Fig. 1. Small Low-Pressure Steam Heating Boiler.

Boilers similar, in a general way, to the one illustrated in Fig. 3 are used for jobs somewhat larger than the boilers above described would be adapted to. These boilers have grates ranging generally from 18 inches to 36 inches diameter, and are rated from about 300 square feet to 1,600 square feet, or more.

The boilers above described have the disadvantage of not being capable of having their grate surface increased by adding sections, as may readily be done with boilers having vertical sections.

Cast-Iron Boilers with Vertical Sections. Boilers for jobs having

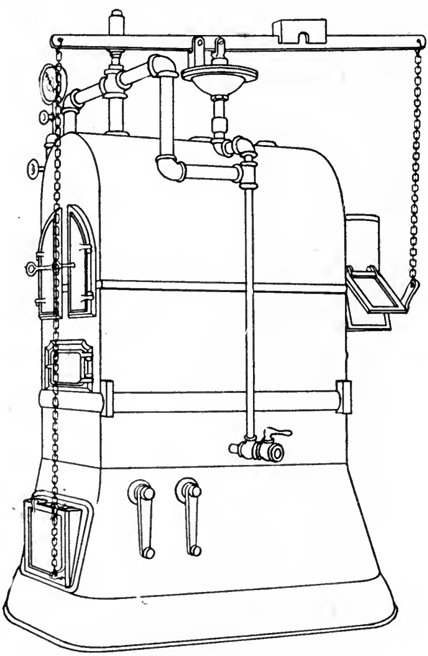
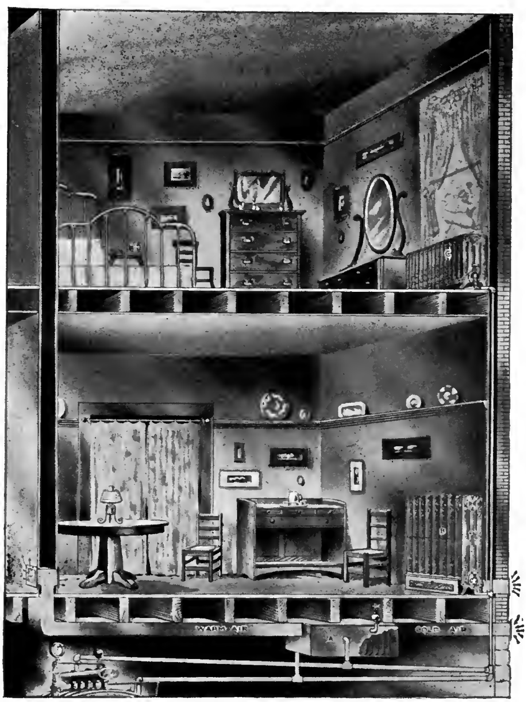


Fig. 2. Small Low-Pressure Steam Heating Boiler.

anywhere from 500 to 5,000 square feet of surface, or more, are made up of vertical sections, as in Fig. 4, connected either by slip nipples or by drums and nipples with long screws and lock-nuts.

Very many slip-nipple boilers are now being manufactured, finding favor with fitters owing to the ease with which they can be erected.



SECTIONAL VIEW OF HOUSE SHOWING THE THREE METHODS OF STEAM AND HOT-WATER HEATING

A. Indirect Radiation; *B*. Semi-Direct Radiation; *C*. Direct Radiation
Pierce, Butler & Pierce Mfg. Co., Syracuse, N. Y.

The larger sizes of vertical sectional boilers are often made up of two sets of sections placed opposite each other, as shown in Fig. 5. Such boilers are rated up to 6,000 square feet and over.

Arrangement of Grates. Certain makers, in order to avoid making patterns for a boiler with a wide grate, secure the necessary grate surface by adding to the length. For ordinary low-pressure heating, the efficiency of any grate over 6 feet in length falls off very rapidly, owing to the difficulty of properly caring for the fire. Six feet should be considered about the limit for the length of a grate in a low-pressure boiler.

Not long ago few portable boilers with grates wider than 36 inches were manufactured. Now, boilers with 42-inch, 48-inch, and even wider grates, are common.

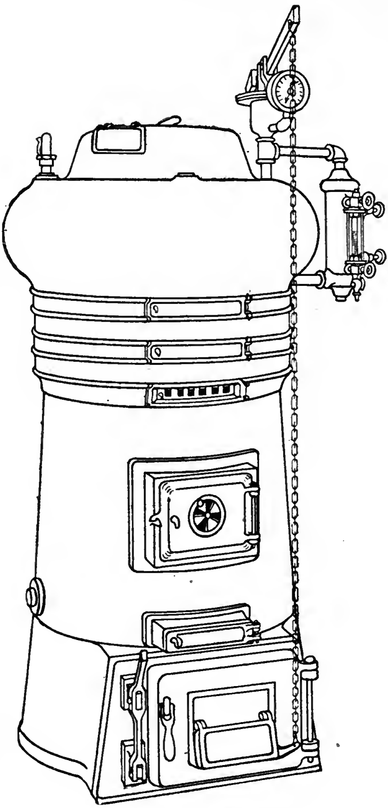


Fig. 3. Steam Heating Boiler.

Selection of Boilers. It is well in selecting a boiler, to see that the proportion of heating surface to grate surface is not less than 16 to 1, and in large boilers not less than 20 to 1; that the fire-box is deep, so that ample coal may be put on to burn through the night; that the grate is not too long for convenient firing and cleaning; that there is ample steam space;

and that the water line is not broken into too many small areas involving the likelihood that water will be lifted by rapid evaporation and wet steam result. See to it, also, that the ash-pit is deep, and that the grate is of a design that will permit convenient operation of the boiler.

On large jobs, it is better, as a rule, to use two boilers. One must remember that a plant must be designed for the coldest weather; and since the average temperature during the heating season is, in many Northern sections, not far from 40°, one of a pair of boilers will be sufficient under average conditions to do the work with economy; whereas a single, large boiler, during a good part of the heating season, would have to be run with drafts checked and under very unfavorable conditions as to economy. It is almost as poor economy to have too large a boiler as to have one too small, for, if run with the feed-door open or drafts closely checked, incomplete combustion takes place.

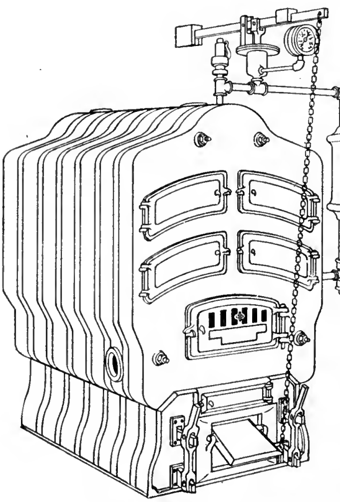


Fig. 4. Steam Heating Boiler with Vertical Sections.

Boilers for Soft Coal. Some boilers for burning soft coal are arranged with a perforated pipe or duct discharging heated air above the fire to make the combustion more complete and thus diminish the amount of smoke given off. This arrangement is of somewhat doubtful utility, since it is difficult to heat the air properly, and to regulate its admission.

It is necessary, for soft coal boilers, that the flues and smoke-pipe be larger than for hard coal heaters, in order to provide for the more rapid accumulation of soot. Soft coal boilers are also built on the down-draft principle, the air being drawn down through the fire instead of passing upward in the usual manner.

Coke Boilers. Coke is a popular fuel in some parts of the coun-

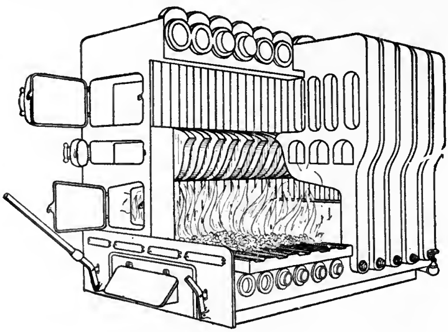


Fig. 5. Vertical Sectional Boiler.

try; and certain makers are putting out specially designed boilers for this service, having a very deep fire-box.

Boiler Setting and Foundations. Brick setting of boilers, as

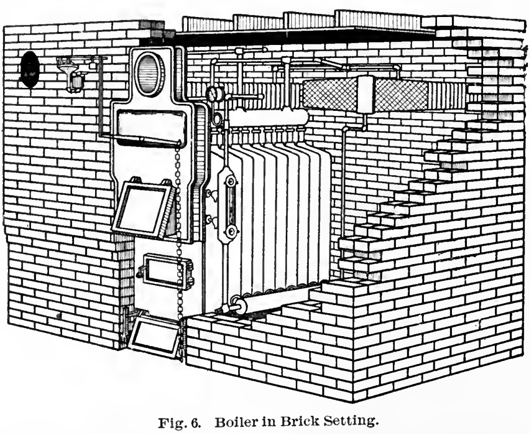


Fig. 6. Boiler in Brick Setting.

in the case of furnaces, has been quite generally discarded, except in cases where the space around and above the boiler is used as a central heating chamber for indirect systems, the radiators being placed above the heater (see Fig. 6). The pipes lead off as in furnace heating.

The ash-pits under most boilers are rather shallow; therefore

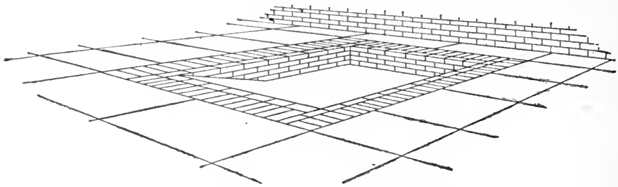


Fig. 7. Pit for Collection of Hot Ashes.

it is a good plan to excavate and build a pit not less than 4 to 6 inches below the floor, to give additional space for the collection of hot ashes, thus avoiding the burning-out of grates. Such pits should be built preferably of brick, and the bottom should be paved with bricks on edge, to prevent their being easily dislodged. Fig. 7 shows the general arrangement of an ash-pit built as described.

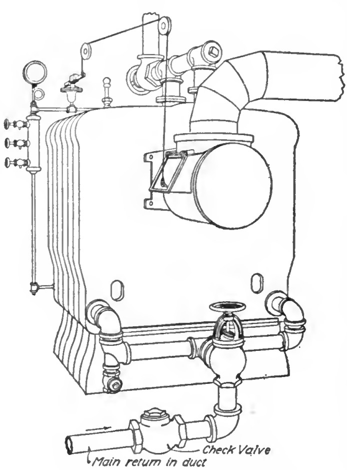
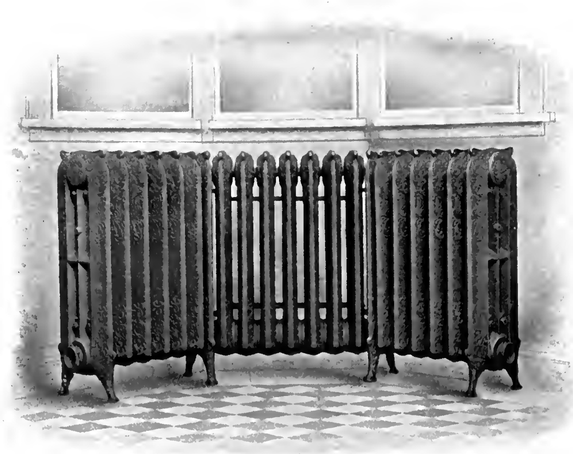


Fig. 8. Typical Arrangement of Return, Showing Check Valve.

Boiler Connections. Small jobs frequently have no stop valves at the boiler. In the case of larger ones, or where there are two boilers, valves in the supply mains must always be accompanied with check valves in the returns; otherwise, in case a stop valve in the main steam line is closed, the water will be backed out of the main returns at the boiler, by the pressure. Should the water partially leave the boiler in this manner and then suddenly return, the water coming in contact with the heated sections will crack them.

A stop valve should be placed between the boiler and the check valve in the return. A typical arrangement of return, etc., is shown



TRITON THREE-COLUMN BAY-WINDOW RADIATOR
United States Radiator Co., Dunkirk. N. Y.

in Fig. 8. It is convenient to have an independent drain connection from the returns to provide for drawing off the water in the system without emptying the water from the boiler. The latter, of course, has its independent blow-off cock. The water supply to the boiler should be controlled by a lock-shield valve or a cock that cannot be tampered with by any person not in charge. Boilers having eight sections or more, as a rule, have two or more steam outlets, thus reducing the likelihood of the boiler priming or making wet steam, since, with a single outlet, the velocity of steam through it may be so great that the water is picked up and carried into the piping system.

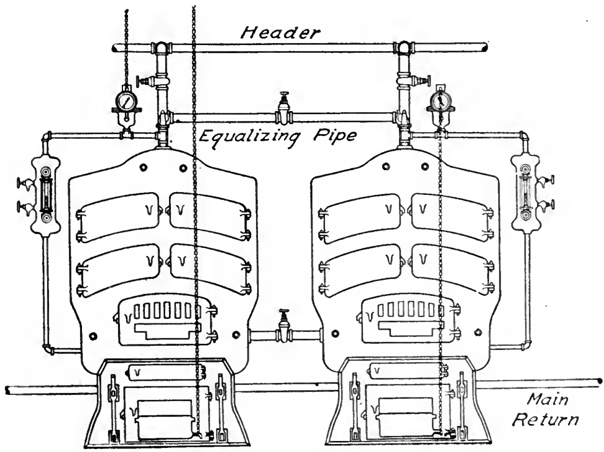


Fig. 9. Method of Connecting Two Boilers.

When two boilers are to be connected, especial care must be taken to make them maintain an even water line when working together. Fig. 9 shows a method of making these connections that is simple and effective. The valved connection between the two boilers, below the water, gives free communication between them, making them work as one and preventing a difference in the water level in the two boilers. The equalizing pipe is often omitted, the header being made about twice the diameter of the pipes leading to it from the boilers.

The returns are connected with the twin boilers practically as shown in Fig. 8, the check valve being placed between the stop valve of each boiler and the main return.

Boiler Fittings or Trimmings. It is important to have a reliable safety-valve, preferably one of the "pop" type specially designed for steam heating systems.

The damper regulators used are of the ordinary diaphragm pattern, and should be connected by chains with both the lower draft door below the grate, and with the cold-air check in the smoke connection.

The steam gauge with siphon, the water column, water gauge, gauge cocks, etc., require no special description.

Capacity of Boilers. Boiler capacities are commonly expressed in the number of square feet of direct radiating surface they will supply without undue forcing. Mains and risers should, of course, be added to the actual amount of surface in the radiators and coils. Even if the pipes are covered, a small allowance should be added to the combined surface of the radiators. Not less than 50 per cent, and preferably 60 per cent, must be added to indirect radiation, to reduce it to equivalent direct radiation; and not less than 25 to 30 per cent to direct-indirect radiation, to get its equivalent in direct surface. Another point to be kept in mind in selecting a boiler for heating rooms to be kept at different temperatures, is that more heat is given off per square foot of radiation in a room at 50°, for example, than in a room kept at 70°, the amount given off being approximately proportional to the difference in temperature between the steam and the air. With steam at, say, 220°, corresponding to a trifle over 2 pounds' pressure, the difference, in the case assumed, would be $220° - 50° = 170°$, and $220° - 70° = 150°$. That is, the actual amount of radiation in the rooms to be kept at 50° should be multiplied by $\frac{170}{150}$ to ascertain the amount of radiation in a 70° room that would give off the same amount of heat.

It is common practice to allow roughly for the loss of heat from uncovered mains, branches, and risers, by adding about 25 per cent to the actual direct radiating surface in radiators and coils.

Example. What should be the capacity of a boiler to supply steam to 1,000 square feet of direct radiation in a room to be kept at 70°, to 800 square feet of indirect radiation; and to 1,500 square feet of direct radiation, in rooms to be kept at 50° F.?

Direct radiation	1,000 sq. ft.
Equivalent in direct radiation of 800 sq. ft. of indirect = $800 \times 1\frac{1}{2}$ =	1,200 " "
Equivalent in direct radiation, in rooms at 70°, of 1,500 sq. ft. in rooms at 50° = $\frac{17}{15} \times 1,500$ =	1,700 " "
Total equivalent D. R. S. (direct radiating surface) exposed in 70° air =	3,900 sq. ft.
Add 25 per cent of actual surface to allow approximately for piping =	825 " "
Total equivalent D. R. S., or Boiler Rating =	4,725 sq. ft.

Grate Surface and Heating Capacity. It is advisable always to check the catalogue ratings of boilers as follows, when selecting one for a given service:

Suppose the Direct Radiating Surface, including piping, is 3,000 square feet. One square foot, it may be assumed, will give off about 250 heat units in one hour—a *heat unit* being the amount of heat necessary to raise the temperature of 1 pound of water 1 degree Fahrenheit. A pound of coal may safely be counted on to give off to the water in the boiler 8,000 heat units. Now, 3,000 sq. ft. × 250 heat units ÷ 8,000 heat units, gives the amount of coal burned per hour; and this, divided by the square feet of grate, gives the rate of combustion per square foot per hour. Suppose in this case, the grate has an area of 15 sq. ft.; then $\frac{3000 \times 250}{8000 \times 15} = 6.25$ pounds coal burned per square foot of grate surface per hour. This is not a high rate for boilers of this size, though for ordinary house-heating boilers the rate should not exceed 5 pounds; and for small heaters having 2 to 4 square feet of grate, the rate should be as low as 3 to 4 pounds per square foot of grate per hour. Otherwise, more frequent attention will be required than it is convenient to give to the operation of such small boilers. This is where depth of fire-box plays an important part, for, with a shallow fire, the coal quickly burns through, necessitating frequent firing.

Coal Consumption. For house-heating boilers a fair maximum rate of combustion is 5 pounds per square foot of grate per hour. In many residences it is the custom to bank the fire at night, when the rate will fall to, say, 1 pound. In cold weather, then, one square foot of grate would burn 5 pounds of coal for each of 16 hours, and 1 pound during each of the remaining 8 hours, a total of 80 + 8 = 88 pounds.

In many sections of the country, the average outside temperature during the heating season is about 40°; and since the heat required is proportional to the difference in temperature between indoors and outside, the average coal consumption would be only $\frac{70^\circ - 40^\circ}{70^\circ - 0^\circ} = \frac{3}{7}$ of the maximum in zero weather.

With a heating season of 200 days, the coal burned on one square foot of grate would be $200 \times \frac{3}{7} \times 88 = 7{,}600$ pounds in round numbers, corresponding to an average rate throughout the season of $\frac{7{,}600 \text{ pounds}}{200 \text{ days} \times 24 \text{ hrs.}} = 1.6$ pounds approximately.

A method of approximating the coal consumption for a given amount of radiating surface, designed to maintain a constant temperature in rooms of 70° day and night, would be to multiply the surface (which, for example, take at 1,000 square feet, including allowance for mains) by 250 heat units—the amount given off by a square foot per hour—and then multiply the product by $\frac{3}{7}$, as explained above, to allow for average conditions. This gives $1{,}000 \times 250 \times \frac{3}{7}$, which, divided by 8,000 heat units per pound of coal, gives the weight of coal required per hour; and this, multiplied by the hours per season, gives the total consumption.

Non-Conducting Coverings. It is customary to cover cast-iron sectional boilers with non-conducting material composed as a rule chiefly of asbestos or magnesia applied in a coating $1\frac{1}{2}$ to 2 inches thick, the exterior being finished hard and smooth.

Exposed basement piping in first-class work is covered with sectional covering $\frac{3}{4}$ inch to 1 inch thick, according to the character of the work.

The loss of heat through fairly good coverings, is not far from 20 per cent of the loss from a bare pipe, which, with low-pressure steam, is approximately 2 heat units per square foot per hour for each degree difference in temperature between the steam and the surrounding air.

STEAM RADIATORS AND COILS

Direct Radiators. The commonest forms of radiators to-day are the cast iron vertical loop varieties, types of which are shown in Figs. 2 and 13 in Part I (Heating and Ventilation). These are made up with slip-nipple or screw-nipple connections, the standard height being about 36 to 38 inches.

It is, of course, advisable to use radiators of standard height when possible, since they are cheaper than the lower radiators, which must

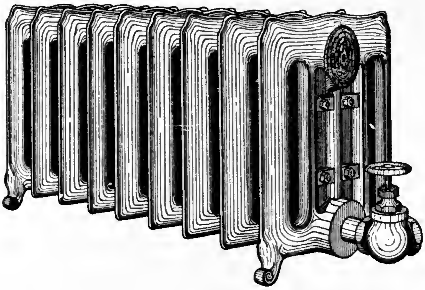


Fig. 10. Low Radiator to be Placed Below Window Sill.

be used when placed below window sills (see Fig. 10). Single-column radiators are more effective than those having a greater number of vertical loops, since in the latter the air flow is retarded and the outer loops cut off the radiant heat from the inner ones. Radiators with four or more columns are generally used where the length of the space in which they must be placed is limited.

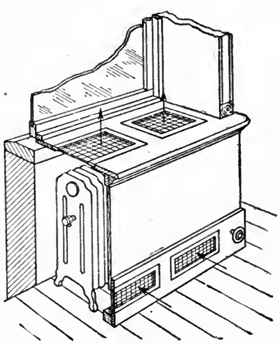


Fig. 11. Concealed Radiator with Register Face.

Wall radiators (see Fig. 4, Part I, Heating and Ventilation) have become very popular because of their neat appearance and the small distance they project into the room. They are very effective heaters, and, although more expensive than certain other types of cast-iron radiators, less surface is required, which tends to offset the increased cost. These radiators are made up in such a variety of forms that they can be adapted to almost any location.

Concealed Radiators. A favorite method of concealing radiators is to place them below window-sills, with a grating or register face in front of and above them, as shown in Fig. 11. By this arrangement, the radiant heat is to a great extent cut off. The gratings must have ample area to permit the free circulation of air, and should have not

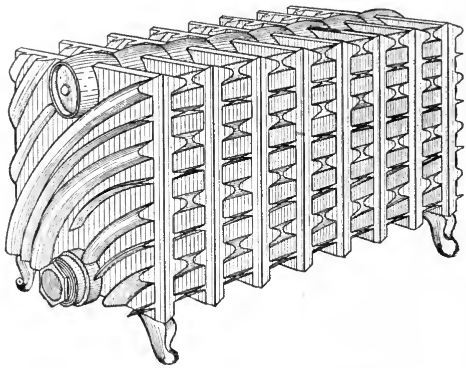


Fig. 12. Radiator for Use without Gratings.

less than 2 or $2\frac{1}{2}$ square inches of free area to each square foot of radiating surface, for inlets and outlets respectively. It is advisable to increase these allowances slightly when possible.

The same rule applies to radiators placed below seats. A radia-

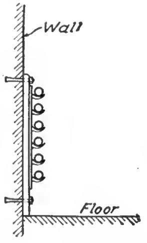


Fig. 13. Hook Plates.

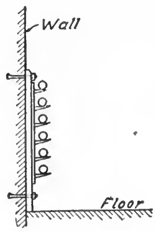


Fig. 14. Expansion Plates.

tor designed specially for this purpose, for use without gratings, is shown in Fig. 12.

Wall Coils. An ordinary wall coil or manifold coil, made up generally of $1\frac{1}{4}$-inch pipe, with branch tees or manifolds, is illustrated in Fig. 39, Part I (Heating and Ventilation). The long runs of such coils rest on hook plates (Fig. 13); the short pipes near the corner, on expansion plates (Fig. 14), on which the pipes are free to move when the long pipes expand. Such coils are very effective when placed below the windows of a factory, in which class of buildings they find their widest application.

Miter Coils. Miter coils, as shown in Fig. 15, are used for over-

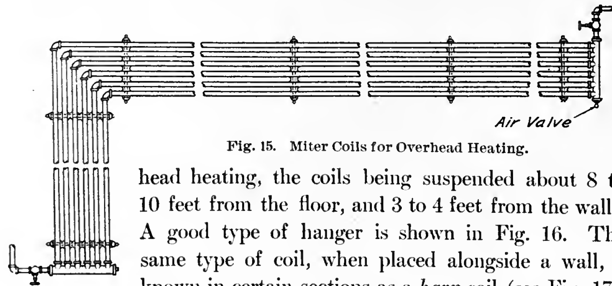


Fig. 15. Miter Coils for Overhead Heating.

head heating, the coils being suspended about 8 to 10 feet from the floor, and 3 to 4 feet from the walls. A good type of hanger is shown in Fig. 16. The same type of coil, when placed alongside a wall, is known in certain sections as a *harp* coil (see Fig. 17), and may be used where long runs must be made along a wall, but where it is impossible to install the type of coil shown in Fig. 39, Part I (Heating and Ventilation), owing to doorways or other obstructions. Two harp coils could be used along a wall, for example, avoiding a doorway; and the expansion of the pipes would be provided for by the short vertical lines.

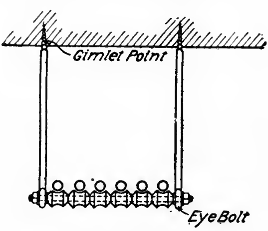


Fig. 16. An Approved Type of Hanger.

Return-Bend Coils. Return-bend coils, known in some parts of the country as *trombone* coils, are shown in Fig. 40, Part I (Heating and Ventilation). These are suitable only for rather short runs, since the steam must pass through the several horizontal pipes successively, and, if the radiating surface is greater than the capacity of the upper line of pipe to supply it properly, the steam is condensed before reaching the lower lines. With the harp or other coils having headers or branch tees, sufficient steam can enter to fill all the pipes at once, passing through the parallel lines at the same time.

Direct-Indirect Radiators. A *direct-indirect* radiator is shown in Fig. 18. The air enters through a louvered or slatted wall opening with screen. Provision is made to shut this off and admit air simultaneously from the room, making the radiator essentially a direct radiator when the cold air is shut off. The best location for the cold-air opening is probably just below the sills, the wall boxes being less conspicuous in this position.

Two forms of indirect radiators are shown in Fig. 7, Part I, and Fig. 3, Part II (Heating and Ventilation), the shallow sections being used largely for house heating, the deep ones for schoolhouse systems. The latter are provided with extra long nipples for spacing the sections about 4 inches on centers, to give a proper passage for a large volume of air.

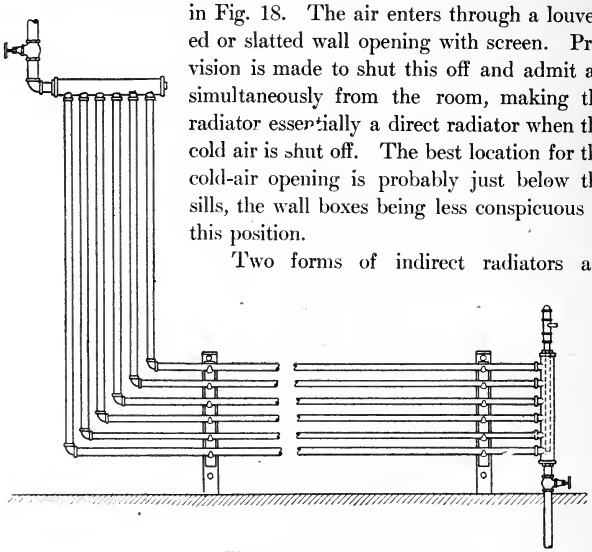


Fig. 17. Harp Coil.

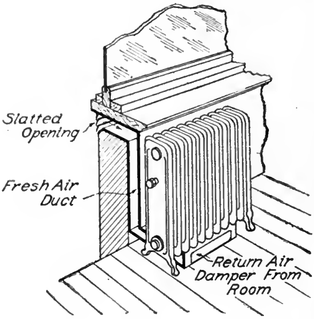
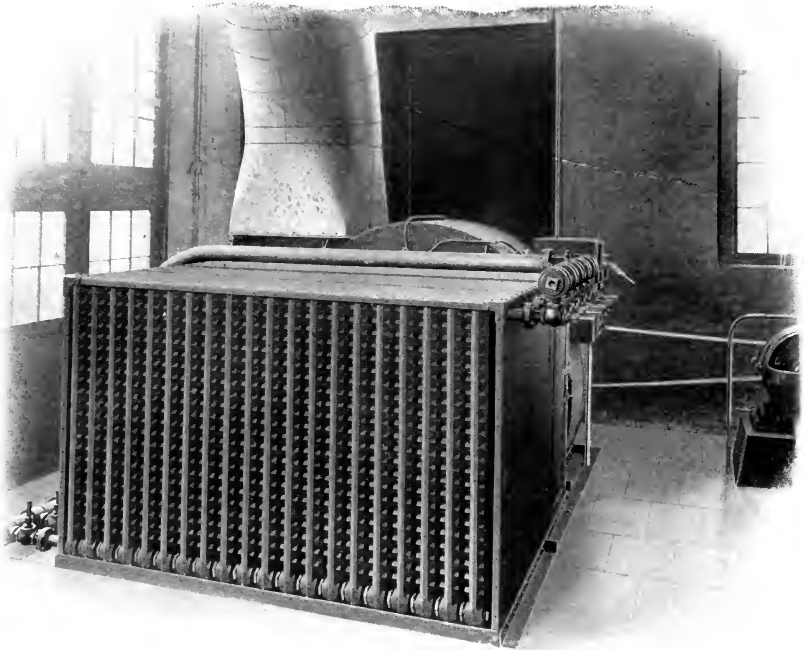


Fig. 18. Direct-Indirect Radiator.

Indirect Radiators. The indirect radiators are enclosed in galvanized-iron casings about 30 inches deep, giving a space of 6 or 8 inches above and below the radiators. The beams over the radiators are commonly covered with rough boards, to which tin or



GROUP OF VENTO CAST-IRON HOT-BLAST HEATERS, TWENTY SECTIONS LONG
American Radiator Co., Chicago, Ill.

tin and asbestos is nailed, the casing being flanged at the top and screwed or nailed to these boards.

The casings should be made with corners of a type that will permit the ready removal of the sides in case of repairs being needed; and the bottom of the casing should be provided with a slide for inspection and cleaning. The larger sections, when used for schoolhouse heating, are arranged as shown in Fig. 19, with a mixing damper designed to cause a mingling of the warm and cold air in the flue, the volume discharged being but slightly reduced, with a decrease in temperature due to opening the damper to cold air. The space for the passage of air between the shallow sections containing about 10 square feet each, is about $\frac{1}{3}$ of a foot; the space between the sections of the deep pattern is not far from $\frac{1}{2}$ a foot when the sections are properly spaced.

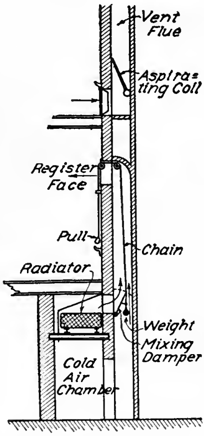


Fig. 19. Arrangement of Casings for Use in Connection with Indirect Radiators.

Heat Given Off by Steam Radiators. Of the heat emitted by direct radiators, approximately one-half is by radiation, the balance by convection or the contact of air. Since practically no heat is radiated from concealed radiators, it is very important that proper provision should be made for the passage of an adequate volume of air over the heating surface.

TABLE I

Heat Units Emitted from Radiators and Coils

Radiation per square foot of radiating surface per hour.—In rooms at 70° F. temperature.—With steam at 3 to 5 pounds' pressure.

Type of Radiator	Heat Units Emitted (Approximate)
Concealed cast-iron direct radiators	175–200
Ordinary cast-iron vertical-section radiators	250
Wall radiators	300
Pipe coils on walls	325
Pipe coils overhead (pipes side by side)	350
Ordinary cast-iron extended-surface indirect radiators (air admitted from outdoors)	400

Wall radiators and coils give off more heat under the same conditions than is emitted by ordinary vertical cast-iron radiators.

Much might be said regarding the efficiency of radiators due to their height, form, and arrangement. For the purposes of this course, however, only fair average values will be given, as set forth in Table I, a discussion of radiator tests, etc., being omitted to avoid unnecessary detail.

STEAM PIPING

Size of Main for Circuit System. Since the main of a circuit system, as described in Part I (Heating and Ventilation), must carry both steam and water of condensation, it should be made considerably larger in proportion to the surface supplied than mains which are dripped at intervals or which carry only the condensation from the main itself.

Sizes, ample for circuit mains of ordinary length, are indicated in the accompanying table:

TABLE II

Sizes of Circuit Mains

Diameter of Circuit Main	Direct Radiating Surface
2 inches	200 sq. ft.
2½ "	350 " "
3 "	600 " "
3½ "	900 " "
4 "	1,200 " "
4½ "	1,700 " "
5 "	2,100 " "
6 "	3,000 " "

Dry Return System. In many cases it is desirable to run the supply and return mains overhead. Such systems contain less water than wet return systems, and are therefore more susceptible to changes in the fire, because of the smaller quantity of water in the apparatus. The return mains must be made larger than when they are placed below the water line, since they are filled with steam, except the space occupied by the return water running along the bottom. The pipes should have a greater pitch than wet returns.

With dry returns, if certain supply risers are of inadequate size, steam is apt to back up into the radiator through the dry returns and to cause a holding-back of the water in the radiators. To prevent this, check valves are sometimes introduced in the branch returns. If the piping is properly proportioned, however, this is unnecessary. Siphon drips are frequently used, as explained in Part I (Heating and Ventilation).

Wet Return Systems. This system, illustrated in Fig. 20, provides for water sealing all returns and drips, and avoids the backing-up action mentioned above. Suppose, for example, the pressure in one of the vertical returns is ½ pound less than in the others; then, since a column of water 2.3 feet high corresponds to 1 pound pressure, the water will back up this particular return about 1.15 feet higher than in the others and thus equalize the difference in pressure. Where the mains must be long, the wet return system affords the opportunity to rise and drip the supply main as often as necessary; whereas, with the dry return system, the main and return have a gradual pitch from start to finish. This often brings the return so low as to interfere with head room. With the wet return system the return may be dropped below the floor line at doorways without interfering with the circulation. The sizes of wet returns may be made considerably smaller than dry returns for a given radiating surface, as shown in Table III.

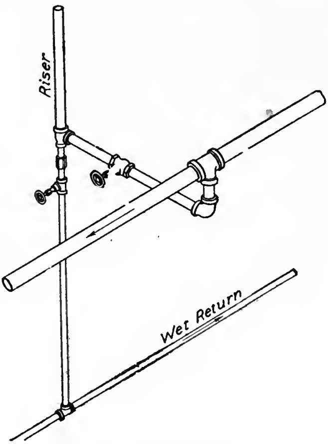


Fig. 20. Wet Return System.

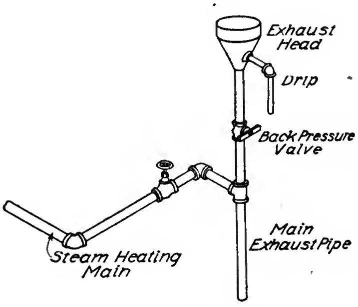


Fig. 21. Overhead Feed System.

Overhead Feed System. The overhead feed system (see Fig. 21) is most commonly used in connection with exhaust steam plants, since in such systems the exhaust pipe from the engines must be carried to the roof, and the steam supply to the building may conveniently be taken from a tee near the upper end of this pipe. The main should be pitched down, and outlets taken from the bottom, to drain the condensation through the risers (see Fig. 22). With this system the water of condensation always flows in the same direction as the steam; hence the horizontal pipes and the risers may be made somewhat smaller than in up-feed systems.

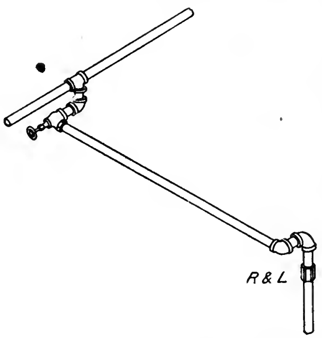


Fig. 22. Outlet Taken from Bottom of Main.

This system has the advantage of placing the big pipes in the attic, where their heating effect is less objectionable than in the basement. As the pipes gradually decrease in size from top to bottom, this gives small pipes on the lower floors, which in modern buildings generally contain a few large rooms and little space for concealing pipes. It is frequently advisable to combine with this system the up-feed method of heating the first floor, which is generally high-studded and requires a large amount of radiation. Relieving the down-feed system of this load means smaller risers throughout the building, which, in the modern sky-scraper, results in a saving that more than offsets the cost of the separate up-feed system for the lower floor. Another reason why it is advisable to put the lower floor on a separate system, is that the steam is dry, whereas the steam from an overhead system becomes pretty wet from condensation by the time it reaches the lower floor.

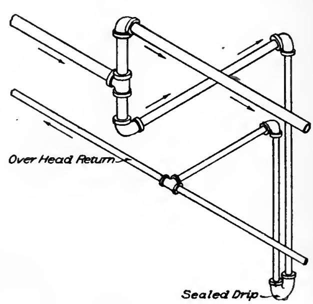


Fig. 23. Siphon Trap.

DIRECT-INDIRECT SYSTEM OF WARMING, SHOWING ADJUSTABLE DAMPER.
American Radiator Company.

One-Pipe System. The one-pipe up-feed system is most commonly used in connection with relatively small heating plants. It has the advantage of simplicity, there being but a single valve to operate. In tall buildings with the up-feed system, the risers must be objectionably large to provide for the passage of steam up, and water of condensation down, the same pipe. With the overhead system, the risers may be made considerably smaller, since the water is not hindered in its passage by a flow of steam in the opposite direction. With this one-pipe system, the radiator connections should be short and pitched downward toward the risers to avoid pockets. When used in high buildings with the overhead system, the lower portion of the risers must be liberally proportioned, otherwise the steam will become too wet.

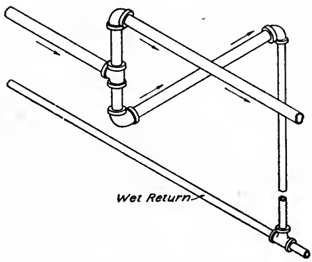


Fig. 24. Arrangement to Rise and Drip in Mains at Intervals.

The Two-Pipe System. This system is commonly used where the radiator connections must be long and where it would be impossible to secure a proper pitch to insure good drainage with one-pipe radiator connections. Coils are nearly always made up with two-pipe connections. In high buildings, where a large amount of radiation must be carried by each riser, they may be made smaller if two-pipe connections are made with the radiators. This is often a decided advantage, especially if the risers are to be concealed.

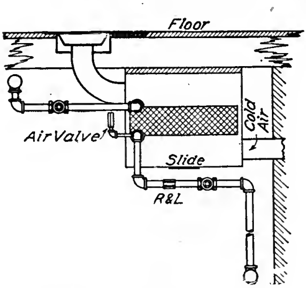


Fig. 25. Arrangement for Draining with Indirect System.

Draining Mains and Risers. With long mains, it frequently is the case that if given a continuous pitch they would be too low at the extreme ends; and it is therefore customary to rise and drip at intervals, as shown in Figs. 23 and 24.

The *siphon trap* (Fig. 23) prevents a greater pressure being introduced along the overhead return than occurs at the extreme end, since any excess in pressure at an intermediate point merely forces down the water in the inlet leg of the siphon trap to a point where the difference in pressure in the two mains is equalized by the higher level of water maintained in the outlet pipe of the syphon trap.

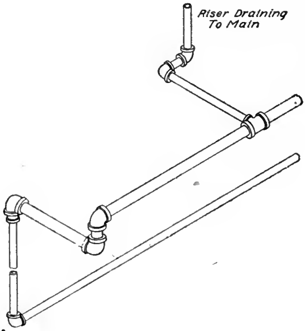


Fig. 26. Risers Drained to Main and Main Drained at End.

With indirect systems, the mains are frequently drained through the benches or stacks of radiators, the connections being taken from the bottom of the main. It is assumed that all the indirects will not be shut off at the same time (see Fig. 25).

Mains and risers are commonly drained as shown in Fig. 20, connections being taken from the bottom of the main and the heel of the riser. Risers are not infrequently drained to the main, which in turn is drained at the end (see Fig. 26). This arrangement requires less fitting than when the risers are relieved at the base, as shown in Fig. 20. If the mains are long, they should be dripped at intervals of 50 to 75 feet.

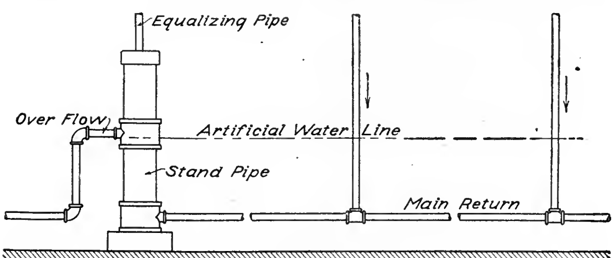


Fig. 27. Showing Artificial Water Line.

Overhead-feed mains on a down-feed system are nearly always dripped from the bottom to the various risers, as previously stated.

Artificial Water Line. It is sometimes necessary, when a boiler is set very low with reference to the returns, and it is desired to use a wet return system, to seal the relief pipes by means of an artificial water line established as shown in Fig. 27. The equalizing pipe is to be connected with a steam main.

When the discharge from the system leads to an open return, a trap must be used. One of the type shown in Fig. 28, arranged with an equalizing pipe and set at the proper level, will hold the water line in the system, no standpipe being required.

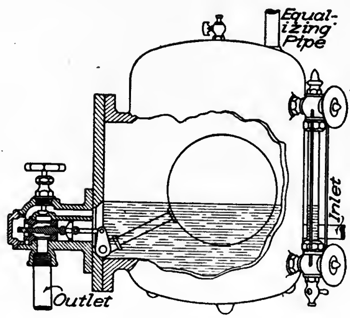


Fig. 28. Water Line Trap with Equalizing Pipe.

Pipe Sizes.—Mains. The capacities of pipes to supply heating surface increase more rapidly than their sectional areas; that is, a 6-inch pipe, with about four times the area of a 3-inch pipe, will supply nearly six times as much surface.

Table III shows the amounts of radiating surface in gravity-return systems which main pipes 100 feet long, of different diameters, may be safely counted on to supply with low-pressure steam (say, 3 to 5 lbs.).

In case the radiating surface is located some distance above the water line in the boiler, the carrying capacity of the pipes may be increased as much as 50 per cent, owing to the greater drop in pressure that may be allowed without interfering with the return of water to the boiler.

Mains are frequently made much larger than necessary, simply because the fact has been overlooked that the radiators are located well above the boiler, and that a drop in pressure between the boiler and the end of the main of $\frac{1}{4}$ lb., or even more, would be permissible.

The greater the drop in pressure allowed the smaller may be the pipe for a given capacity.

Pipe Sizes.—One-Pipe Risers. Riser capacities are given in Table IV.

TABLE III

Capacity of Supply Mains, Gravity Return System, and Size of Dry and Wet Returns

Mains 100 ft. long.—Steam at low pressure (3 to 5 lbs.).

Diameter of Supply Pipe	Capacity in Direct Radiating Surface	Diameter of Dry Return	Diameter of Wet Return
1 inch	55 sq. ft.	¾ inch	¾ inch
1¼ inches	115 " "	1 "	1 "
1½ "	175 " "	1¼ inches	1¼ inches
2 "	325 " "	1½ "	1¼ "
2½ "	570 " "	2 "	1½ "
3 "	1,000 " "	2½ "	2 "
3½ "	1,480 " "	3 "	2½ "
4 "	2,000 " "	3 "	2½ "
4½ "	2,770 " "	3 "	2½ "
5 "	3,500 " "	3½-4 "	3 "
6 "	5,700 " "	4-5 "	3½-4 "
7 "	8,800 " "	4-5 "	4 "
8 "	12,000 " "	4-5 "	4 "
10 "	20,000 " "	5-6 "	4 "
12 "	33,000 " "	5-6 "	4-5 "

For lengths greater than 100 ft. and for same drop in pressure as for 100 ft., multiply the above figures by 0.8 for 150 ft.; 0.7 for 200 ft.; 0.6 for 300 ft.; 0.5 for 400 ft.; 0.4 for 600 ft.; and 0.3 for 1,000 ft. When the pressure at the supply end of the pipe can be increased for long runs so that the drop in pressure for each 100 ft. can be the same, then the figures in the table can be used for long runs.

TABLE IV

Capacities of One-Pipe Risers

Size of Pipe	Capacity, Up-Feed	Capacity, Down-Feed
1 inch	30 sq. ft.	60 sq. ft.
1¼ inches	60 " "	110 " "
1½ "	120 " "	160 " "
2 "	200 " "	260 " "
2½ "	300 " "	400 " "
3 "	450 " "	600 " "
3½ "	620 " "	800 " "
4 "	800 " "	1,000 " "

The capacities of the 1-inch and 1¼-inch pipes for up-feed are somewhat greater than those stated; but they are given as above, since these figures correspond closely to standard radiator tapping, and it is advisable to make the pipes of the same size as the tapped openings.

In high buildings with the down-feed system, the lower half of the risers should be based on not much more than half the capacities stated in the right-hand column, in order that the pipes may be of ample size to carry off the great amount of condensation from the radiators above, without making the steam too wet for use in the radiators below. The pipe to the lowest radiator connection should be not less than 2-inch.

Pipe Sizes.—Two-Pipe Risers. With the two-pipe system, the capacity of the risers is of course, considerably greater than with the one-pipe system, since the condensation is carried off through a separate system of returns.

Table V gives the approximate capacities of risers for the two-pipe system.

TABLE V

Capacities of Two-Pipe Risers

Size, Supply Riser	Capacity, Up-Feed System	Capacity, Down-Feed System	Size, Return Riser
1 inch	50 sq. ft.	55 sq. ft.	¾ inch
1¼ inches	100 " "	115 " "	1 "
1½ "	150 " "	175 " "	1 -1¼ inches
2 "	270 " "	325 " "	1 -1¼ "
2½ "	470 " "	570 " "	1¼-1½ "
3 "	840 " "	1,000 " "	1¼-1½ "
3½ "	1,200 " "	1,480 " "	1½-2 "
4 "	1,600 " "	2,000 " "	1½-2 "

In buildings over six stories high, with the up-feed system, use 10 per cent less surface than stated in the third column, to allow for the increased length and condensation.

Pipe Sizes, Indirect. Supply connections with indirect radiators must be larger for a given surface than for direct radiators. The following table gives ample sizes when the radiators are but little above the water line of the boiler. When this distance is considerable, the pipes may be safely rated to supply one-third more surface; for a greater drop in pressure may be allowed between the

TABLE VI

Sizes of Supply Connections for Indirect Radiators

Diameter of Pipe	Indirect Radiating Surface Supplied
1 inch	40 sq. ft.
1¼ inches	70 " "
1½ "	100 " "
2 "	180 " "
2½ "	330 " "
3 "	600 " "
3½ "	900 " "
4 "	1,200 " "
4½ "	1,600 " "
5 "	2,100 " "
6 "	3,400 " "
7 "	5,400 " "
8 "	7,200 " "

supply and the return mains, and drop in pressure means a greater velocity in the pipes, and consequently a greater flow of steam to the radiators.

Indirect radiators are seldom tapped larger than 2 inches; therefore radiators that require larger connections should be subdivided in groups.

STEAM PRESSURES AND TEMPERATURES

Steam pressures and temperatures have a certain definite relation to each other, the temperature increasing with the pressure, but not as rapidly for a given increase with high-pressure as with low-pressure steam. For example, with an increase in pressure from 10 pounds to 20 pounds, the temperature rises about 19° F.; whereas with an increase of 10 pounds from 90 to 100 pounds the temperature increases

TABLE VII

Temperature of Steam at Various Pressures

Vacuum (in Inches of Mercury)	Temp. °F.	Gauge Pressure (lbs. per sq. in.)	Temp. °F.
0	212.1	0	212
5	203.1	1.3	216.3
10	192.4	2.3	219.4
12	187.5	3.3	222.4
14	182.1	4.3	225.2
16	176.0	5.3	227.9
18	169.4	10.3	240.0
20	161.5	20.3	259.2
22	152.3	30.3	274.3
24	147.9	40.3	286.9
26	125.6	50.3	297.8
28	101.4	60.3	307.4
		70.3	316.0
		80.3	323.9
		90.3	331.1
		100.3	337.8
		150.3	365.7
		200.3	387.7

only about 7° F. From atmospheric pressure to 10 pounds' gauge pressure, the increase in temperature is nearly 28° F; a slight difference in the pressure in radiators making a marked difference in their temperature.

In the case of a *partial vacuum*, so called—expressed generally in inches of mercury—the decrease in temperature as a condition of perfect vacuum is approached is very marked, as shown in table VII, which gives also steam temperatures corresponding to various pressures. The latter are given in each case $\frac{3}{10}$ of a pound in excess of the gauge pressure, as practically all tables of the properties of steam give the absolute pressure—that is, the pressure above a vacuum—the absolute pressure corresponding to 5.3 pounds' gauge pressure, for example, being 20 pounds absolute.

The atmospheric pressure at sea-level is practically 14.7 pounds absolute, and the boiling point of water is 212°. As the pressure decreases, due to altitude or to the removal of air from a vessel by artificial means, the boiling point falls.

EXPANSION

Amount of Expansion. An allowance of $\frac{8}{1000}$ of an inch per 100 feet of pipe for each degree rise in temperature, is a fair allowance in computing the amount of expansion that will take place in a line of pipe.

One must assume the temperature at which the pipe will be put up—say anywhere from 0° to 40° in an unfinished building in winter—and, knowing the pressure to be carried, look up in a table of the properties of saturated steam the temperature corresponding. See table VII.

Example. Find the expansion that will take place in a line 100 feet long put up in 30-degree weather, when it is filled with steam at 80 pounds' pressure. The temperature corresponding to 80 pounds'

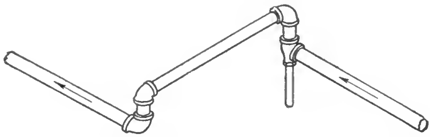


Fig. 29. Offset and Swivels.

steam pressure is 324°; the increase from 30° is 294°, which multiplied by $\frac{8}{1000}$ gives $2\frac{35}{100}$ inches expansion, or, expressed in decimals, 2.35 inches.

In low-pressure work 100 feet of pipe heated from 30° to 230° will expand about 1.6 inches.

Provision for Expansion. The expansion of mains can generally be provided for by offsets and swivels, as shown in Fig. 29. All that is necessary is to have the two vertical nipples placed far enough apart, as determined by the length of the horizontal offset, to permit the expansion to take place without too much turning on the threads. The less the turn, the less will be the likelihood of leakage. The shorter the offsets, the greater the number that must be used.

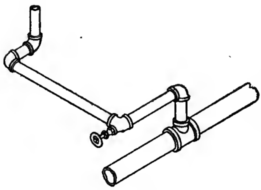


Fig. 30. Swing to Allow for Expansion of Risers.

A pretty conservative rule would be to allow 4 feet of offset to each inch of expansion to be taken up on the line. In the case of underground work a good deal of the expansion can be taken up where pipes enter buildings by the same kind of swings as shown in Fig. 29, making them longer and thus reducing the number of expansion joints or offsets in the tunnel or duct.

Expansion of Risers. In providing for the expansion of risers, considerable skill must be used, especially in tall buildings. In buildings of not over 6 to 8 stories, or possibly 10 floors at the outside, if they are not high-studded, the expansion may all be taken up in the basement, using swings like those shown in Fig. 30, similar swings being used in the attic also if the overhead-feed system is used, the connections being taken from the bottom of the main, as previously stated.

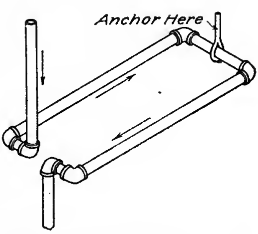


Fig. 31. Expansion Joints. Offsets Nearly Horizontal.

In higher buildings than those mentioned, either slip-pattern expansion joints or swivels made up of pipe and fittings are commonly used. One of these to every six to eight floors is generally considered sufficient, depending on the length and arrangement of the radiator connections. One must be sure the pipes above and below slip joints are in proper alignment; otherwise, binding and leakage will occur. If the risers are concealed, such joints must be made accessible through proper openings in the walls, as the packing will have to be taken up from time to time and replaced.

Expansion joints made up of pipes are illustrated in Fig. 31. Such joints are unsightly if exposed; but they may generally be concealed either in specially provided pockets in the floor or in spaces furred down below the ceilings and near the walls.

When expansion joints are used, the risers should be anchored about midway between them. These anchors consist merely of clamps around the pipes fastened to the beams, one type being shown in Fig. 32.

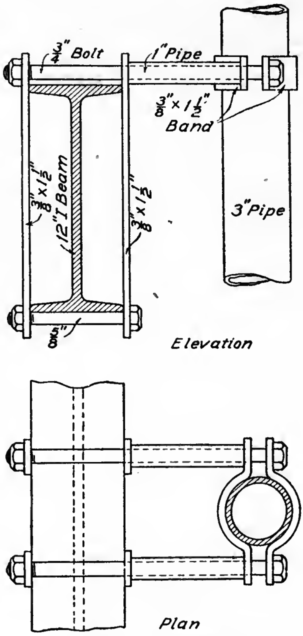


Fig. 32. Anchor for Riser.

Radiator Connections. Considerable ingenuity is exhibited by good fitters in arranging radiator connections. One should always study the end sought, and then provide the necessary means to secure that end. For example, on a floor at which the riser is anchored, almost any sort of radiator connection will answer, since expansion need not be provided for.

Where expansion takes place, swivels must be provided in the radiator connections, to allow for same. Fig. 33 shows a convenient way of taking off radiator connections from risers, any expansion

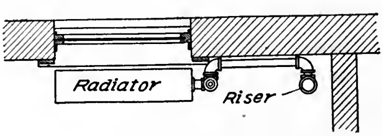


Fig. 33. Radiator Connections from Riser.

being taken up by the turning of the horizontal connection in the parallel nipples. The connection should of course pitch back toward the riser, to drain freely. Where the expansion is considerable, this is difficult to accomplish unless the radiator is slightly raised.

When risers must be located along the same wall as that on which the radiator is placed, the swivels may be arranged as shown in Fig. 34.

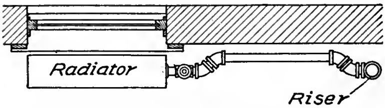


Fig. 34. Arrangement of Swivels when Risers are Located on the Same Wall as Radiator.

Radiators on the first floor have their connections made by angle valves with the pipes in the basement, to avoid running along the base-board. It is well to take the branch to the first-floor radiators from riser connections in the basement, rather than to cut into the mains for these branches. See Fig. 35.

COMPUTING RADIATION

Computing Direct Radiation. It is a perfectly simple matter to compute the amount of radiation required to heat a room, by finding the probable loss of heat per hour, and dividing this by the heat given off by a square foot of radiating surface in the same time.

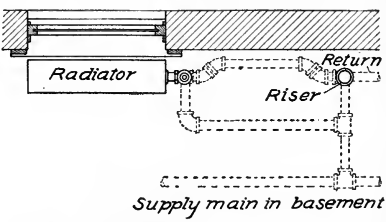


Fig. 35. Branch from Riser Connection in Basement.

Numerous tests have shown that an ordinary cast-iron radiator gives off approximately 1.6 heat units per hour per degree difference in temperature between the steam and the surrounding air. With low-pressure heating a square foot of direct radiation is commonly rated at about 250 H. U. Glass transmits about 85 heat units per square foot per hour, with 70° inside and 0° out; and walls of ordinary thickness may be reckoned as transmitting one-fourth as much heat.

The heat losses stated should be increased about 25 per cent for a north or west exposure, and about 15 per cent for an easterly exposure.

An allowance should be made for reheating rooms that are allowed to cool down slightly at night. This may be done most conveniently by adding to the loss of heat through walls and glass a number of heat units equal to 0.3 of the cubic contents of a room with two exposures, and 0.6 the contents of a room with a single exposed wall.

The way this works out may best be shown by a couple of examples:

Suppose we have a room 16 feet square and 10 feet high, with two exposed walls facing respectively north and west, each having a window three feet 6 inches by 6 feet.

Exposure of room = (16 + 16) × 10 =		320 sq. ft.
Glass surface = 2 × 21 sq. ft. =		42 " "
Net wall		278 sq. ft.
Equivalent glass surface (E. G. S.) of net wall = 278 ÷ 4 =	Approximately	70 sq. ft.
Actual glass surface =		42 " "
Total E. G. S.	Approximately	112 sq. ft.
Heat transmitted = 112 sq. ft. × 85 heat units × 1.25 factor =		11,890 H. U.
Allowance for reheating = 0.3 × cubic contents of 2,560 cu. ft. =		768 " "
Total heat loss to be made good by direct radiation		12,658 H. U.

This 12,658 heat units, divided by 250, the amount given off by one square foot of radiation in one hour, = 50 sq. ft. approximately, giving a ratio of 1 sq. ft. of radiating surface to 53 cubic feet of space.

Take as a second example a room with one exposure toward the east, the dimensions of the room being 14 by 14 by 10 feet, with one window 4 by 6 feet. Proceeding as before,

Exposure =	196 sq. ft.
Glass =	24 " "
Net wall	172 sq. ft.
E. G. S. of net wall = ¼ of same =	43 " "
Add actual glass =	24 " "
Total E. G. S.	67 sq. ft.
Heat loss per hour = 67 × 85 × 1.15 =	6,549 H. U.
Add 0.6 the contents to allow for reheating; 0.6 × 1,960 =	1,176 " "
Total heat loss	7,725 H. U.

This 7,725 heat units ÷ 250 = 31 sq. ft. radiation required, giving a ratio of 1 to 63 cubic ft.

The loss of heat through roofs and through ceilings to unheated attic spaces above may be allowed for conveniently, and with sufficiently close approximation to the actual heat loss, by dividing the area of the roof by 10, and that of the ceiling by 20, to give the E. G. S.

In the case of a well-constructed plank roof, with paper or other material above that will prevent the leakage of air, the roof area may safely be divided by 15 to ascertain the E. G. S.

It is hardly necessary, as a rule, to allow for the loss of heat through a first floor to the basement when the latter is well enclosed and contains steam and return mains or is otherwise kept at a moderate temperature.

Computing Direct-Indirect Radiation. The most common method of computing the amount of direct-indirect radiation required, is to ascertain, in the manner described, the direct radiating surface necessary, and add to it approximately 25 per cent; that is, if a direct radiator of 100 square feet were found to be necessary to heat a given room, a direct-indirect radiator of 125 square feet would be required.

Computing Indirect Radiation. To compute the amount of indirect radiation necessary to heat a given room, about the simplest method to grasp is to compute, first, the direct radiation required, as previously explained, and then add 50 per cent to this amount, since it happens that, under average conditions of 70° inside and 0° outside, practically $1\frac{1}{2}$ times as much surface is required to heat a given space with indirect as with direct heating.

When a stated air supply is required, the loss of heat by ventilation must be computed, and a different method followed in ascertaining the amount of indirect radiation required. For example, take a 50-pupil schoolroom with the common compulsory allowance of 30 cubic feet of air per minute per pupil—equal to 1500 cubic feet per minute per room. Each cubic foot escaping up the vent flue at 70° F., when the outside temperature is zero, removes from the room $1\frac{1}{4}$ heat units; hence the total heat loss by ventilation per hour would be $60 \times 1500 \times 1\frac{1}{4} = 112{,}500$ heat units. A standard schoolroom has about 720 square feet of exposure, of which not far from 180 square feet is glass, leaving a net wall of 540 square feet, which, divided by 4, gives 135 square feet equivalent glass surface. This, added to the actual glass, gives 315 square feet E. G. S., which, in turn, multiplied by 85 heat units × a factor of 1.25 for north or west, gives a total heat loss by transmission of 33,470 heat units approximately.

The combined loss of heat by transmission and ventilation amounts to 145,970 H. U.

With the greater air-flow through indirect heaters used in schools, the heat emitted per square foot per hour should exceed somewhat the amount given off by indirect radiators in residence work—namely, 400 H. U. To be on the safe side, allow 450 H. U. The total heat loss from the room, divided by this number, gives approximately 300 square feet as the surface required.

DUCTS, FLUES, AND REGISTERS

Areas of Ducts and Flues. The area of the cold-air connections with the benches or stacks of indirect radiators, are generally based on 1 to $1\frac{1}{4}$ square inches of area to each square foot of surface in the radiators.

The flues to the first floor should have $1\frac{1}{2}$ to 2 square inches area to each square foot of surface; those to the second floor, $1\frac{1}{4}$ to $1\frac{1}{2}$ square inches; and those to floors above the second, 1 to $1\frac{1}{4}$ square inches per square foot of radiation.

The sides and back of warm-air flues in exposed walls should be protected from loss of heat by means of a nonconducting covering, preferably $\frac{1}{2}$ inch thick.

Flue Velocities. A fair allowance for flue velocities with indirect steam heating is 275 feet per minute for the first floor, 375 feet for the second, 425 feet for the third, and 475 for the fourth.

Registers. The net area of registers should be 10 to 25 per cent in excess of the area of the flue with which they are connected. The net area of a register is commonly taken as $\frac{2}{3}$ the gross area; that is, a 12 by 15-inch register would have a net area of 120 square inches.

Registers in shallow flues must either be of the convex pattern, or be set out on a moulding to avoid having the body project into the flue and cut off a portion of its area.

Aspirating Heaters and Coils. To cause a more rapid flow of air in ventilating flues in mild weather, steam coils or heaters are used. These should be placed as far below the top of the vent flue as possible, for the higher the column of heated air, the greater the chimney effect. The smaller the flue in proportion to the volume of air to be handled, the larger should be the heater. If cast-iron indirect radiators are used, they may be rated to give off about 350 heat units per square foot per hour; coils may be rated to give off nearly double that number of heat units.

To illustrate how to compute the size of coil to be used, assume for example that 1,500 cubic feet per minute are to be removed through a ventilating flue, the air to be raised 10° in temperature. Then

$$\frac{1{,}500 \text{ cu. ft. per min.} \times 60 \text{ min. per hour} \times 10° \text{ rise in temp.}}{55 \text{ heat units} \times 650 \text{ heat units per hour per sq. ft. of coil}} = 25.+ \text{ sq.}$$

ft. of coil required.

(The number 55 is the number of cubic feet of air at 70° that 1 heat unit will raise 1° F.)

In order to work out important problems of this nature, it is necessary to consult a table giving flue velocities for different heights and for excesses of temperature of air in the flue over that out of doors. From such a table, knowing the height of the flue, its size, and the volume of air to be moved, it is readily seen how many degrees the air must be heated. The size of coil is then determined as above. The arrangement of an aspirating heater in a flue is shown in Fig. 36.

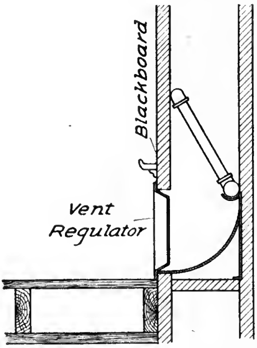


Fig. 36. Aspirating Regulator in Flue.

EXHAUST-STEAM HEATING

Buildings having their own power and lighting plant should be heated by exhaust steam, about 90 per cent of the steam that passes through the engines and pumps being available for this purpose.

A portion of this steam is used for heating the feed-water to the boilers. In a properly arranged system, very little fresh water need be supplied, since the condensation from the radiators, properly purified, is returned to the boilers.

To accomplish this purification, and to rid the steam of oil in order to prevent its coating the pipes and radiators, the steam is passed through a separator attached to the heater when all the steam is allowed to enter it, or through an independent separator when only a portion of the steam passes through the feed-water heater. Only about one-sixth of the exhaust steam in a given plant is required to heat the feed-water that must be supplied to the boilers to take the place of the steam used in the engines, therefore all the exhaust need not enter the heater for the purpose of keeping up the proper temperature of the feed-water.

A type of heater with a coke fitter is shown in Fig. 37; while Figs. 38 and 39 show two methods of making connections, the first when all

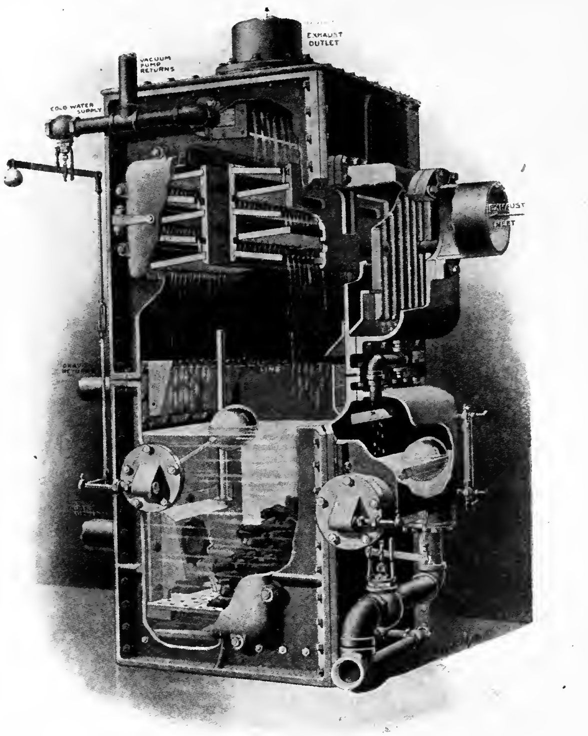


Fig. 37. Heater with Coke Fitter.

the steam is allowed to pass through the heater, the latter when only a portion of the exhaust from the engines is allowed to enter.

A very essential appliance used with exhaust-steam heating is the *pressure-reducing valve*, which makes good with live steam any deficiency in exhaust that may occur. By adjusting the weight, any desired pressure, within limits, may be obtained.

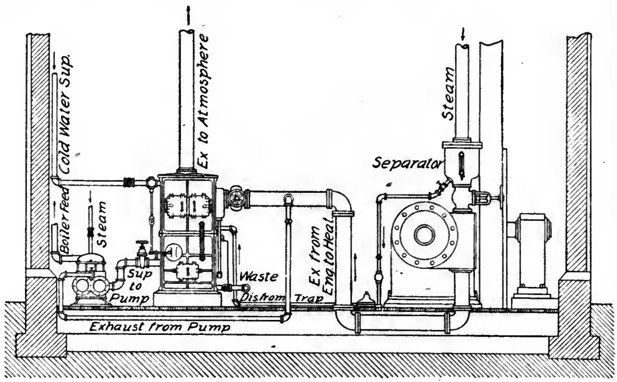


Fig. 38. Method of Making Connections when All the Steam is Allowed to Pass Through the Heater.

A *back-pressure valve* must be used with exhaust-steam heating, to regulate the pressure to be carried. It also acts as a safety-valve in case of over-pressure from any cause.

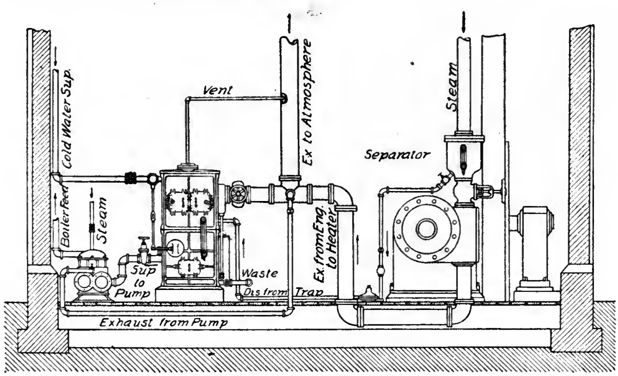
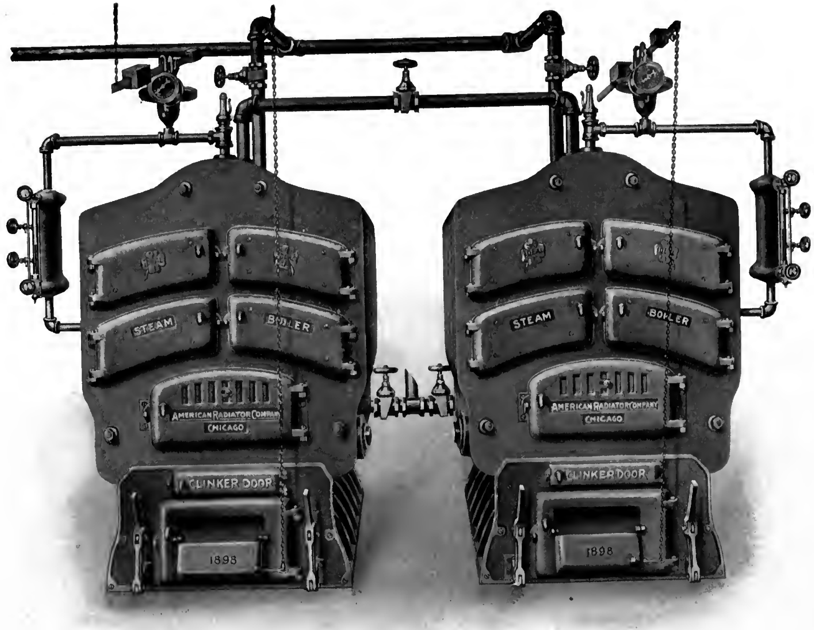


Fig. 39. Method of Making Connections when Only a Portion of Exhaust from Engine is Allowed to Enter.

Heating systems are sometimes arranged by bringing to them live steam to be reduced in the building to any desired pressure by a reduc-



A BATTERY OF IDEAL STEAM BOILERS SHOWING METHOD OF YOKING THE MAIN SUPPLY AND RETURN PIPE.

American Radiator Company.

ing valve. In such cases there is no back-pressure valve; therefore a safety-valve should be placed on the main to act in case of trouble with the reducing valve and prevent too great a pressure on the radiators.

A by-pass should be used in connection with all pressure-reducing valves, to provide for overhauling them: A steam gauge connected not less than 6 feet from the valve on the low pressure side is a necessary attachment.

With exhaust-steam heating, an exhaust head should be placed at the top of the vertical exhaust main, to condense, as far as possible, the steam passing through it.

The drip pipe from the exhaust should be connected with the drip tank; or, if the exhaust has been passed through a first-class separator, it may, if desired, be returned to the feed-water heater.

When a closed type feed-water heater is used (see Fig. 40), a separate tank must be provided for the returns from the heating systems. High-pressure drips are trapped to this tank. In the case of the heater shown in Fig. 37, the live-steam returns are trapped to it. A common type of trap is shown in section in Fig. 41. In the position shown, the float or bucket hinged as shown, is held up by the buoyancy of the water, and keeps the valve at the upper end of the spindle in contact with the seat, preventing the escape of steam entering with the water through the inlet. The water, rising around the bucket, overflows it and overcomes its buoyancy, causing it to fall and open the valve, the steam pressure on the water then forcing it out of the bucket until a point is reached where

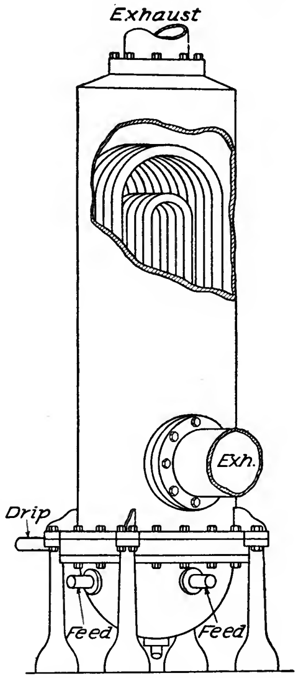


Fig. 40. Closed Type Feed Water Heater.

the buoyancy of the bucket again comes into play and closes the valve until the action is again repeated.

An extremely simple form of float trap is shown in Fig. 42, the

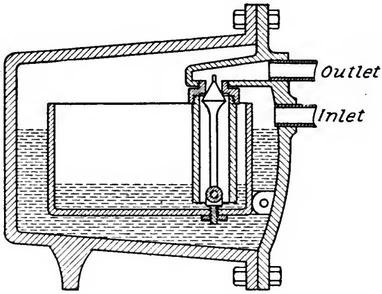


Fig. 41. Common Type of Trap.

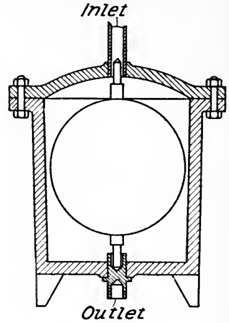


Fig. 42. Float Trap.

hollow float raising the spindle and valve, permitting water to escape, but falling and thus closing the outlet when the water level reaches a point too low to cause the ball to float, thus preventing the escape of steam.

Special forms of traps known as *return traps* are used in small

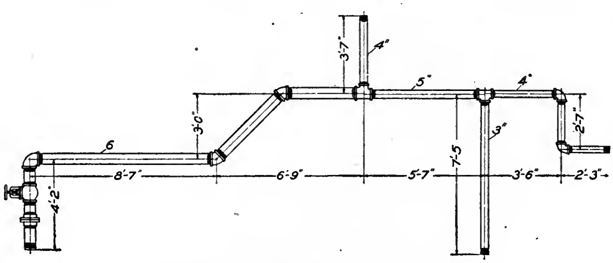


Fig. 43. Dimensioned Sketches for Cutting Pipe.

plants for returning to the boiler the condensation from the heating system.

MODIFIED SYSTEMS OF STEAM HEATING

It is beyond the scope of this course to go into the details of the various modified or patented systems of steam circulation, yet it seems advisable to point out the essential features of certain of these systems. The Webster and Paul Systems will be found described in Part III of the Instruction Paper on Heating and Ventilation.

Thermograde System. With this two-pipe system air valves are omitted; the supply valve on each radiator is of a special construction designed to be set to admit quantities of steam under different conditions—to fill the radiator $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, or entirely full of steam. On the return end of each radiator is placed a so-called *auto-valve*, designed to permit the escape of air and water into a return pipe open to the atmosphere at the top. In the case of large buildings the water flows by gravity to a tank, from which it is pumped to the boilers.

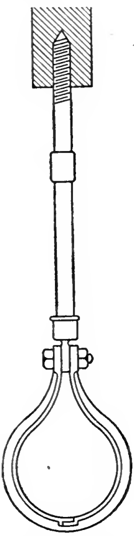


Fig. 44. Hanger.

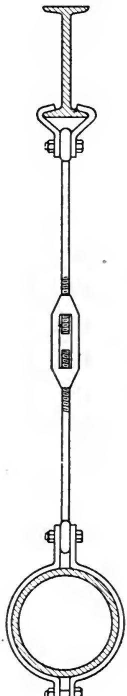


Fig. 45. Adjustable Hanger for Large Pipe.

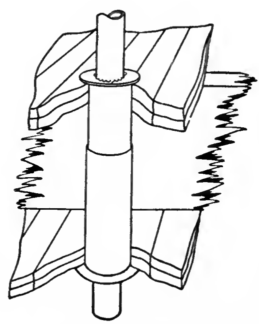


Fig. 46. Sleeve for Encasing Pipe.

Some of the advantages claimed for this system are:—Absence of air-valves and air-lines; control of the heat emitted, by means of the special controlling valve at the supply end of each radiator. The piping is the same as for ordinary gravity systems.

Vapor System. This system is designed, as its name implies, to work on a very low pressure. The radiators, preferably of the hot-water type, must have considerably more surface than with low-pressure steam heating. A special valve is placed at the supply end of each radiator, designed to admit any desired volume of steam.

A little trap or water-seal fitting is connected with the return end of each radiator, a small hole being provided above the water line to permit the escape of air. All returns are joined in the basement and discharge to an open water column alongside the boiler, any steam in the returns being condensed by passing into a coil provided for the purpose.

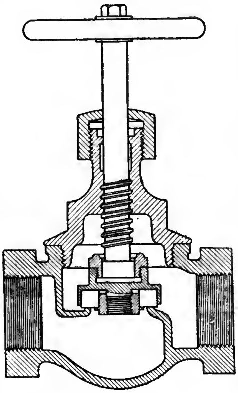


Fig. 47. Globe Valve.

No safety valve is required with this system. In case of an excess of pressure in the boiler, the water is backed out into the column above mentioned; a float is raised; and dampers are closed.

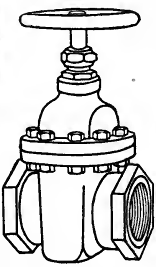


Fig. 48. Gate Valve.

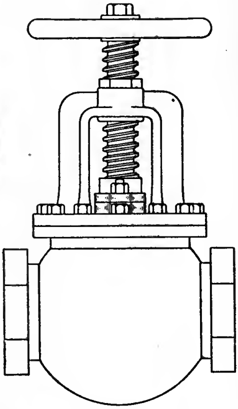


Fig. 49. Iron Body Globe Valve.

The advantages claimed are:—Complete control of the heat given off by the radiators by means of the special regulating valve on each; absolute safety; small pipes; absence of air-valves.

Mercury Seal Vacuum Systems. In one of these systems, commonly used with gravity-return apparatus, air-valves similar to those shown in Fig. 55 are placed on the radiators, and the air-lines connected with a main line discharging through a mercury seal or column, the function of which is to seal the end of the pipe and prevent the entrance of air after the air from the system has been expelled by raising the steam pressure. In another mercury seal system, air-valves are omitted and "retarders"—so called—are placed at the return ends of radiators.

With a tight job of piping when the air in the system has once been got rid of, the plant may be run for some time—or until air leaks in again—at a pressure less than the atmosphere and with radiators at temperatures corresponding to those of hot-water radiators.

Among the claims made for this system are:—Wide range of temperature in the radiators, secured by varying the degree of vacuum; the advantage of a hot-water heating system without large radiators, since steam under pressure can be carried in the radiators in cold weather.

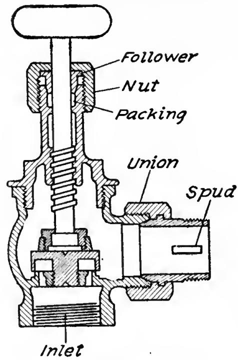


Fig. 50. Radiator Angle Valve.

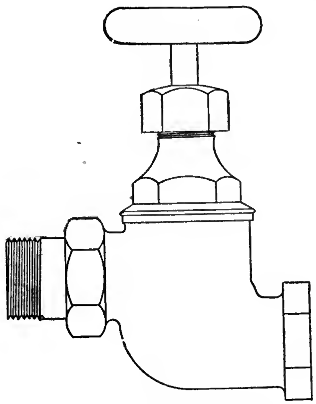


Fig. 52. Radiator Offset Valve.

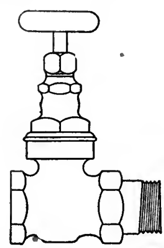


Fig. 51. Radiator Straightway Valve

PIPE AND FITTINGS

Pipe. Pipe for heating systems should be made of wrought iron or mild steel. Sizes up to 1¼ inches diameter inclusive, are butt-welded and proved to 300 pounds' pressure; above that size they are lap-welded and tested to 500 pounds' pressure.

TABLE VIII

Standard Weight Pipe Dimensions and Data

Diameters (Inches)			Areas (Square Inches)			Miscellaneous						
Nominal Diameter	Actual External Diameter	Actual Internal Diameter	External Area	Internal Area	Area of Metal	Thickness of Metal	Linear Feet per Square Foot of External Surface	Linear Feet to Contain One Cubic Foot	Pounds of Water per Linear Foot	Nominal Weight of Pipe per Foot (Pounds)	Threads per Inch	Taper of Threads per Inch of Screw
1/8	.405	.269	.1288	.0568	.0720	.068	9.44	2,500.	.024	.241	27	1/32
1/4	.540	.364	.2290	.1041	.1249	.088	7.075	1,385.	.044	.42	18	1/32
3/8	.675	.493	.3578	.1909	.1669	.091	5.657	751.5	.082	.559	18	1/32
1/2	.840	.622	.5542	.3039	.2503	.109	4.502	472.4	.132	.837	14	1/32
3/4	1.050	.824	.8659	.5333	.3326	.113	3.637	270.	.23	1.115	14	1/32
1	1.315	1.047	1.3581	.8609	.4972	.134	2.903	166 9	.373	1.668	11½	1/32
1¼	1.660	1.380	2.1642	1.4957	.6685	.140	2.301	96 25	.648	2.244	11½	1/32
1½	1.900	1.610	2.8353	2.0358	.7995	.145	2.01	70.65	.883	2.678	11½	1/32
2	2.375	2.067	4.4301	3.3558	1.074	.154	1.611	42.36	1.454	3.609	11½	1/32
2½	2.875	2.467	6.4918	4.7800	1.712	.204	1.328	30.11	2.072	5.739	8	1/32
3	3.500	3.066	9.6211	7.3827	2.238	.217	1.091	19.49	3.202	7.536	8	1/32
3½	4.000	3.548	12.566	9.886	2.680	.226	.955	14.56	4.285	9.001	8	1/32
4	4.500	4.026	15.904	12.730	3.174	.237	.849	11.31	5.517	10.665	8	1/32
4½	5.000	4.508	19.635	15.960	3.675	.246	.765	9 03	6.908	12.34	8	1/32
5	5.563	5 045	24.306	19.985	4.321	.259	.629	7.20	8.668	14.502	8	1/32
6	6 625	6.065	34.472	28.886	5.586	.280	.577	4.98	12.52	18.762	8	1/32
7	7.625	7.023	45.664	38.743	6.921	.301	.501	3.72	16.79	23.271	8	1/32
8	8.625	7.981	58.426	50.021	8.405	.322	.444	2.88	21.68	28.177	8	1/32
10	10.750	10.018	90.763	78.822	11.94	.366	.355	1.80	34.17	40.065	8	1/64
12	12 750	12.000	127.68	113.09	14.59	.375	.293	1.235	49.02	48.985	8	1/64

Circumference = Diameter × 3.1416.
1 cu. ft. = 7½ gallons.
1 gallon = 231 cu. inches.

1 cu. ft. of water weighs 62.4 lbs.
1 gallon of water weighs 8⅓ lbs.

Pipe is shipped in lengths of 16 to 20 feet, threaded on both ends and fitted with a coupling at one end.

It is well, as a rule, to have pipes 2½ inches in diameter and larger cut in the shop from sketches. These should give the distances from end to center, or center to center, and should state the size and kind of valves, whether flanged or screwed fittings are to be used, and in a general way should follow Fig. 43.

The dimensions of standard pipe are given in Table VIII.

NOTES ON WROUGHT-IRON PIPE

(Furnished by the Crane Company, Chicago, Ill.)

Wrought-Iron Pipe:—This term is now used indiscriminately to designate all butt- or lap-welded pipe, whether made of iron or steel.

Merchant Pipe:—This term is used to indicate the regular wrought pipe of the market, and such orders are usually filled by the shipment of soft steel pipe. The weight of merchant pipe will usually be found to be about five per cent less than card weight, in sizes ⅛-inch to 6-inch, inclusive; and about ten per cent less than card weight, in sizes 7-inch to 12-inch, inclusive.

Full-Weight Pipe:—This term is used where pipe is required of about card weight. All such pipe is made frem plates which are expected to produce pipe of card weight; and most of such pipe will run full card to a little above card, but, owing to exigencies of manufacture, some lengths may be below card, but never more than five per cent.

Large O. D. Pipe:—A term used to designate all pipe larger than 12-inch. Pipe 12-inch and smaller is known by the nominal internal diameter, but all larger sizes by their external (outside) diameter, so that "14-inch pipe," if ⅜ inch thick, is 13¼-inch inside, and "20-inch pipe" of same thickness is 19¼-inch inside.

The terms "Merchant," or "Standard pipe," are not applicable to "Large O. D. pipe," as these are made in various weights, and should properly be ordered by the thickness of the metal.

When ordering large pipe threaded, it must be remembered that ¼-inch metal is too light to thread, $\frac{5}{16}$-inch being minimum thickness.

Orders for large outside diameter pipe, wherein the thickness of metal is not specified, are filled as follows:

Fourteen, fifteen, and sixteen inch, O. D., $\frac{5}{16}$-inch or ⅜-inch metal.

Larger sizes, ⅜-inch metal.

This pipe is shipped with plain ends, unless definitely ordered "threaded."

Extra Strong Pipe:—This term designates a heavy pipe, from ⅛-inch to 8-inch only, made of either puddled wrought iron or soft steel. Unless directed to the contrary, steel pipe is usually shipped. If wrought-iron pipe is required, use the term, "Strictly Wrought-Iron Extra Strong Pipe." Extra strong pipe is always shipped with plain ends and without couplings, unless instructions are received to thread and couple, for which there is an extra charge.

This term, when applied to pipe larger than 8-inch, is somewhat indefinite, as 9-, 10-, and 12-inch is made both $\frac{7}{16}$ and $\frac{1}{2}$ inch thick. Pipes $\frac{1}{2}$ inch thick are carried in stock, and furnished on open order.

Double Extra Strong Pipe:—This pipe is approximately twice as heavy as extra strong, and is made from $\frac{1}{2}$ to 8 inches, in both iron and steel. It is difficult, however, to find any quantity in "Strictly Wrought-Iron," and the stock carried is usually soft steel. This pipe is shipped with plain ends, without couplings, unless ordered to thread and couple, for which there is an extra charge.

Fittings. For low-pressure heating systems, standard weight cast-iron screwed fittings are used on pipes up to 7 inches or 8 inches diameter. On larger pipes it is customary to use standard flanged fittings. Flange unions should be placed at intervals in the pipes when screwed fittings are used, to provide for readily disconnecting them in case of alterations or repairs.

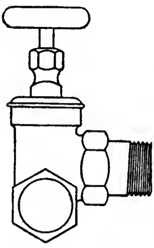


Fig. 53. Radiator Valve.

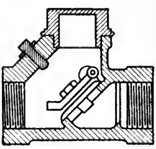


Fig. 54. Swing Check Valve.

Pipe grease or various compounds are used in "making up" the joints. This material should be applied to the male threads only. When the threads of the fittings are coated with it, as is commonly done, the compound is pushed into the fitting when the pipe is screwed in, and, becoming disengaged, is likely to cause trouble later by clogging pipes, etc. For flange fittings it is the practice with many fitters to use inside gaskets, so called, cut to come just inside the bolts.

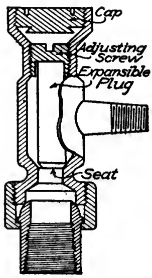


Fig. 55. Air Valve.

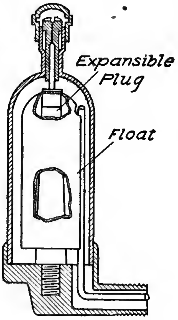


Fig. 56. Air Valve.

To describe a tee, always give the dimensions of the "run" first and the outlet last; for example, a tee 6 inches at one end, 5 inches at the other, with an outlet at the side $3\frac{1}{2}$ inches, would be known as a 6 by 5 by $3\frac{1}{2}$ tee.

A tee with the outlet larger than the openings on the run, is known as a *bullhead* tee. Tees with all three openings of the same size are known as *straight* tees.

It is far better to use reducing sockets or reducing elbows and tees, in place of straight tees with bushings.

Hangers. Pipes up to 4 inches diameter inclusive are commonly suspended by malleable-iron hangers, one type of which is shown in Fig. 44, with a gimlet point on the rod, a beam clamp being substituted

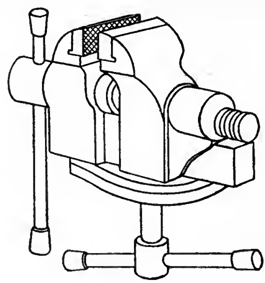


Fig. 58. Flat Jaw Vise.

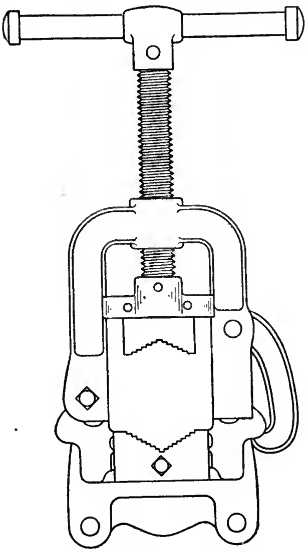


Fig. 57. Pipe Vise.

when I-beams are used in place of floor timbers. One form of adjustable hanger for large pipes is shown in Fig. 45.

Sleeves, etc. Where pipes pass through floors and partitions, they are encased in tubes with plates at floor and ceiling or at walls, as the case may be. One type of these sleeves is shown in Fig. 46.

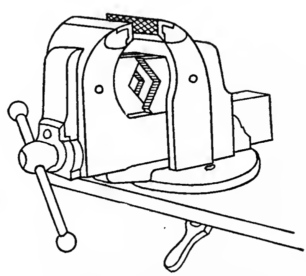


Fig. 59. Combination Vise.

Where branches from risers pass through partitions, it is often necessary to use sleeves of elliptical shape to provide for the expansion of the risers. Sleeves for mains passing through basement walls are generally made of pieces of wrought-iron pipe of the proper length, the diameter of the sleeves to be not less than ½ inch greater than the pipe diameter if covering is omitted in walls, and 2¼ inches greater if covering is continuous along the pipe.

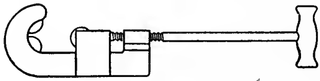


Fig. 60. Pipe Cutter.

When sleeves are placed in plastered walls, they should project a slight distance beyond the face of the plaster. When ceiling plates are made fast to risers, they should be placed at least ⅜ inch down from the ceilings, so that, when the riser expands, the ceiling plate will not be forced into the plaster.

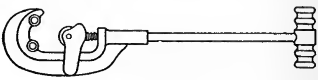


Fig. 61. Pipe Cutter.

Valves. Valves for basement piping are commonly *globe* or *gate* pattern, with rough bodies and plain iron wheels (Figs. 47 and 48). Brass or composition body valves, with screwed tops, are generally used up to 2-inch size inclusive; and iron body valves, with bolted tops, above that size (see Figs. 48 and 49). Both are made with renewable discs or seats.

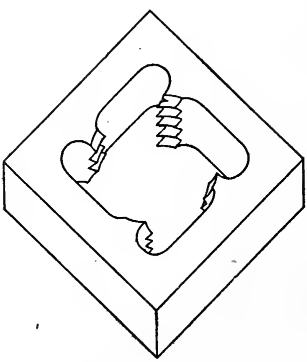


Fig. 62. Solid Die.

It is largely a matter of preference which type of valve shall be used, though of course the straightway gate valves interpose the least resistance to the flow of steam or water.

When the radiators are but little above the water line in the boiler, gate valves are frequently used on the returns to insure an easy flow of the water.

It seems hardly necessary to point out that a globe valve should be connected in the pipe with its stem horizontal, to avoid the water pocket which occurs when the stem is vertical; nevertheless fitters frequently overlook this point.

Several patterns of radiator valves are shown in Figs. 50, 51, 52, and 53. These valves are of brass or composition, rough body nickel-plated, have wood wheels, and are provided with a union. The angle valves are commonly used on first-floor radiators, those on floors

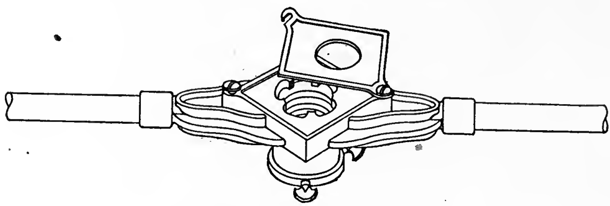


Fig. 63. Stock for Solid Dies.

above having offset or corner offset, offset globe, or straightway gate valves, according to the type of radiator and the arrangement of connections to provide for expansion.

In public buildings, the wheels are often omitted and lock-shields substituted, the valves being operated by a key.

A *swinging-check* valve is shown in Fig. 54. This type, if properly designed, works the easiest of any, and should be used in preference to other types when radiators are placed but little above the water line in the boiler.

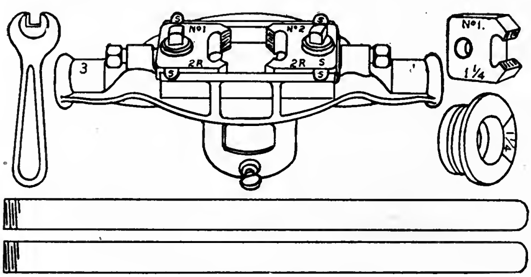


Fig. 64. Adjustable Die and Stock.

Air-Valves. Numerous patterns of air-valves are on the market, some, like Fig. 55, in a general way, being fitted with a union for air-line connections leading to a convenient point of discharge in the basement. Such valves prevent the escape of steam, because of the expansion of the composition plug, which closes the opening when steam comes in contact with it. Air and cold water, however, are permitted to escape.

The general type of air-valve shown in Fig. 56 is frequently used, many modifications of this valve having been manufactured. These

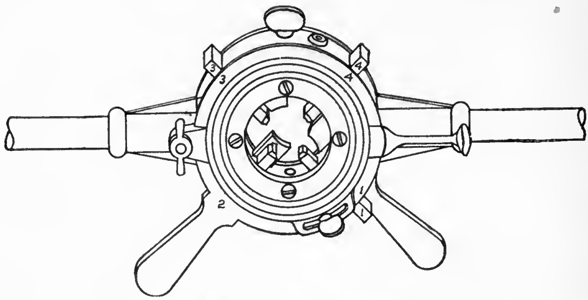


Fig. 65. Adjustable Die and Stock.

valves, as a rule, have no air-line connections, but discharge their air into the rooms; a somewhat objectionable feature. They close when steam enters them; and if water finds its way in, the float is raised and closes the outlet.

Air-valves for direct radiators have a very small opening for the

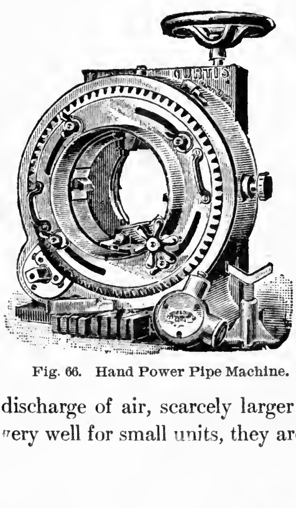


Fig. 66. Hand Power Pipe Machine.

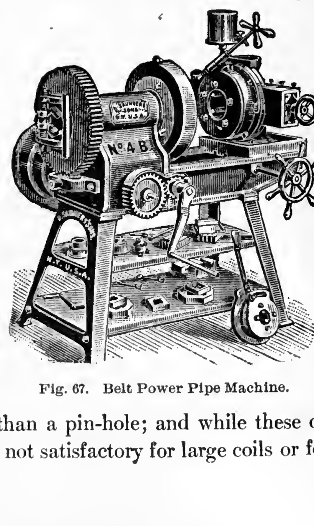


Fig. 67. Belt Power Pipe Machine.

discharge of air, scarcely larger than a pin-hole; and while these do very well for small units, they are not satisfactory for large coils or for large groups of indirect radiators, because of the excessive time required to relieve them from air. For such heating surfaces, a type of air-valve with a much larger opening should be selected, to provide for venting the radiators or coils more quickly.

Several types of vacuum air-valves have been invented, designed to permit the escape of air from the radiators, but to prevent its re-entry. If they remain tight, the steam heating system may be run in mild weather with a pressure below that of the atmosphere, and the radiator kept at a temperature below 200°.

Fig. 68 *a*. Hand Power Pipe Machine.

Pipe-Fitting Tools.—Vise and Bench. When a job is started, the first things needed are vise and bench. The latter should be firmly constructed, and rigidly held in place, the vise to be firmly secured to it by through bolts.

On a good-sized piece of work, it is well to have both a *pipe vise* and a *flat-jaw vise*, these being illustrated in Figs. 57 and 58. A heavy cover should be furnished over the screw of the flat-jaw vise, to provide a bearing for bending pipe, the end of which is passed through a ring bolted to the bench.

Fig. 59 illustrates a combination of the two vises shown in Figs. 57 and 58, making a very useful tool.

Pipe Cutters. There are several kinds of pipe cutters on the market, made with one or more cutting wheels held in a frame. All makes of cutters are operated in practically the same way, by forcing the cutting wheels into the pipe by means of a screw handle. One- and three-wheel cutters are shown in Figs. 60 and 61. The one-wheel cutters are made in sizes for $\frac{1}{8}$-inch to 3-inch pipe; and the three-wheel cutters, for $\frac{1}{8}$-inch to 8-inch pipe.

Stocks and Dies. The several forms of dies and stocks on the market may be divided into two classes—the *solid die* and the *adjustable die.* The solid die is shown in Fig. 62, and is used for cutting both right-hand and left-hand threads. The stock in which solid dies are used is shown in Fig. 63. Adjustable dies and stocks are shown in Figs. 64 and 65. These dies may be adjusted to cut a deep or a shallow thread. It is necessary at times to cut such threads, as the fittings made by different manufacturers are not always tapped alike. To make good joints, the threads must make up tight when they are screwed into the fitting.

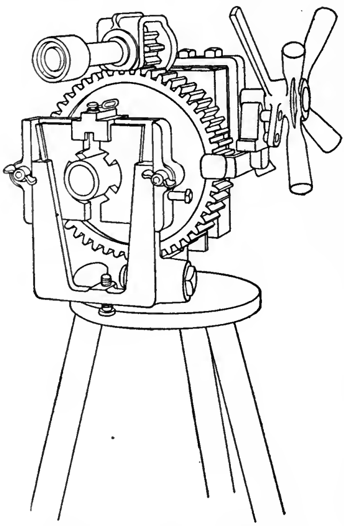


Fig. 68 *b*. Hand Power Pipe Machine.

Table IX shows the approximate distance pipes must be screwed into fittings to make a tight joint.

TABLE IX

Proper Distance to Screw Pipes into Fittings

$\frac{1}{4}$, $\frac{3}{8}$, and $\frac{1}{2}$	inch pipe should be screwed into fittings approximately	$\frac{3}{8}$	in.
$\frac{3}{4}$	" " " " " " " "	$\frac{1}{2}$	"
1	" " " " " " " "	$\frac{11}{16}$	"
$1\frac{1}{4}$ and $1\frac{1}{2}$	" " " " " " " "	$\frac{5}{8}$	"
2	" " " " " " " "	$\frac{3}{4}$	"
$2\frac{1}{2}$ and 3	" " " " " " " "	$\frac{7}{8}$	"
$3\frac{1}{2}$ and 4	" " " " " " " "	1	"
5 and 6	" " " " " " " "	$1\frac{1}{8}$	"
7	" " " " " " " "	$1\frac{1}{4}$	"
8 and 9	" " " " " " " "	$1\frac{3}{8}$	"
10 and 12	" " " " " " " "	$1\frac{1}{2}$	"

In all forms of stocks, whether for solid or adjustable dies, a bushing or guide must be used in the stocks to guide the dies straight onto the pipe. It is necessary that the guides for the different sizes of pipe should fit each size of pipe as closely as will allow the guide to revolve on the pipe freely. The guides should fit the stock as tightly as possible, or a crooked thread will very likely be cut.

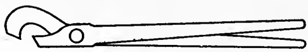


Fig. 69. Pipe Tongs.

Plenty of good lard oil or cotton-seed oil should be used when cutting pipe. The dies must be sharp, to make good joints; and when they are changed in the stocks from one size to another, all chips of iron and dirt should be cleaned off the dies and out of the stocks, as a small chip under dies, especially under one of a set of adjustable dies, will either cut a crooked thread or strip it.

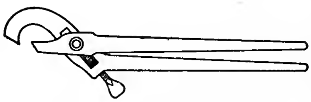


Fig. 70. Adjustable Pipe Tongs.

Fig. 71. Chain Tongs.

Stocks are made in sizes from $\frac{1}{8}$ inch to 4 inches. The small-size stocks and dies commonly carried in pipe-fitters' kits are made to thread pipe from $\frac{1}{8}$ inch to 1 inch inclusive, right-and left-hand; and a larger size to thread pipe from 1 inch to 2 inches inclusive, right- and left-hand. A larger-size stock is used to cut pipes over 2 inches in diameter.

There are a number of hand-power pipe machines on the market, which are very convenient especially for cutting and threading pipe $2\frac{1}{2}$ inches and over. Several makes are shown in Figs. 66, and 68 *a* and 68 *b*.

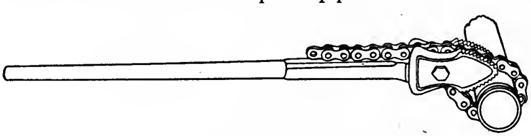


Fig. 72. Chain Tongs.

Pipe Tongs. Plain tongs, like all other tools, must be kept sharp and in good order, to do good work. Many fitters object to tongs because they have to be sharpened very often, and also because they have to carry at least one pair of tongs for each size of pipe; they prefer an adjustable wrench which will fit several different sizes of pipe. There is one advantage in the tongs; that is, they can be worked in places where it would be impossible to use a wrench, such as making up pipe in coils, close corners, etc. Tongs should be made in such a way that when they are on the pipe, the handles will come close enough together to allow them to be gripped in one hand (see Fig. 69).

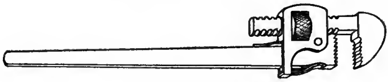


Fig. 73. Pipe Wrench.

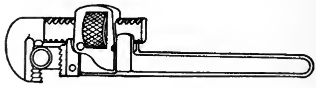


Fig. 74. Pipe Wrench.

Adjustable tongs (Fig. 70) are made to fit several sizes of pipe, the most common sizes used being for $\frac{3}{8}$-inch to 1-inch to 2-inch, and for $2\frac{1}{2}$-inch to 4-inch.

Fig. 75. Wrench for Brass or Nickle-Plated Pipe.

Chain tongs are made in all sizes and in several forms for from 1-inch up to 16-inch pipe. Some makers furnish tongs with the handle and jaws in one piece. Others have the jaws removable. Still others have the jaws so arranged that they can be removed and reversed. See Figs. 71 and 72.

Fig. 76. Wrench for Brass or Nickle-Plated Pipe.

Pipe Wrenches. Several types of adjustable wrenches are shown in Figs. 73 and 74. These wrenches will do good work if used as wrenches on the size pipe they are intended for. Some men who have little regard for tools use on a 2-inch pipe, for example, a wrench which is made to take, say, not over 1-inch pipe, the jaw of the wrench being extended as far as possible, and probably being held by only a few threads of the adjusting screw, a piece of pipe 2 or 3 feet long often being used on the handle of the wrench to

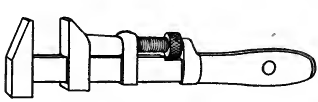


Fig. 77. Monkey Wrench.

ROCOCO ORNAMENTAL THREE COLUMN PATTERN RADIATOR FOR WARMING BY HOT WATER.
American Radiator Company.

increase the leverage. After such usage, the wrench is of little value. At times men will use wrenches in such a way as to make the strain come on the side, with the result that the wrench is badly strained if not broken.

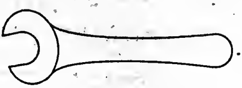


Fig. 78. Open-End Wrench.

The above described wrenches are used on wrought-iron pipe. For brass or nickel-plated pipe, wrenches like those shown in Figs. 75 and 76 should be used; otherwise the pipe will be marred and rendered unfit for use in connection with first-class work.

One of the handiest all-round tools is the *monkey wrench*, shown in Fig. 77. *Open-end* wrenches, illustrated in Figs. 78 and 79, are very handy tools, especially for use on flange fittings. Wrenches for lock-nuts are made about the same as above, only they are larger.

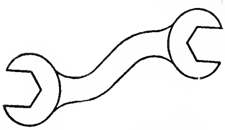


Fig. 79. Open-End Wrench.

The *return-bend wrench* is a very handy tool, and can be made by any good blacksmith. It is used principally on coil work, and is made of heavy bar iron, as shown in Figs. 80 and 81, in which two forms of this type of this wrench are shown.

Another handy tool is what is sometimes called, for want of a better name, a *spud wrench*. This is simply a piece of flat iron about

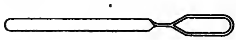


Fig. 80. Return-Bend Wrench.


Fig. 81. Return-Bend Wrench.

10 inches long and made to fit the spuds of the unions of different sizes of union radiator valves and elbows (see Fig. 82).

Pliers. For small work, pliers may be used to advantage. Common and adjustable types are shown in Figs. 83 and 84.

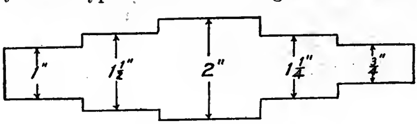


Fig. 82. Spud Wrench.

Drills, Reamers, and Taps. Pipe drills, illustrated in Fig. 85, are made slightly smaller for a given size than the taps illustrated in Fig. 86. A reamer like the one shown in Fig. 87 should be used to start the tap, which should never be hammered in order to start the threads.

Fig. 88 shows a combined drill, reamer, and tap. Fig. 89 shows a pipe reamer for taking the burr from the ends of pipes.

Fig. 83. Common Pliers.

Fig. 84. Adjustable Pliers.

A *ratchet drill* is illustrated in Fig. 90 and a *breast drill* in Fig. 91. Fig. 92 shows a handy tool for drilling pipe flanges which from any cause cannot be drilled in the shop.

Fig. 85. Pipe Drill.

Figs. 93, 94, 95, and 96 show *cold, cape, diamond point,* and *round-nose* chisels respectively.

A good pattern *pean hammer* is shown in Fig. 97 *a*; and a *brick hammer* is represented by Fig. 97 *b*.

Miscellaneous. Every fitter's kit should contain inside and outside *calipers*; a good set of *bits* ¼-inch to 1-inch; *bit stock*; *augers* 1¼-inch to 2-inch; *saws*; *files*; *plumb-bob*; *gimlet*; *lamp*; *oil can*; *steel square*; *tape measure*; etc.

HOT-WATER HEATING

Heaters. Hot-water heaters—or "boilers," as they are sometimes miscalled—are so nearly like the cast-iron steam boilers previously illustrated, that it is unnecessary further to describe them here.

Some makers use the same patterns for both steam boilers and hot-water heaters, while others use a higher boiler for steam, giving more space above the water line.

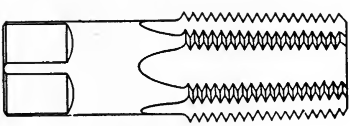


Fig. 86. Pipe Tap.

Practically the same rules should be followed in selecting a hot-water heater as those laid down for steam boilers. Although a hot-water heater is a trifle more efficient than a steam boiler—that is, more of the heat in the coal is transferred to the water, owing to the temperature of the latter being 40 degrees or more lower than in a steam boiler—nevertheless, practically the same size of hot-water heater or steam boiler is required to heat a given space.

It is well to equip the heater with a regulator, of which a number of good ones are manufactured, in order to control the drafts by variations in the temperature of the water, the regulator being set to maintain any desired temperature in the flow pipe.

Fig. 87. Reamer.

Capacity of Heaters. Hot-water heater capacities are based, as a rule, on an average water temperature of 160° in the radiators, when placed in rooms to be kept at 70° F.

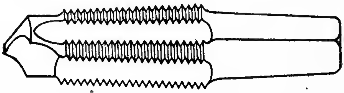


Fig. 88. Combined Drill, Reamer and Tap.

If the *closed-tank system* is used, the radiator temperatures may be 220° to 230° or more; hence, if any attention is to be given to the manufacturers' heater rating, the radiation must be reduced to the equivalent radiation in heat-emitting capacity of radiators at 160°.

This is very easily computed, since the heat given off by a radiator is proportional to the difference in temperature between the water in the radiator and the air surrounding it. This, in the first case, is 160° less 70°,

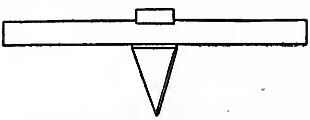


Fig. 89. Pipe Reamer for Taking the Burr from Ends of Pipe.

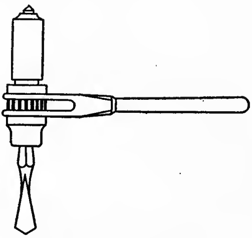


Fig. 90. Ratchet Drill.

or 90°; and in the other case, say, 225° less 70°, or 155°; that is, one foot of radiating surface at 225° will give off $\frac{155}{90}$ of the heat given off at 160°; therefore, a job with 900 square feet, for example, at 225° would be equivalent in heating power to $\frac{155}{90} \times 900 = 1550$ square feet at 160°, and a boiler with the higher rating would be required

It is always well to check the boiler rating as explained under "Steam Heating," except that in hot-water heating only 150 heat units are allowed per hour per square foot of radiating surface.

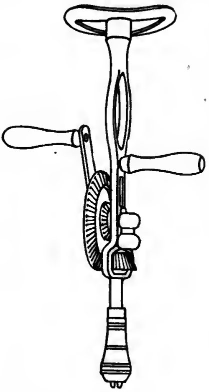


Fig 91. Breast Drill.

Of the heat given off by the coal, it is safe to assume that 8000 heat units per pound are transferred to the water in the heater.

Suppose there are 900 square feet of radiation on the job. Add $\frac{1}{3}$ to cover the loss of heat from pipes; total = 1200 square feet. Assume that in coldest weather 5 pounds of coal are burned per hour on each square foot of grate; that is, $5 \times 8000 = 40,000$ heat units are transferred to the water in the heater. The heat given off per hour by the radiators and pipes is $1200 \times 150 = 180,000$ heat units. This, divided by 40,000, the heat utilized per square foot of grate, equals $4\frac{1}{2}$ square feet of grate required.

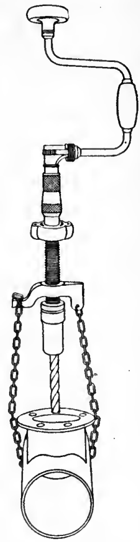


Fig. 92. Tool for Drilling Pipe Flanges.

Some judgment is necessary in assuming the rate of combustion; but this varies from about 3 pounds per square foot of grate per hour in small heaters, to 7 or 8 in larger ones, operated by a regular attendant.

HOT-WATER RADIATORS AND VALVES

Hot-water radiators have top and bottom nipple connections, as shown in Fig. 31, Part II (Heating and Ventilation). A hot-water

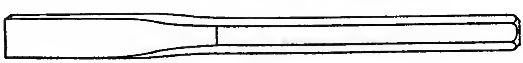


Fig. 93. Cold Chisel.

radiator may be used for steam, but a steam radiator cannot be used for hot water. The valve may be placed at the top or the bottom—it matters little which; it is, however, more convenient, though more unsightly, at the top. The circulation will be practically as good when the valve is located at the bottom. One valve is all that is necessary,

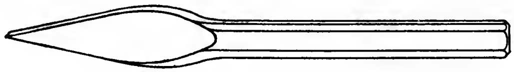


Fig. 94. Cape Chisel.

and this may best be of the quick-opening pattern, a partial turn being all that is necessary to open or close it (see Figs. 44 and 45, Part II, Heating and Ventilation).

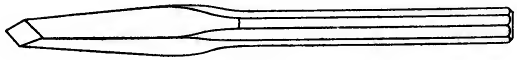


Fig. 95. Diamond-Point Chisel.

A union elbow is generally connected with the return end of a radiator (see Fig. 46, Part II, Heating and Ventilation).

Key-pattern air-valves are more frequently adopted in hot-water

Fig. 96. Round-Nose Chisel.

heating than are any types of automatic valves. They do not have to be operated often; hence the popularity of the simple and reliable air-cocks like those shown by Fig. 98.

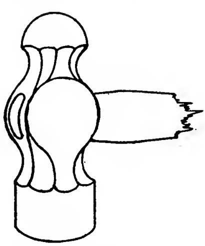


Fig. 97 *a*. Pean Hammer.

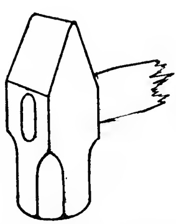


Fig. 97 *b*. Brick Hammer.

Direct-indirect hot-water radiators are seldom used, owing to the danger from freezing in case they are thoughtlessly shut off.

Indirect radiators should be of a deep pattern—say, 10 to 12 inches, or even more for use with outdoor air in a severe climate. These radiators give off far less heat per square foot than is emitted by steam radiators; hence they should be deeper, to bring the air up to proper temperature.

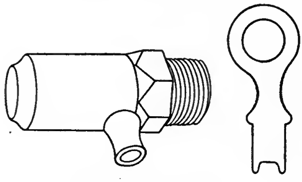


Fig. 98. Air Cock.

HOT-WATER PIPING

Heater Connections. Where only one heater is used, the connections are practically the same as for steam heating, except that no check-valves are used.

Where two boilers are to be connected and arranged to be run independently or together, valves must be inserted somewhat as shown

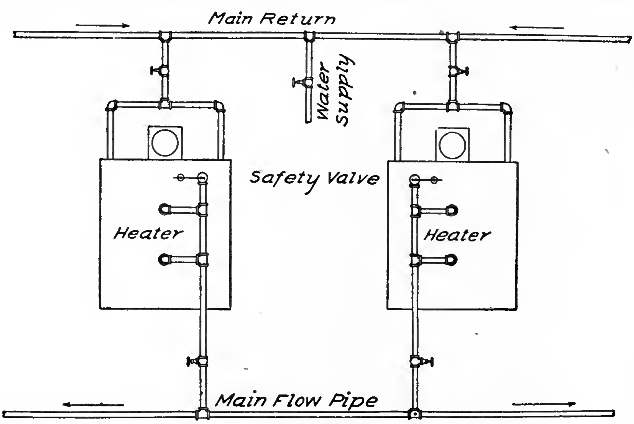


Fig. 99. Arrangement of Valves for Two Boilers which are to Run Independently or Together.

by the plan view represented in Fig. 99. It is important that safety-valves be used with this arrangement, as, in case one boiler is shut down and then fired up without opening the stop-valves, the pressure due to the expanding water will burst the heater.

Single-Main System. The single-main system, arranged somewhat like the circuit system in steam heating, is sometimes employed for hot-water heating. Fig. 100 shows the arrangement of this system. The supply branches are taken from the top of the main, where the water is hottest; and the returns are connected at the side, the cooler water passing along the lower portion of the pipe back to the heater. On systems of considerable size, this arrangement of piping causes the water in the supply main to cool more rapidly as the distance from the heater increases than in systems where the supply and return water are kept separate.

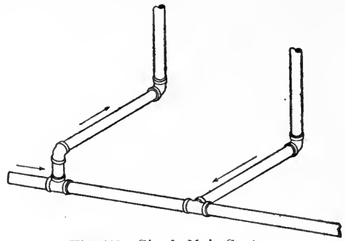


Fig. 100. Single Main System.

Two-Pipe Up-Feed System. With the two-pipe up-feed system, the pipes should be pitched up from the boiler 1 inch in 10 feet, if possible. Pockets in which air can collect must be avoided, as air will cut off the flow as much as a solid substance in the pipe would do.

In the basement, the branches near the boiler should be taken from the side of the flow main, in order to favor the branches farther

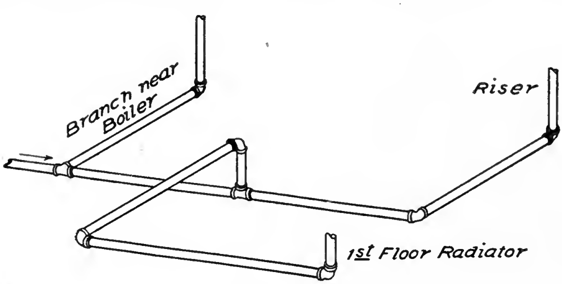


Fig. 101. Two-Pipe Up-Feed System.

away, which should be taken from the top of the main. First-floor radiators should be given the preference, as to ease of flow in their connections, over riser connections with the floors above. If possible, feed the last first-floor radiator on a line before branching to riser. Fig. 101 illustrates the above points.

Keep the mains near the ends of long runs ample in size, even if somewhat larger than stated in the table, if runs are long and crooked. No chances should be taken in regard to insuring the proper circulation of water in the system. Use no horizontal pipe smaller than 1¼-inch.

Return mains pitch in the same direction as the flow pipes, and

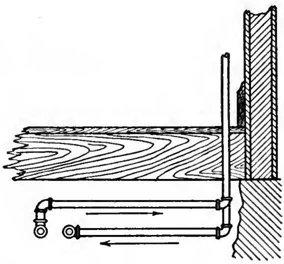


Fig. 102. Connections for Return Mains.

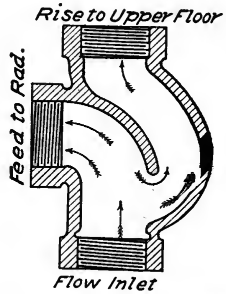


Fig. 103. Distributing Fitting.

are generally paired with them, the connections being made on the side as shown in Fig. 102, or at an angle of 45 degrees.

The risers should be arranged to favor the radiators on the lower floors, since the water tends to rise and pass by the lower radiators. Distributing fittings, as shown in Fig. 103, are often used for this purpose, or the pipes may be arranged as shown in Fig. 104. Some labor is saved by the use of the special fittings described.

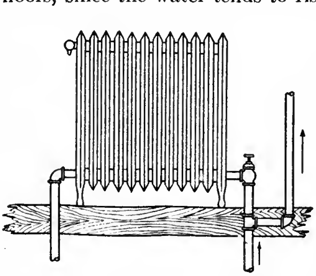


Fig. 104. Arrangement of Pipes.

Overhead-Feed System. Where attic space is available, the overhead-feed system presents certain advantages over the two-pipe up-feed method of piping. In residences, single risers are used, these serving for both supply and return, the water entering the top of the radiator and flowing back into the same riser from the lower opening in the radiator. No air-valves are necessary, all air passing up the risers and out through the vent, on the expansion tank. The overhead mains are connected with a rising main large enough to supply all the surface; these mains may be run around the building near the walls, as in the one-pipe steam circuit system; or may be carried down the middle of the building, with long branches extending to the risers near the walls, it being assumed that the radiators will be located near the exposed parts of the building.

The mains and branches should pitch down toward the risers, permitting the air to escape freely to the expansion tank (see Fig. 105).

Special care should be used in hot-water heating, to secure an easy flow. The ends of the pipes should be reamed, and long-turn

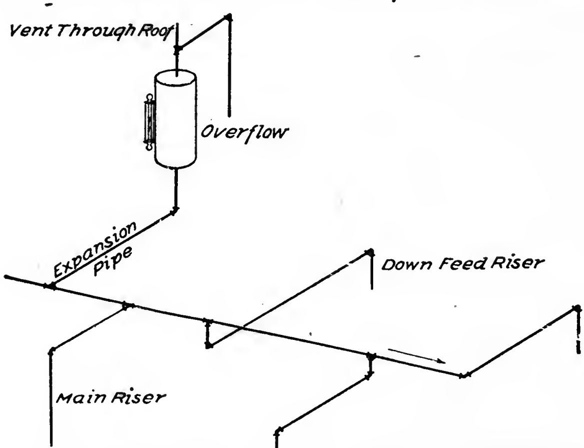


Fig. 105. Showing the Mains and Branches Pitched Down Towards the Risers.

fittings used for first-class work, although, if the piping is generously proportioned, standard fittings will answer. A hot-water thermometer should always be placed on the boiler or near it, in the flow-main.

Radiator Connections. For direct radiators, the connections are commonly 1-inch for sizes up to 40 square feet; $1\frac{1}{4}$-inch, for sizes of 72 square feet; $1\frac{1}{2}$-inch to 2-inch for sizes larger than 72 square feet. On floors above the first, the connections may be made smaller if the horizontal runs are short, the sizes to conform to table.

Expansion-Tank Connections. About the simplest arrangement of expansion-tank connections is shown in Fig. 106. The expansion pipe is commonly connected with a return line in the basement, there being less likelihood of the water boiling over in case of a hot fire with this arrangement than when the expansion pipe is merely an extension of a supply riser. There must be no valve on this pipe, as its closure would almost certainly result in a bursting of some part of the system.

Great pains must be taken to guard against the freezing of the expansion pipe. If there is any danger whatever, a circulating pipe should be added, as shown, this pipe being connected with one of the flow-pipes or supply risers, to insure a continuous circulation.

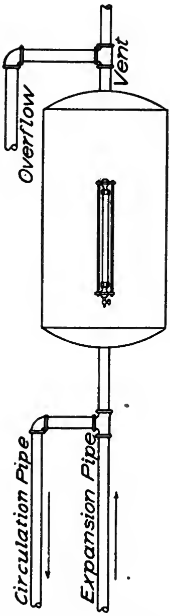


Fig. 106. Expansion Tank Connections.

Open-Tank versus Pressure System. The open-tank system, although having its disadvantages, is generally to be preferred to the pressure or closed-tank system. With the open-tank system, the water cannot get much above 212° at the heater, without boiling in the expansion tank and blowing part of the water out of the system, causing, meanwhile, objectionable noises in the system. On the other hand, the open expansion tank into which the water can freely expand when heated is the best possible safety device to prevent overpressure.

With the closed-tank system, a safety-valve is used. If it operates properly, well and good; otherwise an element of danger is introduced, and, in case an excessive pressure is developed, the heater becomes far more dangerous than a steam boiler, owing to the much greater volume of water in the system.

With this system, two safety-valves with non-corrosive seats should be used, unless some well-tested device of demonstrated merit designed especially for this purpose is adopted.

The advantage of the closed-tank system is that smaller radiators may be used, since they can be heated as hot with water under pressure as they would be if heated with steam.

When full street pressure is applied to a system, and no expansion tank is used, the radiators are subjected to an unnecessary strain; and in case of rupture in any part of the system, much greater damage results than would be the case with an open-tank system.

System of Forced Circulation. In extensive systems the water is kept in circulation by pumps, which are capable of producing a much higher velocity in the pipes than could be secured by gravity. This system is used principally in connection with power plants, the water being heated in tubular heaters, by means of the exhaust steam from the engines. Much smaller supply mains may be used in this system than with steam heating, because of the greater capacity of water for carrying heat. On the other hand steam returns are smaller.

Table X gives the capacities of expansion tanks:

TABLE X

Radiation Capacities of Expansion Tanks

Capacity of Tank	Direct Radiating Surface to which Tank is Adapted
5 gallons	200 sq. ft.
10 "	450 " "
15 "	700 " "
20 "	1000 " "
30 "	1400 " "
40 "	1900 " "
50 "	2400 " "
60 "	2900 " "

COMPUTING RADIATION

Computing Direct Radiation. The process of computing hot-water radiating surface is precisely the same as that explained for ascertaining the amount of steam radiation required for a given case, with this important exception: the hot-water radiators give off only about $\frac{3}{5}$ as much heat per square foot as is emitted by a steam radiator; hence calculations must be based on an allowance of 150 heat units per square foot of direct radiating surface per hour, instead of 250 heat units used in connection with steam-heating work.

It has been stated that direct-indirect hot-water radiators are rarely used. In case, however, it is desired to compute the amount of this class of radiation for a given service, proceed as explained for steam heating, but allow only $\frac{3}{5}$ as much heat emitted per square foot as that given off by steam radiators.

Computing Indirect Radiation. With indirect hot-water radiation in connection with the open-tank system, the radiators must be deeper than for steam heating, in order properly to heat the air.

The greater depth retards the flow of air; and since the water is at a much lower temperature than steam, the heating capacity of indirect extended-surface hot-water radiators should be taken at not far from 300 heat units per square foot per hour, as against 400 or more heat units for indirect steam radiation.

To compute the amount of radiation required, proceed as explained for indirect steam heating; that is, compute the amount of direct radiation as pointed out under the preceding heading, then add not less than 60 per cent to this amount, to ascertain the indirect radiating surface required.

This method, though perhaps crude, has the advantages of being simple and of affording a check on the work, since one soon knows by experience about what the ratio should be to heat a room of given size by direct radiation. For example, take a room with 3000 cubic feet, to heat which the ratio for direct radiation should be, say, 1 square foot to 30 cubic feet, giving a 100-square foot radiator. Adding 60 per cent for indirect radiation, gives 160 square feet, or a ratio of 1 square foot to a little less than 20 cubic feet of space.

Indirect hot-water radiators with extended pins or ribs will, with the open-tank system, give off not far from 250 to 300 heat units per hour per square foot of extended surface.

DUCTS AND FLUES

Areas of Ducts and Flues. When indirect radiation is installed primarily for heating, ventilation being a secondary consideration, it is desirable to make the flues somewhat smaller in proportion to the heating surface than is done with steam heating. If the flues are made too large, the flow through the radiators will be too rapid, and the air will not get hot enough. It costs far more in fuel to heat with a large volume of moderately warmed air than with a smaller volume of hotter air.

Duct and flue proportions for hot-water heating should be approximately as follows:—Cold-air ducts, $\frac{3}{4}$ to 1 sq. in. per sq. ft. of indirect radiating surface; first-floor flues, $1\frac{1}{4}$ to $1\frac{1}{2}$ sq. in. per sq. ft.; second-floor flues, 1 to $1\frac{1}{4}$ sq. in. per sq. ft.; third-floor flues and above, $\frac{3}{4}$ to 1 sq. in. per sq. ft. of surface.

The backs and sides of flues in exposed walls should be covered with non-conducting material.

Flue Velocities. The flue velocities will be somewhat lower than with steam heating, because of the lower temperature of the air. Reasonable allowance would be 250, 350, 400, and 450 feet per minute for the first, second, third, and fourth floors respectively.

Heating Water. The size of heater or steam coil necessary to heat water may be very readily determined on the heat-unit basis, if one knows the volume of water to be heated, the number of degrees its temperature is to be raised, and the time during which the heating must be done.

For example, what size of heater would be required to heat 300 gallons of water in 6 hours from 60° to 160°?

In one hour 50 gals. would be heated 100° F.; and since one gal. weighs $8\frac{1}{3}$ lbs., $50 \times 8\frac{1}{3} \times 100 = 41,667$ heat units would be required.

Small heaters may be counted on to transmit to the water about 7000 heat units per pound of coal burned. The rate of combustion should be assumed to be from 3 to 6 pounds per square foot of grate per hour, according to the amount of attendance it is convenient to give.

With a 4-pound rate, 28,000 heat units would be furnished per square foot of grate surface per hour for heating the water. Therefore the heat units per hour necessary to raise the temperature of the water—*viz.*, 41,667—divided by 28,000, gives the number of square feet of grate surface required, which is equal to about $1\frac{1}{2}$ corresponding to a diameter of $16\frac{1}{2}$ inches.

To determine the size of steam boiler and coil required to heat a large volume of water in a tank, proceed as follows: Take, for example, a 24,000-gallon tank, the water in which is to be heated from 45° to 75° in 10 hours. Now 24,000 gals. $\times$ $8\frac{1}{3}$ pounds $\times$ 30° rise in temperature = 6,000,000 heat units, or 600,000 heat units per hour.

Assuming 8000 heat units to be utilized per pound of coal burned at, say, a $7\frac{1}{2}$-pound rate, one square foot of grate will supply 60,000 heat units per hour; hence, 10 square feet of grate surface will be required.

There will, however, be a certain loss of heat from the tank by radiation, conduction, and evaporation; therefore, not less than, say, 12 square feet should be used in order to provide a reasonable margin.

As to the size of steam coil required, a square foot of pipe surface surrounded by circulating water may be assumed to transmit to the water not far from 100 heat units per degree difference in temperature between the steam and the water in contact with the pipe.

Assume the steam temperature to be 230°, corresponding to a trifle more than 5 pounds gauge pressure. When the water in the tank is cold, the condensation of steam in the coil will be much more rapid than when the surrounding water becomes warmer. The average temperature of the water during the 10-hour period is 60°; but the water leaving the pipe and in contact with the upper half of its surface is at a considerably higher temperature than the main body of water in the tank; therefore, with natural circulation, it is well to make ample allowance for the effect of this skin of warm water surrounding the steam coils, and to assume that they will not give off more than $\frac{2}{3}$ as much heat as that corresponding to the difference in temperature between the steam and the water in the tank, based on 100 heat units per degree difference as stated above.

In other words, allow only $66\frac{2}{3}$—or, in round numbers, 70—heat units per hour per degree difference in temperature between the steam and the water in the tank.

If the difference in temperature is $230° - 70° = 160°$, on the basis stated, one square foot of coil would give off $70 \times 160 = 11{,}200$ heat units per square foot per hour; and since 600,000 heat units must be supplied to the water, a 53-square foot coil or slightly larger would be required, equal to about 122 ft. of $1\frac{1}{4}$-inch pipe.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for College, Civil Service, or Engineer's License. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

MARINE BOILERS.

1. Why are center punch marks placed one inch apart on a test piece?

2. Describe the double butt treble riveted joint and state its approximate efficiency.

3. A Purves furnace is 7 feet 6 inches long, 38 inches in diameter and the pressure is 170 pounds per square inch; what should be the thickness of the plate? Ans. .46 inch.

4. What is the difference between ordinary and stay tubes?

5. What constitutes the heating surface of a cylindrical marine boiler?

6. What should be the area of the spring safety valve for a cylindrical boiler having 60 square feet of grate area?

English Board of Trade Rules.

7. Why are the ends of some marine boilers curved at the top?

8. Describe briefly the Foster Automatic Stop Valve.

9. Why is a large quantity of salt in the boiler undesirable?

10. Describe the process of building the fire?

11. Why are stud bolts or patch bolts used for repairs instead of rivets?

12. The U. S. S. "Massachusetts" is running with steam up in all the main boilers. If the rate of combustion is 22 pounds of coal per square foot of grate, how many long tons of coal are consumed per day of 24 hours? Ans. 130 tons (about).

13. Give the advantages of corrugated furnaces. Name the most common forms.

REVIEW QUESTIONS

ON THE SUBJECT OF

MARINE ENGINES.

1. How could a vertical marine engine be run if the go ahead eccentric breaks?

2. Sketch the arrangement of the cylinders of a three cylinder compound engine and show where the steam enters and leaves the cylinders.

3. Referring to Fig. 41, how many tons of coal must be burned per day to attain a speed of 16 knots?

4. Define the pitch of a screw propeller.

5. Explain with sketch a method of marking off nuts.

6. Why are leads taken?

7. Give the advantages of a centrifugal pump.

8. A ship is steaming at a speed of 13 knots per hour, the screw has a pitch of $17\frac{1}{2}$ feet. What is the apparent slip in per cent. if the engines are working 84 revolutions per minute?

9. Sketch some method for securing the liner of a cylinder in place, showing how it is made steam tight at both ends.

10. What is the displacement in tons if the volume of the ship under the water line is 26,250 cubic feet?

11. Describe the cylinder relief valve. Where are they placed?

12. If a propeller shaft is 14 inches in diameter and there are 7 collars what should be the diameter of the collars if the total thrust is 48,000 pounds? Ans. $18\frac{1}{2}$ inches.

13. How is a thrust block constructed so that the collars may be separately adjusted?

REVIEW QUESTIONS

ON THE SUBJECT OF

HEATING AND VENTILATION.

PART I.

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1. What advantage does indirect steam heating have over direct heating? What advantages over furnace heating?

2. What are the causes of heat loss from a building?

3. Why is hot water especially adapted to the warming of dwellings?

4. What proportion of carbonic acid gas is found in outdoor air under ordinary conditions?

5. A room in the N. E. corner of a building of fairly good construction is 18 feet square and 10 feet high; there are 5 single windows, each 3 by 10 feet in size. The walls are of brick 12 inches in thickness. With an inside temperature of 70 degrees, what will be the heat loss per hour in zero weather?

6. State four important points to be noted in the care of a furnace.

7. A grammar school building, constructed in the most thorough manner, has 4 rooms, one in each corner, each being 30 ft. by 30 ft. and 14 ft. high, and seating 50 pupils. The walls are of wooden construction, and the windows make up $\frac{1}{3}$ of the total exposed surface. The basement and attic are warm. How many pounds of coal will be required per hour for both heating and ventilation in zero weather, if 8,000 B. T. U. are utilized from each pound of coal?

8. What two distinct types of furnaces are used? What are the distinguishing features?

9. What is meant by the efficiency of a furnace? What efficiencies are obtained in ordinary practice?

10. What are the principal parts of a furnace? State briefly the use of each.

11. A brick house of the best construction, 20 ft. by 40 ft., has 3 stories, each 10 feet high. The walls are 12 inches in thickness; and $\frac{1}{4}$ the total exposed wall is taken up by windows, which are double. The basement is warm, but the attic is cold. The house is to be warmed to 70 degrees when it is ten degrees below zero outside. How many square feet of grate surface will be required, assuming usual efficiencies of coal and furnace?

12. A high school is to be provided with tubular boilers. What H. P. will be required for warming and ventilation in zero weather if there are 600 occupants, and the heat loss through walls and windows is 1,500,000 B. T. U. per hour?

13. What are the three essential parts of any heating system?

14. Is direct-steam heating adapted to the warming of schoolhouses and hospitals? Give the reason for your answer.

15. The heat loss from a dwelling-house is 280,000 B. T. U. per hour. It is to be heated with direct steam by a type of sectional boiler in which the ratio of heating surface to grate surface is 28. What will be the most efficient rate of combustion, and how many square feet of grate surface will be required?

16. What is the use of a blow-off tank? Show by a sketch how the connections are made.

17. How are the sizes of single-pipe risers computed?

18. What weight of steam will be discharged per hour through a 6-inch pipe 300 feet long, with an initial pressure of 10 pounds, and a drop of $\frac{3}{4}$ pound in its entire length?

19. What is an air-valve? Upon what principles does it work?

20. What size of steam pipe will be required to discharge 2,400 pounds of steam per hour a distance of 900 feet, with an initial pressure of 60 pounds, and a drop in pressure of 5 pounds?

21. What objection is there to a single-pipe riser system? How is this sometimes overcome in large buildings?

22. What patterns of valves should be used for radiators? What conditions of construction must be observed in making the connections between the radiator and riser?

REVIEW QUESTIONS

ON THE SUBJECT OF

HEATING AND VENTILATION.

PART II.

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1. How would you obtain the sizes of the cold-air and warm-air pipes connecting with indirect heaters in dwelling-house work?

2. What is an aspirating coil, and what is its use?

3. What efficiencies may be allowed for indirect heaters in schoolhouse work? How would you compute the size of an indirect heater for a room in a dwelling-house?

4. How is the size of a direct-indirect radiator computed?

5. A schoolroom on the third floor is to be supplied with 2,400 cubic feet of air per minute. What should be the area of the warm-air supply flue?

6. What is the chief objection to a mixing damper, and how may this be overcome?

7. How many square feet of indirect radiation will be required to warm and ventilate a schoolroom when it is 10 degrees below zero, if the heat loss through walls and windows is 42,000 B. T. U., and the air-supply 120,000 cubic feet per hour?

8. What is the difference in construction between a steam radiator and one designed for hot water? Can the steam radiator be used for hot water? State reasons for answer.

9. How may the piping in a hot-water system be arranged so that no air-valves will be required on the radiators?

10. What efficiency is commonly obtained from a direct hot-water radiator? How is this computed?

11. How should the pipes be graded in making the connections with indirect hot-water heaters? Where should the air-valve be placed?

12. Describe briefly one form of grease extractor.

13. What is the office of a pressure-reducing valve in an exhaust-steam heating system?

14. Upon what principle does a pump governor operate?

15. What type of pipe fittings should always be used in hot-water work?

16. How is the water of condensation returned to the boilers in exhaust steam heating?

17. How many cubic feet of air per hour will be discharged through a flue 2 feet by 3 feet, and 60 feet high, if the air in the flue has a temperature of 80 degrees and the outside air 60 degrees?

18. In a hot-water heating system, what causes the water to flow through the pipes and radiators? How does the height of the radiator above the boiler affect the flow?

19. What precaution should always be taken before starting a fire under a steam boiler?

20. What is the free opening in square feet through a register 24 inches by 48 inches?

21. Why are return pumps or return traps necessary in exhaust-steam heating plants?

22. What efficiency may be obtained from indirect hot-water radiators under usual conditions? What is the common method of computing indirect hot-water surface for dwelling-house work?

23. State briefly how a return trap operates.

24. What is the use of an expansion tank, and what should be its capacity?

25. Describe the action of one form of damper regulator.

26. What is the principal difference between a hot-water heater and a steam boiler? What type of heater is best adapted to the warming of dwelling-houses?

27. Upon what four conditions does the size of a pipe to supply any given radiator depend?

28. What is the use of an exhaust head?

29. A hospital ward requires 60,000 cubic feet of air per hour for ventilation, and the heat loss through walls and windows is 140,000 B. T. U. per hour. How many square feet of indirect steam radiation will be required in zero weather?

30. For what purpose is a back-pressure valve used?

REVIEW QUESTIONS

ON THE SUBJECT OF

STEAM AND HOT WATER FITTING.

1. What points should be borne in mind when selecting a heating boiler for a given service?

2. Explain by an example how to check the catalogue rating of a boiler.

3. Point out the difference between (a) direct, (b) direct-indirect, and (c) indirect radiation.

4. State the advantages of each type.

5. What advantages do overhead coils possess over other classes of direct radiation?

6. (a) With overhead coil heating, how should the coils be placed with reference to walls and floor to secure the best results? (b) Why?

7. In what two ways is heat given off by a radiator?

8. What advantages has a wet return system over one with dry returns?

9. (a) In what classes of buildings, as a rule, may the overhead feed system be used and why? (b) What advantages are possessed over the up-feed system?

10. When should a two-pipe system be used in preference to a one-pipe?

11. Explain the action of a siphon trap in balancing a low pressure steam heating system.

12. When is it advisable to establish an artificial water line?

13. Explain in detail how to compute the radiating surface for low pressure steam in a corner room 18 ft. square, 10 ft. high, the exposed wall to be 16 in. thick, exposed toward the north and

west, and having glass surface equal to one-fourth the total exposed surface of wall and glass combined.

14. Describe the action of aspirating heaters. To be most effective in causing a rapid flow of air in a flue, at what point should they be placed?

15. State some advantages to be secured by exhaust steam heating.

16. What appliances are necessary in connection with exhaust steam heating that are not used with ordinary low pressure heating?

17. (a) What are the main features in the so-called Vapor System? (b) What advantages are claimed over ordinary steam heating systems?

18. What is the purpose of the "mercury-seal" in that type of heating system?

19. State the purpose and explain the action of steam traps.

20. What is meant by "absolute pressure" of steam?

21. If a pipe is 80 ft. long when filled with steam at 10.3 pounds pressure, what will be its length when filled with steam at 100.3 pounds? Show method of computation.

22. Describe (with sketches) several methods for taking up expansion.

23. What is meant by the term "O. D." pipe?

24. What is the minimum thickness of "O. D." pipe to permit threading?

25. (a) With low pressure piping, up to what size is it advisable to use screwed fittings? (b) What advantages are there in using flanged fittings for the larger sizes?

26. Describe two types of air valves.

27. (a) Mention two kinds of dies.

(b) What points must be attended to in order to secure the best results in using them?

28. What advantages have pipe tongs over wrenches?

29. What advantages are possessed by the overhead feed system of hot water heating over the up-feed system?

30. What precautions is it necessary to take with regard to expansion tank connections and why?

31. State some advantages claimed for (a) open tank (b) closed tank hot-water heating systems.

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