# STEAM BOILERS

ENGINEERING EDUCATION SERIES

# STEAM BOILERS

PREPARED IN THE
EXTENSION DIVISION OF
THE UNIVERSITY OF WISCONSIN

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# PREFACE

This book has been written out of the experience of correspondence teaching in this subject in the Extension Division of The University of Wisconsin. It is the result of well-matured plans to produce a suitable text for instruction by mail as developed through actual experience. The work, therefore, was written primarily for correspondence students, and is intended for the use of firemen and others who may be in responsible charge of boiler rooms.

In order to best fulfill the main purpose of this instruction, the operation of boilers, rather than their design, is treated in considerable detail. Much descriptive matter relating to boilers and boiler-room equipment is included because it is realized that many firemen are familiar with only the particular equipment which they happen to be using, and wish to know something of other types of equipment.

On account of the increasing importance of efficient combustion of fuels and of the attention now being given to smoke prevention, these subjects are treated in detail. The chapters on "Chemistry of Combustion" and "Fuels" form a basis for the study of the proper burning of fuels. Following these are chapters on "Firing" and "Smokeless Combustion of Coal." These chapters treat of the best methods of using fuel, and also of different forms of furnaces and apparatus for securing smokeless combustion, and of different forms of mechanical stokers.

The chapter on "Smokeless Combustion of Coal" was compiled by Mr. E. B. Norris, Associate Professor of Mechanical Engineering in the Extension Division of The University of Wisconsin. The author desires to acknowledge the assistance of Mr. Norris and Mr. H. J. Thorkelson, Associate Professor of Steam and Gas Engineering in the College of Engineering of The University of Wisconsin, for their careful reading of the manuscript and for many valuable suggestions which have been utilized.

The text is liberally illustrated in order to enhance its value to those for whose use it was prepared. A number of manufacturers furnished cuts of their apparatus for this purpose and their coöperation which, in some cases, involved considerable effort and expense on their part, is gratefully acknowledged.

E. M. S

MADISON, WIS.
*Dec.* 1, 1912.

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# STEAM BOILERS

## CHAPTER I

### TYPES OF BOILERS—FLUE AND FIRE-TUBE BOILERS

**1. Boilers.**—A Steam Boiler is a closed vessel in which water is boiled and steam formed for power or heating purposes. Boilers intended for power purposes are made of plates of rolled steel, riveted together, and of steel or wrought-iron tubes. Steel is a most desirable material for boilers as it is strong, cheap, and easily worked. Cast iron is used extensively for the construction of house-heating boilers, but it is not well adapted for power boilers which carry high pressures. Copper is also used to some extent for special kinds of boilers, such as those used on fire engines.

**2. The Shell.**—The Shell of a boiler is the round or cylindrical part in which the steam is formed from the water. The shell is only partly filled with water, the space above the water being used as a storage space for steam.

**3. The Water Line.**—The Water Line in a boiler is the height at which the surface of the water stands. This, of course, will vary somewhat, but should be kept as nearly constant as possible. The water level is usually shown by a gauge glass which has the two ends connected to the inside of the shell. The upper end of the glass is connected to the steam space while the lower end is connected to the water space. The water will then stand in the glass at the same level as in the shell.

**4. The Steam Space.**—The Steam Space is all the space in the boiler above the water line. If the steam space is too small, the violent boiling that takes place will cause water to be carried off with the steam as it leaves the boiler.

**5. The Disengagement Area.**—The area of the surface of the water at the water line is called the Disengagement Area, since it is from this area that steam is released from the water and rises into the steam space. This area must be considered in designing a boiler. If the disengagement area is small in proportion to the amount of steam generated, the boiling will be so violent over this small surface that large amounts of water will be thrown up with the steam and possibly be carried off with the steam into the steam pipes. If the disengagement area is small the steam space should be high, in order that the moisture thrown up may be drained back before the steam leaves the boiler.

**6. The Heating Surface.**—The Heating Surface of a boiler is that surface which has flames or hot gases on one side and water on the other side. It is by the amount of heating surface that boilers are generally rated, since this shows in a general way their ability to generate steam. However, all heating surface is not equally effective. The surfaces subjected to the greatest heat will naturally evaporate water at a greater rate than those surfaces more remote from the fire. In some boilers, a part of the surface has hot gases on one side and steam on the other. This surface, which is called superheating surface, is not considered as heating surface, since steam will not take the heat from the metal very rapidly, and, therefore, this surface is not very effective in producing steam.

**7. The Grate Surface.**—By Grate Surface is meant the area of the grate upon which the fire rests. It is usually expressed in square feet; for example, if a grate is 6 ft. wide and 7 ft. deep the grate surface is $6 \times 7 = 42$ sq. ft. The air openings in the grate, through which the air passes from the ash pit into the fire, should be from 30 per cent to 50 per cent of the total grate surface. The amount of grate surface for a boiler of a certain size depends on the kind of fuel to be burned and on the force of the draft available.

**8. Tools.**—The tools used by a fireman are a shovel, a slice bar, a hoe, a rake, and a lazy bar. The slice bar is a straight heavy iron rod pointed at one end and having the other end bent in the form of a handle. It is run under the fire next to the grate and is used to break up the clinkers and lift them to the top of the fire, so they may be raked out of the furnace. The hoe and rake should be of a heavy and durable form. They are used for drawing clinkers from the fire and for leveling or drawing the fire. The lazy bar is a heavy bar of iron, bent at one end to hook over the door hinge on one side, while the other end rests on the catch. The part extending across the doorway is horizontal and is used as a support for the hoe or rake while the fire is being cleaned or banked.

**9. Classes of Boilers.**—For the purpose of this course, boilers will be divided into three general classes, viz.: *Flue boilers*, *Fire-tube boilers*, and *Water-tube boilers*. These three classes will include most of the boilers in use to-day but, owing to the great number of forms being sold, some will necessarily not belong entirely to any class but will be a combination of two or more classes. These general classes may be further subdivided, as will be noted later.

The simplest type of boiler that can be imagined is the plain cylinder boiler with the fire beneath it. A longitudinal cross-section of such a boiler is shown in Fig. 1. Although such boilers have been used in the past, they are seldom seen at present as they are very wasteful of fuel. They have the advantage,

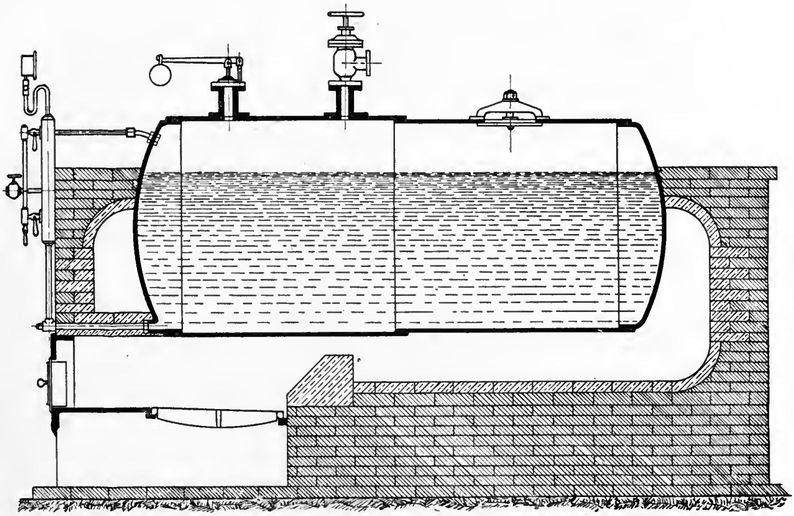


FIG. 1.—Plain cylindrical boiler.

however, of being extremely simple and, as they contain a large amount of water compared to the volume of the steam space, they will maintain a very steady pressure. These boilers, therefore, do not require close attention. For these reasons they have been used to a considerable extent in small power plants for buildings, particularly for heating purposes. The plain cylindrical boiler represents the first step in the development of modern power boilers.

The next step in the development of the boiler was the putting of a flue through the shell. After the gases from the fire had passed the length of the shell they were directed back through this flue, and more heat extracted. With the use of this flue began the practice of making boilers internally fired. The flues were made large enough to contain the grates. In this way the furnace was surrounded by water on all sides except in front and at the rear. After the gases had passed through this flue they were lead along the outside of the shell so that more heat might be obtained from them.

Following certain slight modifications of this type, the next development was the fire-tube boiler, in which the large flue was replaced by a number of small tubes. This greatly increased the heating surface and made a much more efficient boiler. This type is still the most common in the United States for stationary steam plants. The modern locomotive boiler and the Scotch marine boiler are modifications of this type for locomotive and marine uses. The latest development is the water-tube boiler, which contains the water within a number of small tubes, thus securing the maximum heating effect combined with rapidity of action.

Flue Boilers are those having one or more large flues passing through them. The grates are usually placed in the flues. The name "flue boilers" is also applied to boilers having the fire outside the shell and having flues over 6 in. in diameter passing through the shell.

Fire-tube Boilers have tubes 6 in. or less in diameter passing lengthwise through the shell. The hot gases pass through the tubes, while the water surrounds them on the outside. Although the name "flues" is quite commonly applied to the tubes of fire-tube boilers, it should be noted that, strickly speaking, the name "flues" applies only when they are over 6 in. in diameter and that when 6 in. or less they are "tubes."

In Water-tube Boilers the water is contained within the tubes while the hot gases pass on the outside. In these boilers there are no very large drums containing great volumes of water and there is less danger from explosion, and high pressures can be carried without requiring excessively thick sheets of steel.

**10. Cornish Boilers.**—As before mentioned, the first improvement on the plain cylinder boiler was the addition of a flue running from end to end. The flue ran entirely through the boiler from one end to the other and contained the grates and bridge wall. This arrangement made what is called an internally fired boiler, that is, the furnace was placed inside the shell of the boiler and was surrounded by water. Boilers of this form were called Cornish boilers. The heating surface formed by the sides and top of the furnace absorbed a large quantity of heat and was, therefore, very effective. The heating surface was further extended by arranging the setting of the boiler in such way that there were two passages for the hot gases, one on each side of the shell and another along the bottom. The hot gases passed first through the flue inside the shell to the back of the boiler; at this point they divided, part passing to the front through the passage on one side of the shell and the other part passing along the other side of the shell. The gases then reunited and passed to the back through the passage along the bottom of the shell and out the stack. Fig. 2 illustrates this type of boiler. This view shows clearly the internal arrangement of the boiler, including the flue passing through the shell and containing the grate and bridge wall. The view shown in Fig. 3 is a cross-section of the same boiler and shows the arrangement of flues in the setting for leading the flue gases along the sides of the shell. The name "Cornish" as applied to this form of boiler comes from the fact that it was first used at the Cornish mines in England. Only those boilers which have a single flue are known as Cornish boilers. This boiler was a great improvement over the cylindrical boiler, as the hot furnace gases

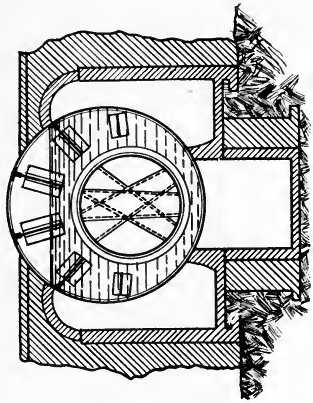


Fig. 3.—Cross-section of Cornish boiler.

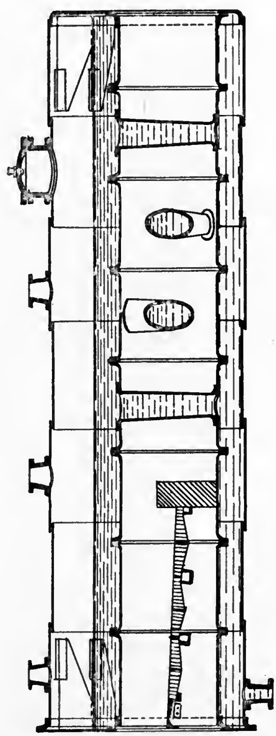


Fig. 2.—Longitudinal section of Cornish boiler.

were made to pass the length of the boiler four times, and thus a larger part of the heat might be extracted from the gases. Cornish boilers were made in sizes up to 28 ft. long by 7 ft. in diameter with a 3-ft. flue. They are not being manufactured to any extent at present, though there are still some of them in use in some of the older power plants of England.

These boilers are slow steaming on account of the large mass of water in them, but they have a large steam space and, therefore, are not liable to sudden fluctuations in pressure with changes of load. They are not well suited to high pressures owing to the difficulty of properly bracing the heads and to the difficulty in making the flue strong enough to withstand the crushing pressures. In Fig. 2 the flue is shown made in sections with the ends flanged outward and riveted together. This construction braces it and makes it much stiffer than a simple straight flue would be. Another method of stiffening these flues is to make them of corrugated sheets, arranging the sheets in such manner as to have the corrugations pass around the flue. It should be noted that in Fig. 2 the flue of the Cornish boiler is supplied with Galloway tubes, or short tubes extending across the flue. The Cornish boiler may or may not have these Galloway tubes, as will be noted later.

**11. Lancashire Boilers.**—The next form of boiler to be developed was what is known as the Lancashire boiler. This is also an English type very similar in construction to the Cornish boiler but differing from it in having two flues instead of one. These two flues may extend through the boiler separately but in some cases they are joined together just back of the bridge wall, forming a single flue which extends from this point to the rear end of the boiler, and also forming a common combustion chamber for gases from the two grates. In England, this type is given the name of "breeches" boiler. The two furnaces may be fired alternately and the gases from the freshly fired grate will be burned in the combustion chamber by the air that passes through the other grate. In this way a uniformly high temperature is maintained in the combustion chamber.

The Lancashire is usually somewhat larger than the Cornish boiler and has more heating surface for the same outside dimensions. As this additional heating surface forms the walls of the fire box, it is very effective. Just as with the Cornish boiler, the Lancashire may or may not have Galloway tubes. The setting for the Lancashire boiler is the same as for the Cornish. These boilers are usually from 7 to 8 ft. in diameter and about 30 ft. long, with flues 30 in. to 40 in. in diameter.

**12. Galloway Boilers.**—Any boiler whose flue is supplied with Galloway tubes, whether it be of the Cornish or Lancashire type, is known as a Galloway Boiler. Galloway tubes are tapered tubes extending through the flue from bottom to top as shown in Fig. 2. These tubes stiffen the flues; they add very effective heating surface, since they are directly in the path of the hottest gases; and they maintain a good circulation of the water in the boiler. The tapered form makes the tubes easy to put in and to replace, since the flange on the smaller end passes through the hole for the larger end. The end flanges are riveted to the flue.

The settings for Lancashire and Galloway boilers are similar to that shown for the Cornish boiler, though the Galloway boilers sometimes have but one pass for the gases along the outside of the shell. This is permissible because the Galloway tubes extract considerable heat from the gases before they reach the rear of the boiler.

All of the boilers so far described are internally fired except the plain cylindrical boiler. Boilers of these types are seldom used for pressures greater than 100 lb. per square inch. They are rarely seen in the United States, though they are quite common abroad, especially in England. They are slow steamers but will maintain a steady pressure on account of the large volume of water which they contain.

**13. Fire-tube Boilers.**—Fire-tube boilers are more commonly used than any other kind. They are simple in construction, comparatively cheap, and are quite durable when they receive proper care. The heating surface is large for the space it occupies and, therefore, the boiler will occupy but small space in proportion to its steaming capacity. It is a fairly rapid steamer, with large steam space, and is well suited to pressures up to 150 lb. This boiler came into use before the water-tube type and this, together with its simplicity and ease of attendance, accounts for the large number in use.

Fire-tube boilers are made in a variety of forms. They may be either externally or internally fired, and either horizontal or vertical. Large sizes are practically all horizontal, except the

FIG. 4.—Horizontal fire-tube boiler with dome.

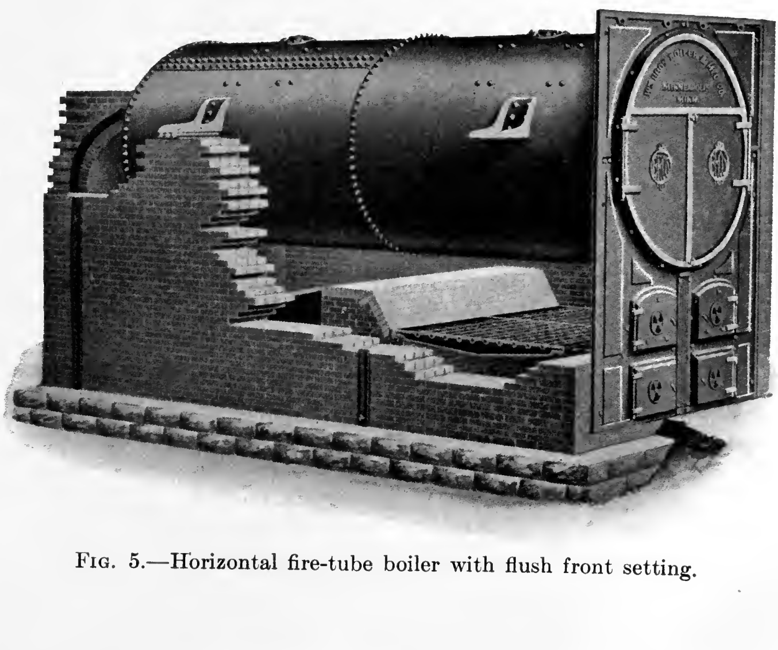


FIG. 5.—Horizontal fire-tube boiler with flush front setting.

Manning boiler, mentioned later; while the very small sizes are practically all vertical.

The most common form of fire-tube boiler for stationary purposes is the externally fired horizontal fire-tube boiler shown in Fig. 4. This boiler, without the dome, is also shown with its setting in Fig. 5. The shell is cylindrical in form with flat heads, and the tubes, which are from 2 to 4 in. in diameter, pass through the shell from one head to the other.

In the form of boiler shown in Figs. 4 and 5 the smoke connection is made a part of the shell, being riveted to the front end. The hot gases pass along the bottom of the shell from front to back and then to the front again through the tubes. Since there are a large number of tubes of small diameter, the surface of these tubes forms the principal part of the heating surface.

Sometimes this form of boiler is set so the hot gases pass along the bottom of the shell from front to back and then to the front through the tubes, and the setting is so arranged that the gases may then pass to the back again in the space between the top of the shell and the setting, giving the heat in the gases a further chance to be absorbed by the boiler. The extra heating surface added in this way is not very effective since the larger part of it has *steam* on one side of the metal and hot gases on the other. Heat transmission through the metal under such conditions is not so rapid as if there were water on one side of the metal.

The water line in this boiler is carried about 3 in. above the top row of tubes and all the space in the shell above this is the steam space. In addition to this steam space, a steam dome is sometimes placed on top of the shell, increasing the volume of the steam space and also allowing the steam to be taken from the boiler at a point somewhat removed from the surface of the water. This insures a supply of steam drier than if the supply was taken directly from the shell.

Fig. 5 shows a boiler supported by means of two brackets on each side, one near the front and the other near the back. The front ones rest directly on the side walls, thus holding the front end of the boiler stationary, while the back ones rest on iron rollers placed on cast-iron plates which rest on the side walls. This allows the back end of the boiler to move as the shell expands, without injuring the side walls or front setting. The setting for this type of boiler is described in detail in a later chapter.

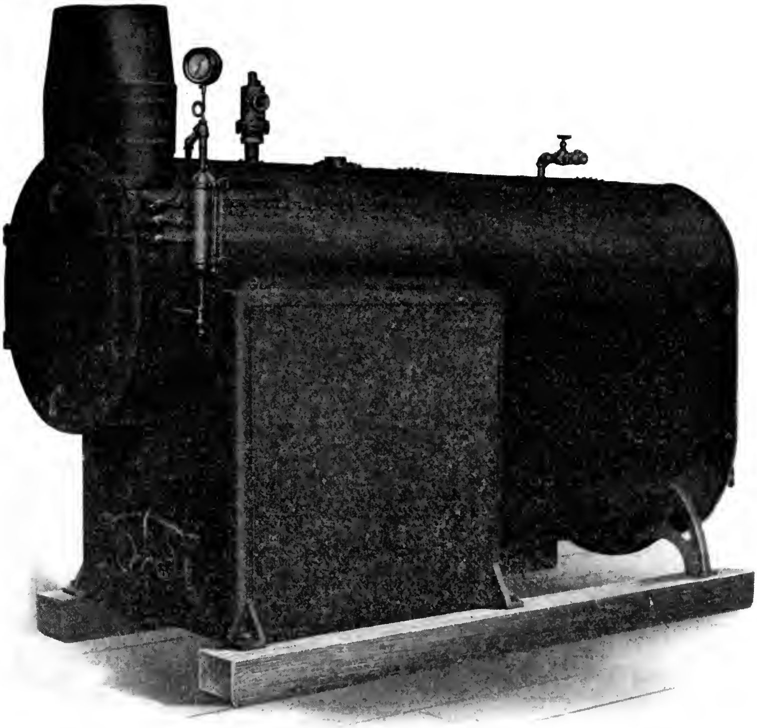


Fig. 6.—Portable fire-tube boiler on skids.

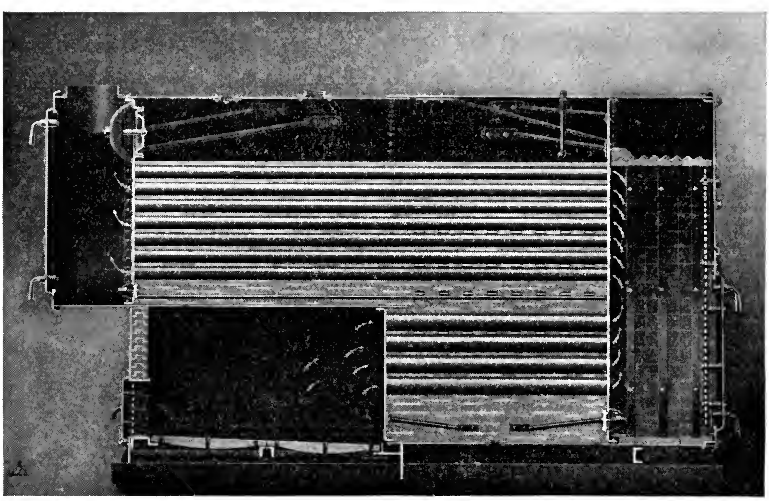


Fig. 7.—Longitudinal section of portable fire-tube boiler.

**14. Portable Boilers.**—A portable boiler is one which requires no built-up setting and which can therefore be easily moved from place to place. This type of boiler is often used in small saw mills and other small and isolated power plants, and where it may be desirable to change the location of the boiler after a time. Portable boilers are practically always of the fire-tube type.

An example of a small fire-tube portable boiler is shown in Fig. 6. In this boiler the fire box is made of cast-iron plates riveted to and beneath the front end of the boiler shell. The fire box is lined with brick to prevent the heat from destroying the cast-iron plates. The boiler and furnace are mounted on skids so it may be easily moved.

Fig. 7 is a longitudinal section of the same boiler and shows the location of the fire tubes and the path of the hot gases. The tubes are in two sets; one of short tubes which connect the fire box with the combustion chamber at the back of the shell; and the other of longer tubes which connect the combustion chamber with the smoke chamber at the front of the shell. The path of the hot gases is from the fire box through the short tubes to the combustion chamber and from the combustion chamber through the long tubes to the smoke chamber. As a short and light steel stack is used on these boilers, its weight is carried directly on the front end of the shell. Fig. 7 also illustrates the method of staying that part of the heads which lies above the tubes.

**15. Locomotive Boilers.**—The locomotive boiler is named from its shape, that of the boiler used on locomotives. It is a fire-tube boiler and is internally fired, that is, the furnace is surrounded by water. This is made possible by extending the shell downward to form the sides of the furnace or fire box. The walls of the furnace are made double with a space between the side plates which is connected directly with the water space in the shell and thus forms a water leg.

Fig. 8 shows a small portable locomotive boiler mounted on skids. These boilers are made only in small sizes and are often used in isolated locations where only a small amount of power is used. The barrel or shell of the boiler is cylindrical in shape and contains a large number of small tubes. The hot gases leaving the furnace pass through these small tubes, which are surrounded by water, to the smoke chamber at the back of the shell, thus passing the length of the boiler but once. The small steel smoke stack rests directly on the shell.

These boilers are usually provided with a steam dome from the top of which the supply of steam is taken, thus securing a drier supply than if taken from a point nearer the water line.

A locomotive boiler such as is used on locomotives is shown in Figs. 9 and 10. The shell of the locomotive boiler is cylindrical and the furnace is attached to the front of the boiler as shown in Fig. 10. A large number of small tubes pass through the cylindrical part of the shell, giving a large amount of heating surface. The sides of the furnace form a continuation of the

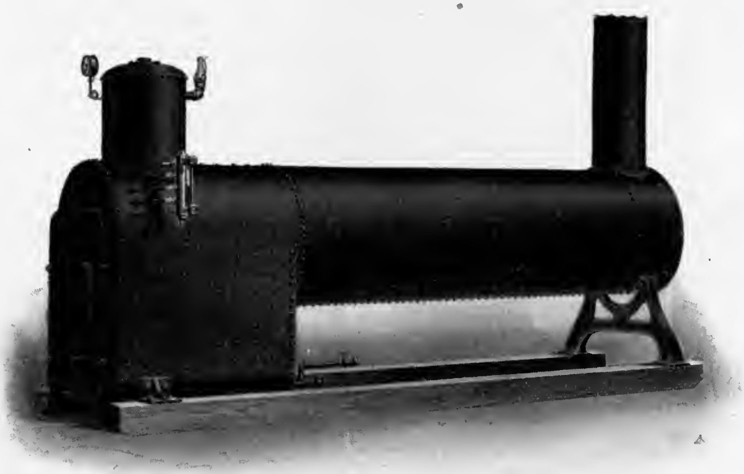


FIG. 8.—Portable locomotive boiler on skids.

shell and are formed into water legs extending down the sides, front, and back of the furnace. The water legs are thoroughly braced by means of short bolts which extend through the water legs and which have nuts on both ends, or are riveted over. In the form shown in Fig. 9, which is known as the "wagon-top" boiler, there is considerable pressure exerted on the crown sheet which is the sheet directly over the furnace. This accounts for the large numbers of stays which extend from the crown sheet to the top of the shell. As these stays are not perpendicular to the surface of either the crown sheet or the shell, the calculation

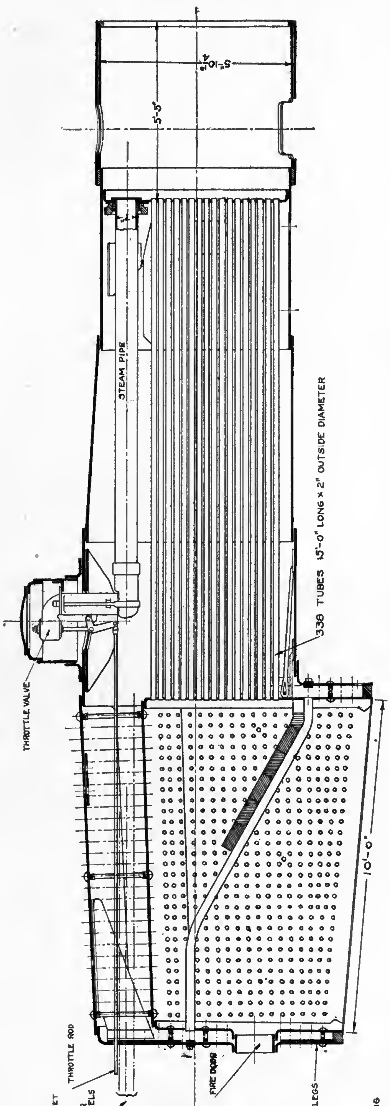



Fig. 10.—Longitudinal section of locomotive boiler.

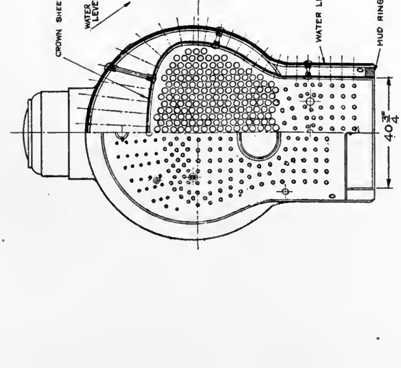



Fig. 9.—Cross-section of locomotive boiler.

of their strength is rather uncertain. To simplify this, the furnace is sometimes made in the shape shown in Fig. 11, having all opposing sides parallel to each other and the stays perpendicular to the surfaces which they support.

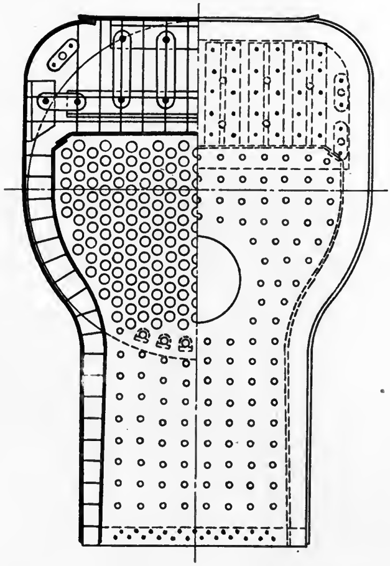


Fig. 11.—Belpaire locomotive fire box.

**16. Scotch Marine Boilers.**—The Scotch marine type of bolier is shown in Figs. 12, 13, and 14. It is very large in diameter and comparatively short in length, which is a shape best suited to fitting into the hulls of steamships, where it is most commonly used. In this boiler the grates are placed in flues as shown, there being one, two, three, or even four of these flues, depending on the size of the boiler. Just back of the bridge wall, which is also in the flue, the flue is enlarged into a combustion chamber. After leaving the combustion chamber the hot gases pass to the front of the boiler through a large number of fire tubes and then out of the stack, which is connected to the front of the boiler. Sometimes two of these boilers are placed back to back with a common combustion chamber and with the smoke stacks from each uniting into one above the boilers. As the heads of the boilers are flat and very large they require strong bracing. Therefore, a number of rods are run entirely through the boiler from the front to the back head, being held by nuts on each end.

In addition to this bracing, some of the tubes are made extra heavy and are threaded and screwed into the heads so they may act as braces. This boiler requires no setting and is supported on large cast-iron yokes which are bolted to the bottom of the ship or to the floor. The Scotch marine boiler is used very extensively in steamships and has given excellent service.

The Scotch marine boiler described above is known as a "wet-back" boiler and is used principally on vessels. This type of

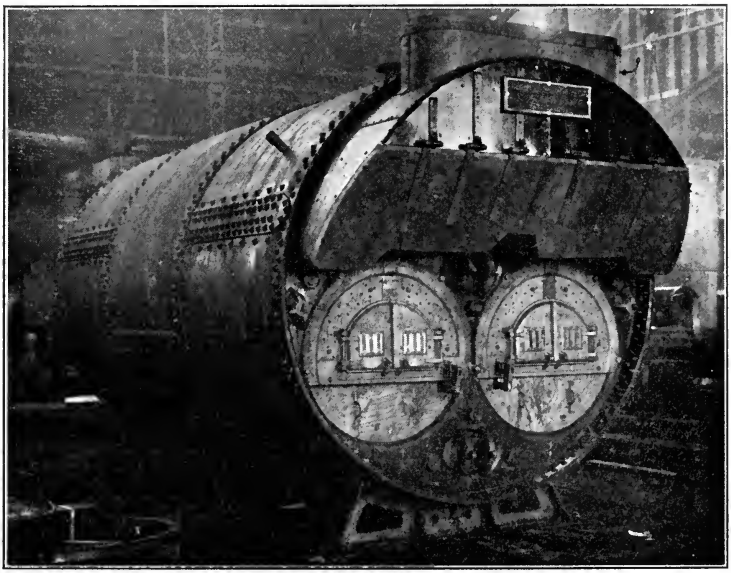


Fig. 12.—Scotch marine boiler.

boiler is modified somewhat for stationary work, being longer in proportion to its diameter and having a "dry back." A "dry-back" boiler of the Scotch marine type is illustrated in Fig. 15, from which it will be seen that the back of the boiler is protected by a brickwork lining instead of a water leg. The grates and bridge wall are placed inside a corrugated flue, the corrugations being for the purpose of giving additional strength to the flue and for making it flexible enough to take up expansion. The hot gases pass from the furnace to the combustion chamber at the back of the boiler and thence forward through the tubes to the smoke connection at the front. The space inside the

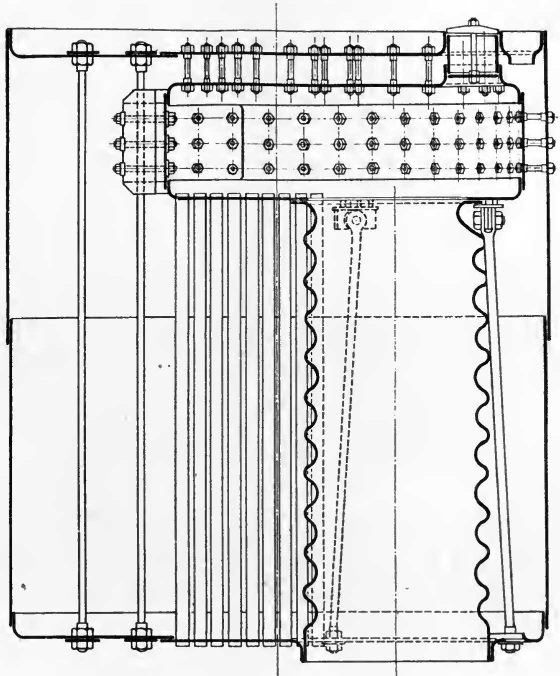


FIG. 14.—Longitudinal section of Scotch marine boiler.

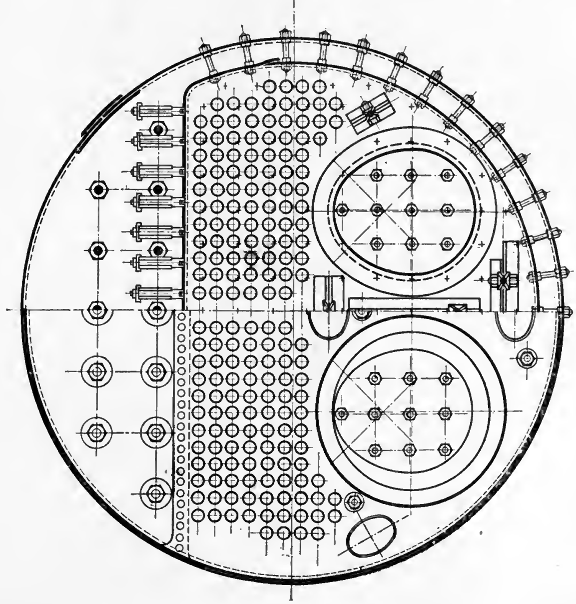


FIG. 13.—Half section of Scotch marine boiler.

shell, above and at the sides of the flue, is filled with fire tubes, giving a large amount of heating surface. The flat surfaces of the heads which are not occupied by the flue or tubes are braced by rods extending through the shell from one head to the other.

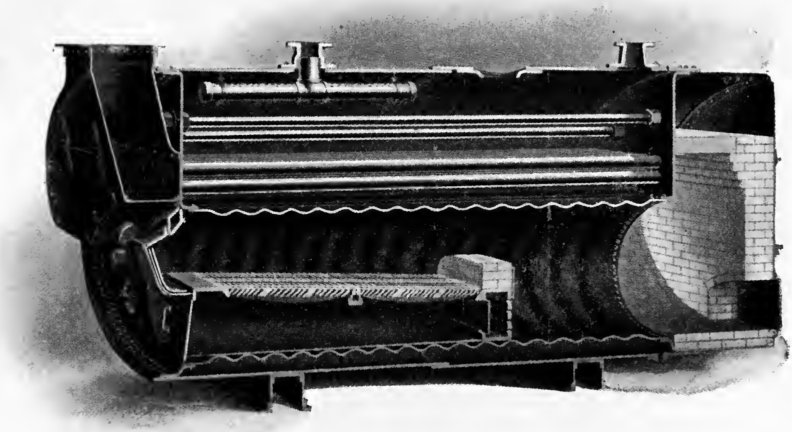


FIG. 15.—Dry back Scotch marine boiler.

**17. Vertical Fire-tube Boilers.**—The vertical fire-tube boiler is often used in places where there is not much floor space and also where a light, easily portable boiler is required, such as for supplying steam to hoisting engines. Vertical fire-tube boilers are usually internally fired, the furnace being completely surrounded with water, except the bottom, which is used as an ash pit. The tubes lead directly from the top of the furnace to the smoke connection at the top, thus allowing the hot gases to pass the length of the boiler but once.

In the form of a small vertical fire-tube boiler shown in Fig. 16 the tops of the tubes are above the water level and are thus exposed to the high temperature of the flue gases on one side and to steam on the other. Thus they are liable to become overheated and to leak from unequal expansion between them and the head when the boiler is forced. To prevent injury from this cause, these boilers are sometimes made in the form shown in Fig. 17, in which the ends of the tubes are below the water level or are submerged. The submerged type has the disadvantage, however, of not having a large or free disengagement surface, and steam is apt to collect under the top sheet and blow water into the steam connection.

A type of large vertical fire-tube boiler, known as the Manning boiler, is shown in Fig. 18. The tubes of this boiler are

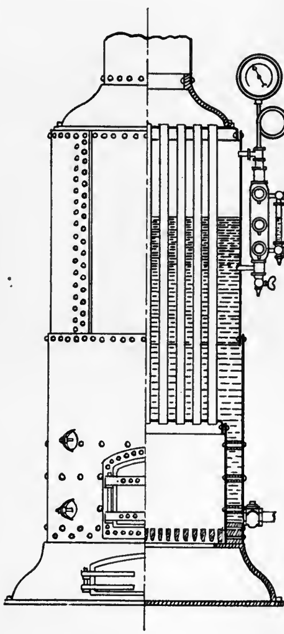


FIG. 16.—Small vertical boiler.

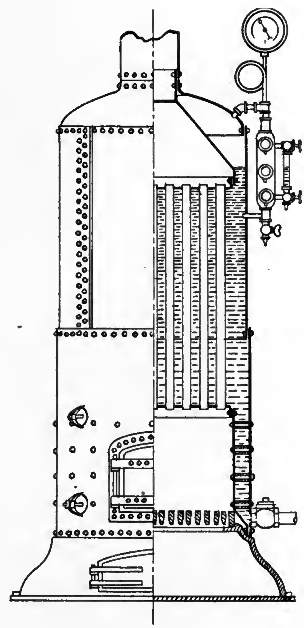


FIG. 17.—Vertical boiler with submerged tube sheet.

usually about 2 1/2 in. in diameter and from 12 to 15 ft. long, extending from the crown sheet just over the furnace to the smoke connection on top. The part of the boiler forming the furnace is made larger than the shell in order to allow more grate area and, by forming a horizontal ring around the boiler, to permit expansion and contraction between the furnace and the shell without straining the joints.

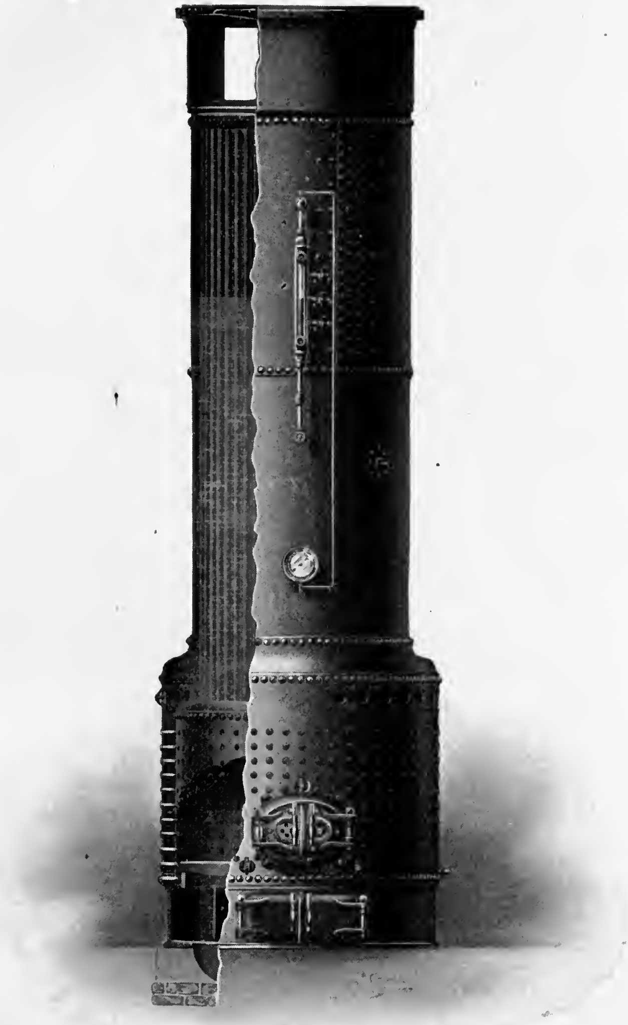


FIG. 18.—Manning vertical boiler.

# CHAPTER II

## WATER-TUBE BOILERS

**18. Water-tube Boilers.**—As stated in the previous chapter, water-tube boilers are those which carry the water on the inside of the tubes, while the hot gases are circulated on the outside. Water-tube boilers are made in a great variety of forms, differing from each other in details of construction, but being alike in principle. The more important forms of water-tube boilers are illustrated in this chapter.

The water-tube boiler, which represents the latest type of boiler construction, has been brought into extensive use by the demand for a boiler to withstand high pressures. In this type of boiler, the water is divided into elements of small size. This permits the walls of the parts containing the water to be much thicker in proportion to the area exposed to pressure, thus giving the boiler great strength. Dividing the water into small elements also has the advantage of exposing a large surface for the absorption of heat. This makes a rapid steaming boiler and one which can be forced readily, but it also requires that the boiler be closely watched as it contains only a small amount of water, which may go below the low-water level quickly.

**19. Babcock and Wilcox Boilers.**—Fig. 19 shows a type of water-tube boiler known as the Babcock and Wilcox. This was the first type of water-tube boiler placed on the market and, as it was patented, it was on the market for some time before other types were introduced. Hence, there are more of them in use than of others.

The B. & W. boiler consists of a number of straight tubes connected into steel or cast-iron headers at the ends, the headers being connected to the horizontal steam drum at the top. The end connections are made in sections; each holding two vertical rows of tubes. A number of headers are placed side by side to make up the complete set of tubes. The headers are in the form of hollow steel boxes. Holes are bored in the back of the header into which the ends of the tubes are expanded, and other holes, called handholes, are bored in the front side of the header directly opposite the ends of the tubes, in order that a cleaner may be introduced through them into the tubes and scale or other deposits cleaned from the inside. The handholes are closed by means of handhole covers which are made steam- and water-tight by means of gaskets.

The steam drums vary in size from 18 to 42 in. in diameter and are from 16 to 20 ft. long. A mud drum, for collecting mud

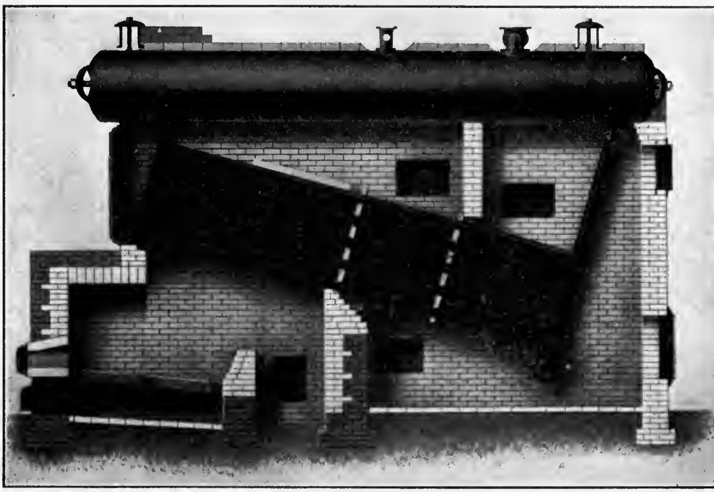


Fig. 19.—Babcock and Wilcox water-tube boiler.

and sediment which may be brought in by the feed water, is placed at the back end of the tubes at their lowest point. This is a good location for the mud drum as the feed water will be heated sufficiently by the time it reaches the drum to deposit the greater part of its scale-forming impurities. The water flows downward in the back headers and the impurities, being heavier, continue downward and settle in the mud drum.

The feed pipe enters through the front head of the steam drum as shown in Fig. 20. The direction of circulation of the water in the boiler is through the tubes from the back to the front and then up through the front headers into the steam drum, carrying the steam bubbles along with it. The water passes to the back through the steam drum and down the back headers to the tubes. The tubes slope upward toward the front and this aids the circulation, as hot water always tends to rise. Fig. 20 shows clearly the construction of the front end of the steam drum and the connection of the headers at the front of the boiler. A deflector plate is placed in the steam drum immediately in front of the front header connections. This is for the purpose of

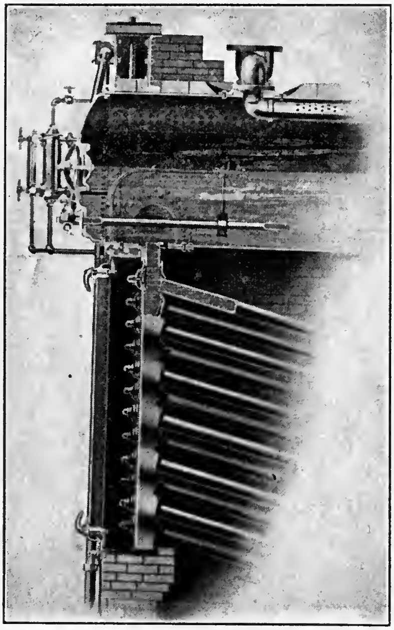


Fig. 20.—Partial section of B. and W. water-tube boiler.

deflecting the current of water rising through the front headers toward the back of the steam drum, thus helping to give a more positive circulation. Fig. 19 shows this boiler with inclined headers, while Fig. 20 shows it with vertical headers, which permit of a shorter setting.

The construction and location of the handholes and covers is also shown by Fig. 20. The removal of a handhole cover permits ready access to the tube immediately back of it and, as the tubes are straight, the inside may be examined if a lighted candle or lamp is held in front of one end of the tube while the eye is held at the other end.

The hot gases leaving the grate are made to pass across the tubes by means of the baffle plates placed across them; then they pass downward across the tubes again into the combustion chamber back of the bridge wall; and then upward again across the tubes and out at the smoke connection which leads out from the back of the boiler.

This form of boiler is not supported from the side walls as is done in the case of some fire-tube boilers, but it is suspended by means of straps passing under the steam drum and connected to I-beams across the top of the boiler. These beams are supported by steel columns built into the side walls. The boiler is thus independent of the setting and is free to expand and contract without injuring the brickwork. Long, narrow doors are provided in the side walls, through which a steam-hose may be inserted for blowing soot and ashes off the tubes.

**20. Murray Water-tube Boiler.**—A type of water-tube boiler which is manufactured by a number of firms is shown in Fig 21. The one illustrated here is a Murray water-tube boiler. It has the large drum on top placed parallel with the tubes, and the end connections made into one large box instead of being divided into sections as in the B. & W. This boiler is set very much the same as the B. & W. boiler. The back ends of the tubes are placed lower than the front ends and, as the drum is parallel with the tubes, this throws the drum into an inclined position. As the water line must come above the ends of all the tubes, this causes the back end of the drum to be almost completely filled with water and allows very little steam space at this end. In order to secure dry steam, the steam connection is taken from the front part of the drum, where the end of the pipe may be as far removed from the surface of the water as possible and, as an additional safeguard in preventing water from entering the steam pipe, a dry pipe is connected to it. In some cases, this type of boiler has an extra drum placed above and across the front end of the main drum, the two being connected by a very short length of flanged pipe. This gives more steam space and acts as an additional safeguard in securing dry steam, as the steam pipe is taken from the top of the auxiliary drum.

The drum of this boiler is also provided with a baffle plate near the front and above the connection of the front header. The baffle plate serves the double purpose of directing the circulation and, since the steam connection is made in front of the baffle plate, it aids in preventing water from entering the steam pipe.

The hot gases travel parallel to the tubes instead of across them, as in the B. & W. boiler. They are made to take this

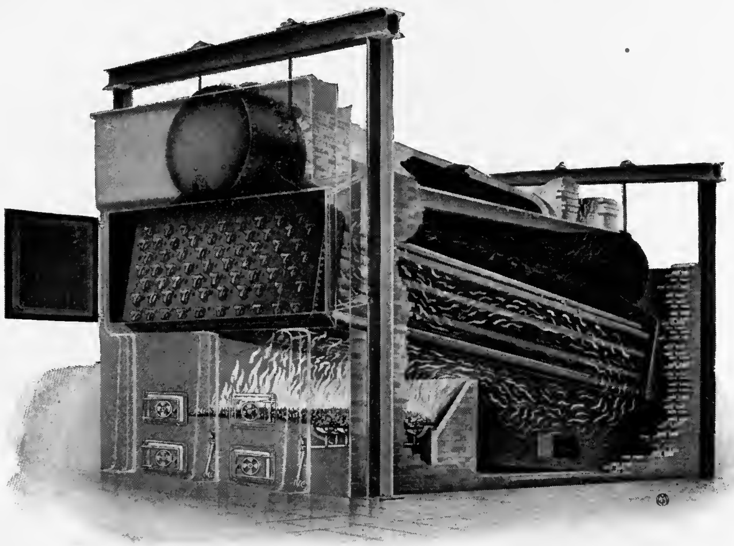


Fig. 21.—Murray water-tube boiler.

direction by the layers of tile which are placed on certain tubes as shown in the illustration. The path of the gases is from the grate over the bridge wall to the rear of the boiler; they then return to the front along the tubes and between the two layers of tile; then they rise to the steam drum and follow along it to the smoke uptake which is placed at the rear of the boiler.

**21. Edge Moor Water-tube Boiler.**—The Edge Moor water-tube boiler shown in Fig. 22 is somewhat similar to the Murray boiler, just described, in that each end connection is a single box made from riveted sheets of steel. The steam drums, however, are placed horizontally, while the tubes are inclined as in the types just described. There may be one or more drums, depending on the size of the boiler.

In the Edge Moor boiler the end connections are placed at the ends of the drums and the drums are riveted directly to the back sheets of the headers, thus giving a very simple construction. An opening as large as the drums is made in the outside sheets of the headers, and these openings are covered by dished cover plates.

The tubes are expanded into the back sheets of the headers

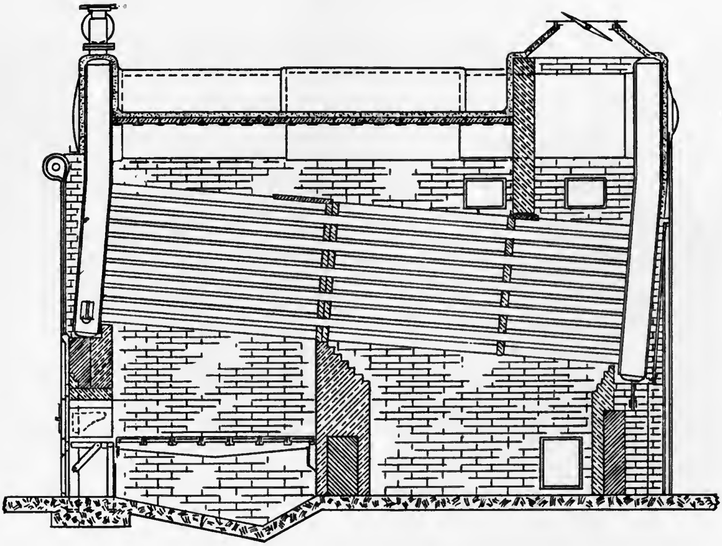


Fig. 22.—Edge Moor water-tube boiler.

and an oval-shaped handhole is directly opposite each tube. The handholes are flanged inward to give greater strength, and the cover plate is on the inside of the header where the steam pressure keeps it tightly to its seat. The opposing sheets of the header are braced by stay bolts placed between the handholes and riveted to the sheets.

The construction of the headers and drums, described above, gives a large and free area for the passage of water and the circulation is not likely to be clogged when the boiler is forced.

In the Edge Moor boiler shown here, the path of the flue gases is the same as that described in connection with the B. &W. boiler, but, of course, the gases may, by a rearrangement of the tile baffle plates, be made to follow a path similar to that described in connection with the Murray boiler, provided the tube spacing will give the requisite area.

**22. Atlas Water-tube Boiler.**—The Atlas water-tube boiler illustrated in Fig. 23 shows a radical depature in design from the types shown before. The tubes of this boiler are inclined, though not so steeply as in the B. & W., and the path of the

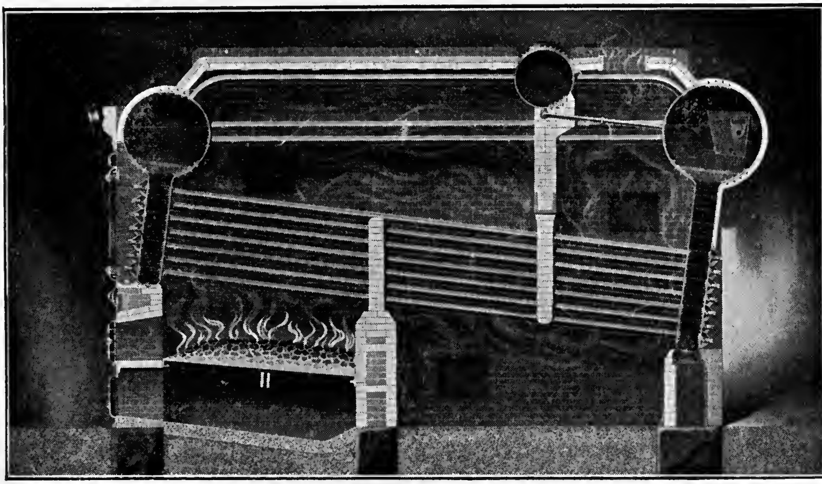


FIG. 23.—Atlas water-tube boiler.

flue gases is the same as in that boiler. The headers are constructed like those of the Murray boiler.

Instead of having a single steam drum placed lengthwise of the boiler, the Atlas boiler is provided with three drums which are placed across it. The advantage in this arrangement of the drums is that it allows a cheaper and, at the same time, a stronger connection between the header and drums.

The front and rear drums are larger than the middle one, which is used entirely as a steam drum. The normal water level is about the middle of the two lower drums. These two drums are connected below the water line by a series of tubes.

The circulation is in the same direction as in the B. & W. boiler. The steam drum is connected to both the front and rear drums above the water line in order to collect steam from them, although the larger part of the steam comes from the front drum. The steam connection is to the middle drum where the driest steam may be obtained.

The feed water is led into the rear drum, where it is discharged at the bottom of a deep trough. Here it has an opportunity to become heated and deposit most of its scale-forming impurities before it overflows the trough and enters the circulation path.

**23. Stirling Water-tube Boiler.**—The water-tube boiler shown in Fig. 24 has come into extensive use within recent years, and is proving very satisfactory. This is the Stirling boiler and, as may be seen from Fig. 24, it differs greatly from any of the forms of water-tube boilers previously described. The boiler consists of three horizontal drums at the top and one at the bottom. Each one of the top drums is connected to the bottom drum by a number of water tubes, some of which are bent in order that they may enter the drums at right angles to the surface. The bent tubes are a disadvantage in that they are hard to examine. A straight tube may be examined by looking in one end of the tube while a light is held to the other end, but this cannot be done with bent tubes.

The path of the flue gases is from the furnace over the bridge wall and along the front set of tubes to the front drum at the top. From here it passes over to the second set of tubes and follows these down to the bottom drum where it crosses to the rear set of tubes and follows these to the top, where the smoke connection is made. From this it is seen that the hot gases are in contact with the tubes for a considerable distance, which allows a large part of the heat in them to be extracted.

The two front drums at the top are connected by two sets of cross tubes, one set connecting the tops of the drums and the other connecting the bottoms. The circulation of the water is as follows: The water is fed into the upper rear drum, passes down the rear bank of tubes to the lower drum, thence up the front bank to the front drum. Here the steam formed during the passage up the front bank of tubes is disengaged and passes through the upper row of cross tubes to the middle drum, while the water passes through the lower row of cross tubes to the middle drum, thence down the middle bank of tubes to the lower drum, from which it is again drawn up the front bank to continue this course until it is evaporated. Steam is taken from the top of the middle drum and the steam spaces in the other two top drums are connected to the steam space of the middle drum.

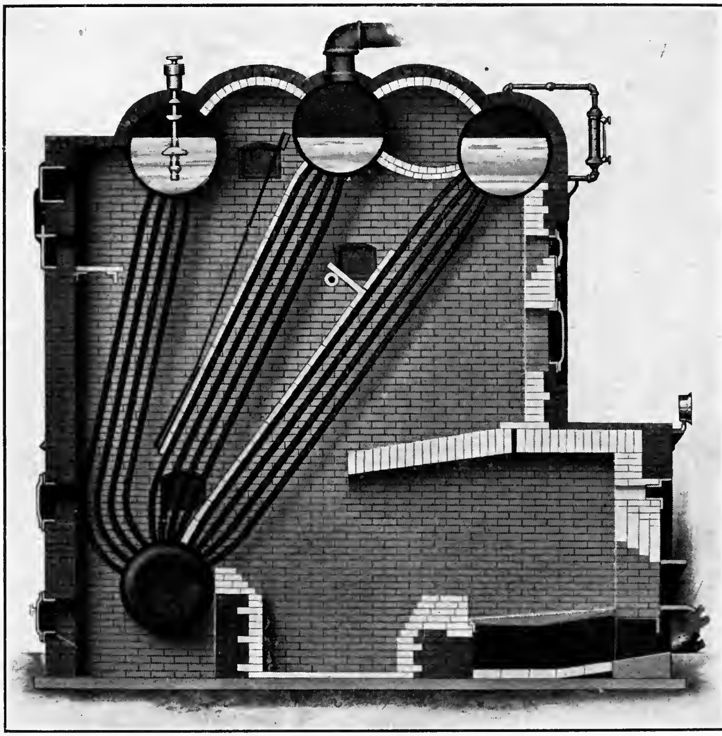


FIG. 24.—Stirling water-tube boiler.

The bottom drum serves as a mud drum for collecting mud and sediment, which settles as the water is heated. The blow-off is connected to the bottom of this drum.

The shape of the Stirling boiler is such that it occupies only a small amount of floor space for a given power and hence it is used largely where land is valuable.

**24. Vogt Water-tube Boiler.**—The Vogt water-tube boiler is another rather distinct form. The steam drum is horizontal, as in other forms, but the arrangement of the tubes is quite different. As seen in Fig. 25 there are three sets of slightly inclined tubes along which the flue gases travel, thus passing the length of the boiler three times.

The circulation is upward through the sets of inclined tubes to the steam drum, where the steam is released. The water

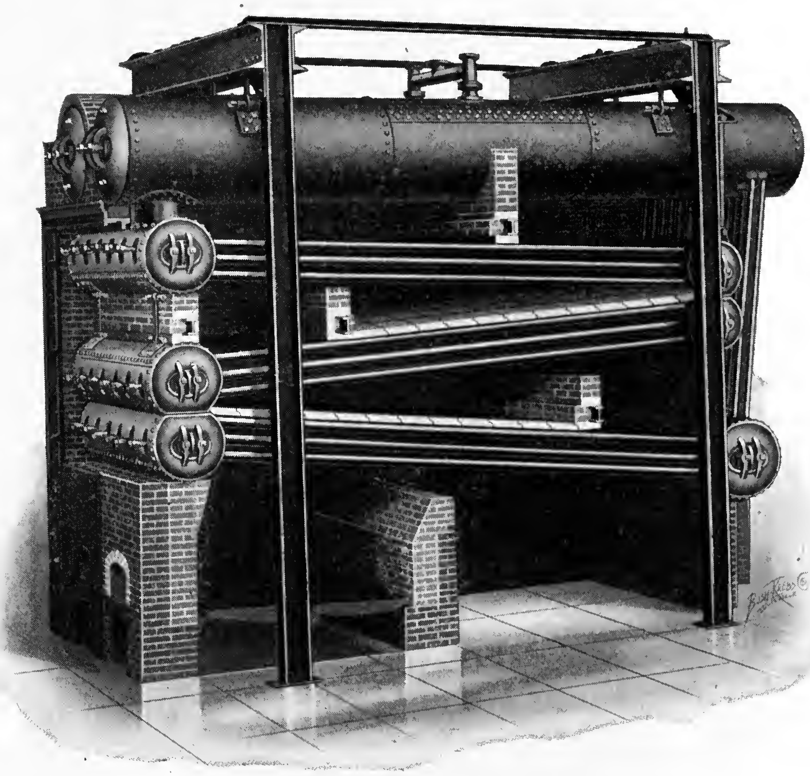


Fig. 25.—Vogt water-tube boiler.

then passes along the steam drum to the rear, whence it flows down through the vertical downcast tubes to the mud drum and from there into the inclined tubes again. The feed water enters the steam drum on top near the rear and discharges downward into the downcast tubes.

The arrangement of tubes used in this boiler gives great flexibility against expansion and contraction, while retaining straight tubes, but in order to accomplish this advantage some rather complicated flanging and riveting is required.

**25. Vertical Water-tube Boilers.**—There has been considerable demand in recent years for a boiler of large power which would occupy but small floor space, and the vertical water-tube boiler has been designed to meet these conditions. Practically all vertical water-tube boilers consist of large drums at the top and bottom and a series of water tubes placed vertically, or nearly so, connecting these drums. This construction places the tubes in the best position for promoting a rapid circulation, as water tends to rise when heated, and the more nearly vertical the tube, the faster it will rise.

**26. Wickes Vertical Water-tube Boiler.**—The Wickes vertical water-tube boiler is illustrated in Fig. 26. It consists of a large steam drum at the top and a smaller drum, having the same diameter, at the bottom. The water tubes are vertical and connect these two drums. The top or steam drum is large enough for a man to enter and stand upright. This makes cleaning the tubes easier.

The tubes are divided into two sets by a tile baffle plate which extends from the lower drum almost to the bottom of the upper one, thus directing the flue gases upward along the front set of tubes and downward along the rear set to the smoke connection which is placed at the lower end of the tubes.

The circulation is upward in the front set of tubes to the steam drum and downward in the rear set. A baffle plate is placed in the steam drum directly over the ends of the front set of tubes. This directs the current of water across the steam drum to the entrance of the downcast tubes at the rear.

The feed pipe enters the steam drum just over the rear tubes and discharges downward into these tubes. By the time the feed water has reached the lower ends of the tubes, it has become heated sufficiently to cause it to deposit the larger part of its scale-forming elements, and these, together with the mud and sediment, collect in the lower drum where the water is nearly quiet. The blow-off pipe is connected to the bottom of the mud drum.

The boiler is supported by four lugs riveted to the mud drum, the lugs resting directly on the foundation, which consists of a circular masonry wall.

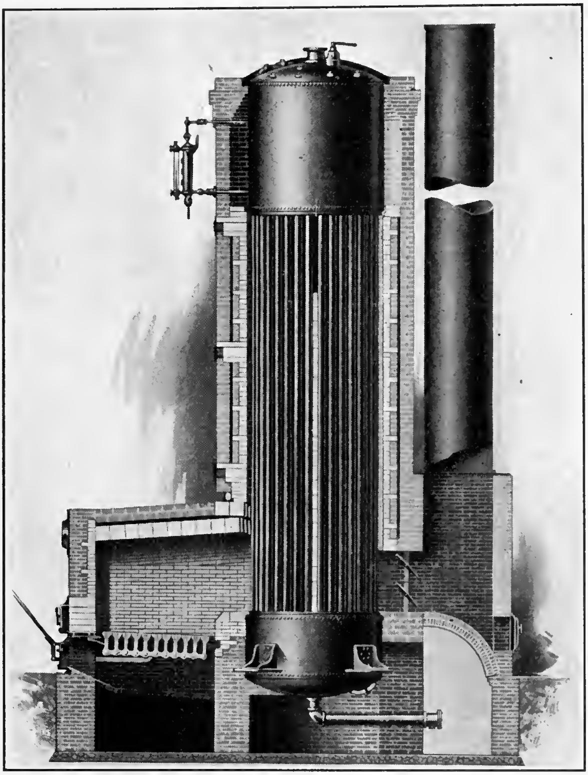


FIG. 26.—Wickes vertical water-tube boiler.

**27. Cahall Vertical Water-tube Boiler.**—Fig. 27 shows a Cahall vertical water-tube boiler. As in the Wickes boiler, there are two drums connected by a series of straight tubes, but in the Cahall boiler the upper drum is in the form of a hollow ring and is larger in diameter than the bottom drum. This gives the nest of tubes a conical instead of cylindrical form.

The flue gases pass the length of the boiler but once, rising from the grate through the nest of tubes directly to the top where they pass out through the central part of the top drum to the smoke connection. The flue gases are deflected across the tubes by means of baffle plates located in the hollow interior of the cone formed by the tubes.

The circulation is upward in the tubes to the top drum, where the steam is released and the water is carried to the bottom drum by means of a circulating pipe which connects the two drums outside the setting. The feed water enters the bottom drum where the mud and sediment settles and may be blown out.

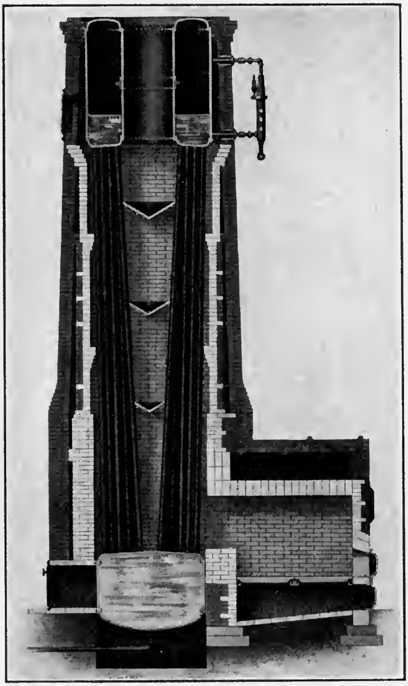


FIG. 27.—Cahall vertical water-tube boiler.

**28. Rust Vertical Water-tube Boiler.**—The Rust vertical water-tube boiler shown in Fig. 28 is somewhat different in form from the other vertical water-tube boilers shown. It consists of two horizontal water and steam drums at the top, connected by two nests of tubes to two mud drums at the bottom. Thus, there is one steam drum directly over each mud drum. The two steam drums at the top are connected by two sets of tubes, one connected below, and the other above the water line of each drum. The bottom or mud drums are also connected by a series of short straight tubes. A baffle wall, extending from the mud drums nearly to the top of the tubes, is built between the two sets of tubes.

The flue gases pass from the grate to the front set of tubes

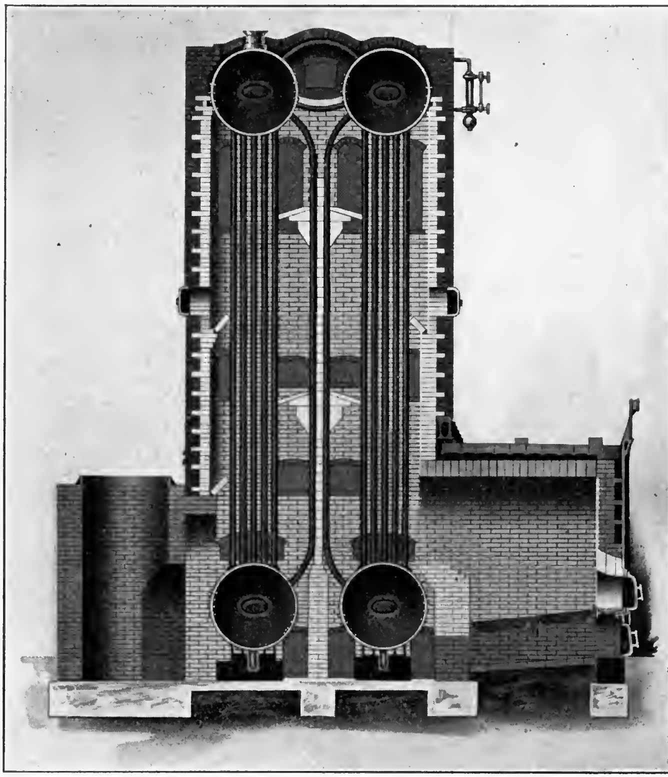


FIG. 28.—Rust vertical water-tube boiler.

and follow along these to the top of the baffle wall, where they pass across to the rear set of tubes and down these to the smoke connection at the bottom. A series of baffle plates are placed both on the baffle wall and on the setting to deflect the gases across the tubes in their passage to the smoke connection.

The Rust boilers are made in two forms, one of which has an extra row of curved tubes built against each side of the baffle wall, as shown in Fig. 28, while the other form does not have these rows of tubes. The purpose of the extra rows of tubes is to strengthen the baffle wall and also to give additional heating surface.

The circulation of water in the Rust boiler is up the front set of tubes to the front steam drum, where the steam formed in this set of tubes is separated. The steam passes across to the rear steam drum through the tubes connecting the steam spaces of the two drums, while the water passes over to the rear steam drum through the lower row of tubes. The water then continues down the rear set of tubes to the rear mud drum and through the short connecting tubes to the front drum.

The feed water enters through one end of the rear steam drum and is discharged downward into the rear set of tubes. Each of the bottom drums is provided with a blow-off for discharging the mud and sediment that collects in them.

**29. Comparison of Types.**—It is often desirable to compare boilers of different types in order to determine which is best suited for certain conditions. For this purpose it is well to know something of the advantages and disadvantages of the different types. These are briefly stated here for the three types, the flue, the fire-tube, and the water-tube types.

### Lancashire Type

| Advantages | Disadvantages |
|---|---|
| 1. Simple in construction. | 1. Slow steaming. |
| 2. Easily cleaned and examined. | 2. Liability to leak from unequal expansion. |
| 3. Large steam space. | 3. Great floor space required. |
| 4. Not liable to prime. | 4. Specially skilled men required for repairs. |
| | 5. Reduction in pressure necessary after a time. |

As may be seen from Fig. 2, the flue boiler is simple in construction and is easily examined and cleaned since there are but few flues in it. This boiler has a large steam space, since the shell is long and is only partly filled with water. On account of the large surface of the water the boiling need not be very violent and, hence, quite dry steam may be obtained.

Owing to the large mass of water contained in the shell it takes considerable time to get up steam. This boiler is not well adapted to sudden large demands for steam as the pressure cannot be changed quickly since the entire mass of water in the boiler must have its temperature changed before the pressure can be changed.

Since the flue boiler has but little heating surface for a given size, it occupies a large floor space. Repairs are not easily made on it because the repairs to this type of boiler usually require some riveting, as the flues are riveted to the heads, and such work cannot be done by an unskilled workman.

On account of the weakening of the shell by corrosion and pitting caused by impure feed water, it becomes necessary after a time to reduce the pressure carried by a flue boiler.

### Fire-tube Type

| Advantages | Disadvantages |
|---|---|
| 1. Small floor space required. | 1. Small steam space, hence, pressure liable to fluctuate. |
| 2. Quick steaming. | 2. Not easily cleaned or examined. |
| 3. Ruptured tubes easily replaced. | 3. Liable to leak at ends of tubes, at stays, and at corners of fire box. |
| | 4. Reduction of pressure necessary in time. |

Most of the heating surface in a fire-tube boiler is in the large number of small tubes which are grouped closely together. Thus a large amount of heating surface is placed within a small amount of floor space. The tubes divide up the mass of water in the boiler and distribute the heat throughout it, thus making it possible for steam to be raised or the pressure to be changed quickly to respond to changes in the load. As the flues are simply expanded into the tube sheets, it is not a difficult matter to remove one when burned, and replace it by a new one.

Since so large a portion of the boiler is occupied by the tubes and since the water line must be carried above the top row of them, there is a comparatively small steam space. Consequently, when a sudden load is thrown on an engine, the steam supply may not be sufficient to meet the demand and the pressure may fall.

On account of the tubes being placed very close together and the rows staggered, it is difficult to clean or examine them. For this reason, only very good feed water should be used with this type of boiler. But even then there will be a certain amount of corrosion, which will weaken the shell in time and make it necessary to reduce the pressure. The liability to leak is a natural consequence of the large number of tubes and seams.

### Water-tube Type

| Advantages | Disadvantages |
|---|---|
| 1. Rapid steaming. | 1. Small steam space. |
| 2. Safety. | 2. Not easily cleaned. |
| 3. Small floor space required. | 3. Liable to prime. |
| 4. Repairs easily made. | |
| 5. Reduction of pressure *not* necessary in time. | |
| 6. Large capacity for small weight and size. | |

In the water-tube boiler, the water is divided into a large number of small masses contained in the tubes and, as the surface of these tubes comprises the larger part of the heating surface, the heat is easily and quickly transmitted to the water. Therefore, the boiler is a rapid steamer and fluctuations in load are easily taken care of, but as the steam drum has but small capacity the pressure is liable to fluctuate unless watched closely.

Another result of having the larger part of the water contained in the tubes is the increased safety against explosion. The tubes are small in diameter, and their walls comparatively thick, so they are quite strong and able to withstand a high pressure. Even should one of them burst, the amount of water brought into action is small and no very serious explosion can result.

About the only part of a water-tube boiler that is liable to give out is the tubes, especially those directly over the fire. As these are simply expanded into the headers, they may easily be replaced by new ones, and the strength of the boiler maintained at its original value. Consequently, it is not necessary to reduce the pressure after the boiler has been in use for a time.

By the statement that the water-tube boiler is not easily cleaned is meant not so much that there is any special difficulty in getting at the surfaces of the tubes but rather that it is considerable trouble to clean them on account of the large number of handhole covers that have to be removed, cleaned, and replaced. The liability of this type of boiler to prime is a natural consequence of the comparatively small steam drum and the small surface for the liberation of the steam.

# CHAPTER III

## BOILER CALCULATIONS

**30. Boiler Horse-power.**—The term "horse-power" or "boiler horse-power" (abbreviated boiler h.p.) is generally used to express the size or capacity of a boiler. Strictly speaking, the use of the term *horse-power* in this connection is not correct, since the word horse-power indicates a rate of doing work, whereas a boiler does no work in the ordinary sense in which we speak of work. It is the engine that does the work in a power plant, and the boiler merely supplies the steam to the engine. However, the term horse-power has become so generally used to designate the sizes of boilers that it is probable its use will be continued always. No confusion need result, however, if the meaning of the term as applied to boilers is throughly understood. It must be kept in mind, however, that there is no definite relation between the horse-power of an engine and the horse-power of a boiler.

The manufacturers of boilers generally rate their boilers on the basis of the number of square feet of heating surface which they contain. For water-tube boilers, 10 sq. ft. of heating surface are considered sufficient for one horse-power. Thus a water-tube boiler containing 1000 sq. ft. of heating surface would be rated as a 100 horse-power boiler. For Scotch marine boilers 8 sq. ft., for fire-tube boilers 10 to $12\frac{1}{2}$ and for flue boilers 12 to 15 sq. ft. are allotted to each horse-power.

It can be readily seen that this method of rating boilers is not very satisfactory from the standpoint of the purchaser, as a boiler from one maker may have its heating surface more advantageously arranged than that of another which has the same number of square feet of heating surface. Yet, according to this method of rating, they would both be rated at the same horse-power. It is well known that all the heating surface in a boiler is not equally effective, but that the surface immediately surrounding the furnace transmits a much larger proportion of heat than the surface near the smoke connection.

A much more satisfactory method of rating boilers is upon the amount of water which they will evaporate under ordinary running conditions. This is a reasonable way to rate a boiler, since its duty consists in evaporating water. A method of rating boilers upon this basis will be taken up in a later chapter, after the properties of steam have been studied.

**31. Heating Surface.**—In measuring the heating surface of boilers it is customary for manufacturers to base their measurements on the outside diameter of the tubes and flues rather than on the inside diameter. This, of course, gives a greater area than if the inside diameter was used. They give as reasons for doing this that it is simpler, since boiler tubes are catalogued and ordered according to their outside diameters; that there is no need of being so very accurate, since the heat transmitting ability of the tube varies for different locations of the heating surface and with the thickness of the metal; and that this method is better for making comparisons.

Many engineers argue that the surface which receives the heat should be the measure of the heating surface, since this surface is the technically correct heating surface. This, of course, results in the outside diameter of water-tube and the inside diameter of fire-tube boilers being taken. The American Society of Mechanical Engineers favors the latter plan of computing the heating surface; that is, taking the surface area of shells, tubes, furnaces, and fire boxes in contact with the fire or hot gases.

All of the surface in contact with fire or hot gases on one side and water on the other side is called heating surface and all the surface which has fire or hot gases on one side and steam on the other side is called superheating surface. Water-heating surface is very effective in transmitting heat, while the heat transmission through superheating surface is very slow, and for this reason the superheating surface should not be counted in as heating surface in rating a boiler. These two surfaces should be computed and noted separately in giving the data concerning a boiler test. The surface below the line of the grates, to which the fire does not have access, should be counted, nor any surface that is covered by brickwork. Only three-eighths of the shell of fire-tube boilers should be counted as heating surface when the side walls come straight up tangent to the shell, because the sharp corners between the shell and the brickwork form a dead space in which the hot gases cannot circulate. If the brickwork is corbeled off from the shell the full half of the shell may be counted as heating surface. As an aid in calculating the heating surface in boiler tubes, the following table of boiler tube sizes is given:

To illustrate the method of calculating heating surface, and from it the horse-power of a boiler, consider the overhung fire-tube boiler shown in Fig. 4. This boiler has 34 three-inch tubes and is 14 ft. long, the diameter of the shell being 42 in. Let us consider that the brickwork of the setting will be brought up close to the shell, so that only three-eighths of the surface of the shell will be effective heating surface.

The circumference of a circle = 3.1416 times the diameter, therefore, the circumference of the shell $= 3.1416 \times \frac{42}{12} = 3.1416 \times 3.5 = 11.00$ ft.

Surface of the shell $= 14 \times 10.99 = 154$ sq. ft.

As only three-eighths of this is effective, the effective heating surface of the shell is $3/8 \times 153.9 = 57.8$ sq. ft.

Internal circumference of one tube $= 3.1416 \times 2.782 = 8.74$ in. (See table on page 42.)

Internal area of one tube $= 14 \times 12 \times 8.74 = 1468.3$ sq. in.

Internal area of 34 tubes $= 34 \times 1468.3 = 49{,}922$ sq. in.

Area of tubes in square feet $= 49{,}922 \div 144 = 346.6$ sq. ft.

Total heating surface $= 57.8 + 346.6 = 404.4$ sq. ft.

If this boiler was rated on the basis of 10 sq. ft. of heating surface to each horse-power, it would have $404.4 \div 10 = 40.44$ boiler h.p., while, if it was rated on the basis of 12 sq. ft. to each horse-power, it would have $404.4 \div 12 = 33.7$ boiler h.p.

The area of the tube sheets need not be counted in the heating surface as their area is small and the surface not very effective in transferring heat.

In calculating the heating surface of a water-tube boiler, the external surface of the tubes must be considered. Take for example the Murray water-tube boiler shown in Fig. 21, which has 67 tubes $3\frac{1}{2}$ in. in diameter and 16 ft. long. The headers are 64 in. wide and 42 in. high. Consider the steam drum as having a diameter of 30 in., with the hot gases in contact with it for a length of 16 ft., and with one-half of its drum surface effective heating surface.

The circumference of each tube is $3.1416 \times 3.5 = 11$ in., and its surface is $11 \times 16 \times 12 = 2112$ sq. in.

## LAP-WELDED CHARCOAL-IRON BOILER TUBES

Table of Standard Dimensions

| Diameter | | Thickness, inches | Wire guage No. | Circumference | | Transverse area | | | Length of tube per square foot of | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| External, inches | Internal, inches | | | External, inches | Internal, inches | External, square inches | Internal, square inches | Metal, square inches | Ex. surf., feet | Int. surf., feet | Nominal weight per foot, pound |
| 1 | .856 | .072 | 15 | 3.142 | 2.689 | .785 | .575 | .21 | 3.819 | 4.462 | .71 |
| 1¼ | 1.106 | .072 | 15 | 3.927 | 3.475 | 1.227 | .961 | .266 | 3.056 | 3.453 | .89 |
| 1½ | 1.334 | .083 | 14 | 4.712 | 4.191 | 1.767 | 1.398 | .369 | 2.547 | 2.863 | 1.24 |
| 1¾ | 1.56 | .095 | 13 | 5.498 | 4.901 | 2.405 | 1.911 | .494 | 2.183 | 2.448 | 1.66 |
| 2 | 1.81 | .095 | 13 | 6.283 | 5.686 | 3.142 | 2.573 | .569 | 1.909 | 2.11 | 1.91 |
| 2¼ | 2.06 | .095 | 13 | 7.069 | 6.472 | 3.976 | 3.333 | .643 | 1.698 | 1.854 | 2.16 |
| 2½ | 2.282 | .109 | 12 | 7.854 | 7.169 | 4.909 | 4.09 | .819 | 1.528 | 1.674 | 2.75 |
| 2¾ | 2.532 | .109 | 12 | 8.639 | 7.954 | 5.94 | 5.035 | .905 | 1.389 | 1.509 | 3.04 |
| 3 | 2.782 | .109 | 12 | 9.425 | 8.74 | 7.069 | 6.079 | .99 | 1.273 | 1.373 | 3.33 |
| 3¼ | 3.01 | .12 | 11 | 10.21 | 9.456 | 8.296 | 7.116 | 1.18 | 1.175 | 1.26 | 3.96 |
| 3½ | 3.26 | .12 | 11 | 10.996 | 10.241 | 9.621 | 8.347 | 1.274 | 1.091 | 1.172 | 4.28 |
| 3¾ | 3.51 | .12 | 11 | 11.781 | 11.027 | 11.045 | 9.676 | 1.369 | 1.018 | 1.088 | 4.6 |
| 4 | 3.732 | .134 | 10 | 12.566 | 11.724 | 12.566 | 10.939 | 1.627 | .955 | 1.024 | 5.47 |
| 4½ | 4.232 | .134 | 10 | 14.137 | 13.295 | 15.904 | 14.066 | 1.838 | .849 | .902 | 6.17 |
| 5 | 4.704 | .148 | 9 | 15.708 | 14.778 | 19.635 | 17.379 | 2.256 | .764 | .812 | 7.58 |
| 6 | 5.67 | .165 | 8 | 18.85 | 17.813 | 28.274 | 25.249 | 3.025 | .637 | .673 | 10.16 |
| 7 | 6.67 | .165 | 8 | 21.991 | 20.954 | 38.485 | 34.942 | 3.543 | .546 | .573 | 11.9 |
| 8 | 7.67 | .165 | 8 | 25.133 | 24.096 | 50.266 | 46.204 | 4.062 | .477 | .498 | 13.05 |
| 9 | 8.64 | .18 | 7 | 28.274 | 27.143 | 63.617 | 58.629 | 4.988 | .424 | .442 | 16.76 |
| 10 | 9.594 | .203 | 6 | 31.416 | 30.14 | 78.54 | 72.292 | 6.248 | .382 | .398 | 20.99 |

67 tubes will have an area of $67 \times 2112 = 141,504$ sq. in. $141,504 \div 144 = 982.7$ sq. ft.

The circumference of the drum is $3.1416 \times 30 = 94.25$ in. and its surface is $16 \times 94.25 \times 12 = 18,096$ sq. in. Since one-half of this area is heating surface, this will amount to

$$18,096 \div 2 = 9,048 \text{ sq. in.}$$
$$9048 \div 144 = 62.8 \text{ sq. ft.}$$

The headers have a total area each of $64 \times 42 = 2688$ sq. in. The cross sectional area of each tube is $.7854 \times 3.5^2 = 9.62$ sq. in. and the area of all tubes is $67 \times 9.62 = 645$ sq. in. The net area of each header is

$$2688 - 645 = 2043 \text{ sq. in.}$$
$$2043 \div 144 = 14.19 \text{ sq. ft.}$$

or in two headers there will be $2 \times 14.19 = 28.4$ sq. ft.
This gives a total heating surface of $982.7 + 62.8 + 28.4 = 1074$ sq. ft.

From the small part of the total heating surface which the headers contain it will be seen that the area of the headers may well be neglected. Leaving this out would give a total heating surface of 1045.5 sq. ft., which, on a basis of 10 sq. ft. per horse-power would give 104.6 boiler h.p. This boiler would probably be rated as a 100 h.p., boiler.

The following table of standard steam-boiler measurements is inserted as an aid in determining quickly the horse-power of a boiler of standard size. This table applies only to return fire-tube boilers.

STANDARD STEAM-BOILER MEASUREMENTS

Based on 12 sq. ft. of heating surface to a horse-power

| Size | | Thickness | | Boiler with handholes | | | | Boiler with manholes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Tubes | | Heat surf. sq. ft. | Horse-power | Tubes | | Heat surf. sq. ft. | Horse-power |
| Dia. | Length | Shell | Heads | No. | Dia. | | | No. | Dia. | | |
| 30 | 6 | 1/4 | 3/8 | 19 | 2 1/2 | 106 | 9 | .... | ...... | ....... | ...... |
| 30 | 8 | 1/4 | 3/8 | 19 | 2 1/2 | 141 | 12 | .... | ...... | ....... | ...... |
| | | | | 38 | 2 1/2 | 256 | 21 | .... | ...... | ....... | ...... |
| 36 | 8 | 1/4 | 3/8 | 28 | 3 | 226 | 19 | .... | ...... | ....... | ...... |
| | | | | 25 | 3 1/2 | 234 | 20 | .... | ...... | ....... | ...... |
| | | | | 38 | 2 1/2 | 311 | 26 | .... | ...... | ....... | ...... |
| 36 | 10 | 1/4 | 3/8 | 28 | 3 | 283 | 24 | .... | ...... | ....... | ...... |
| | | | | 25 | 3 1/2 | 292 | 24 | .... | ...... | ....... | ...... |

STANDARD STEAM-BOILER MEASUREMENTS—*Continued*

Based on 12 sq. ft. of heating surface to a horse-power

| Size | | Thickness | | Boiler with handholes | | | | Boiler with manholes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Tubes | | Heat surf. sq. ft. | Horse-power | Tubes | | Heat surf. sq. ft. | Horse-power |
| Dia. | Length | Shell | Heads | No. | Dia. | | | No. | Dia. | | |
| 42 | 10 | $\frac{1}{4}$ | $\frac{3}{8}$ | 38 | 3 | 372 | 31 | .... | ...... | ....... | ...... |
| | | | | 34 | $3\frac{1}{2}$ | 385 | 32 | .... | ...... | ....... | ...... |
| 42 | 12 | $\frac{1}{4}$ | $\frac{3}{8}$ | 38 | 3 | 446 | 37 | .... | ...... | ....... | ...... |
| | | | | 34 | $3\frac{1}{2}$ | 462 | 39 | .... | ...... | ....... | ...... |
| 42 | 14 | $\frac{1}{4}$ | $\frac{3}{8}$ | 38 | 3 | 520 | 43 | .... | ...... | ....... | ...... |
| | | | | 34 | $3\frac{1}{2}$ | 539 | 45 | .... | ...... | ....... | ...... |
| 42 | 16 | $\frac{1}{4}$ | $\frac{3}{8}$ | 38 | 3 | 595 | 50 | .... | ...... | ....... | ...... |
| | | | | 34 | $3\frac{1}{2}$ | 616 | 51 | .... | ...... | ....... | ...... |
| 44 | 12 | $\frac{1}{4}$ | $\frac{3}{8}$ | 48 | 3 | 544 | 45 | .... | ...... | ....... | ...... |
| | | | | 38 | $3\frac{1}{2}$ | 510 | 43 | .... | ...... | ....... | ...... |
| 44 | 14 | $\frac{1}{4}$ | $\frac{3}{8}$ | 48 | 3 | 635 | 53 | .... | ...... | ....... | ...... |
| | | | | 38 | $3\frac{1}{2}$ | 491 | 41 | .... | ...... | ....... | ...... |
| 48 | 12 | $\frac{5}{16}$ | $\frac{7}{16}$ | 58 | 3 | 647 | 54 | 50 | 3 | 572 | 48 |
| | | | | 50 | $3\frac{1}{2}$ | 651 | 54 | 34 | $3\frac{1}{2}$ | 475 | 40 |
| 48 | 14 | $\frac{5}{16}$ | $\frac{7}{16}$ | 58 | 3 | 755 | 63 | 50 | 3 | 667 | 55 |
| | | | | 50 | $3\frac{1}{2}$ | 759 | 63 | 34 | $3\frac{1}{2}$ | 547 | 46 |
| 48 | 16 | $\frac{5}{16}$ | $\frac{7}{16}$ | 58 | 3 | 862 | 72 | 50 | 3 | 762 | 64 |
| | | | | 50 | $3\frac{1}{2}$ | 867 | 72 | 34 | $3\frac{1}{2}$ | 633 | 53 |
| 48 | 18 | $\frac{5}{16}$ | $\frac{7}{16}$ | 58 | 3 | 970 | 81 | 50 | 3 | 857 | 71 |
| | | | | 50 | $3\frac{1}{2}$ | 976 | 81 | 34 | $3\frac{1}{2}$ | 712 | 59 |
| 54 | 14 | $\frac{5}{16}$ | $\frac{1}{2}$ | 71 | 3 | 912 | 76 | 59 | 3 | 780 | 65 |
| | | | | 56 | $3\frac{1}{2}$ | 851 | 71 | 48 | $3\frac{1}{2}$ | 748 | 62 |
| | | | | 43 | 4 | 763 | 64 | 40 | 4 | 719 | 60 |
| 54 | 16 | $\frac{5}{16}$ | $\frac{1}{2}$ | 71 | 3 | 1042 | 87 | 59 | 3 | 891 | 74 |
| | | | | 56 | $3\frac{1}{2}$ | 972 | 81 | 48 | $3\frac{1}{2}$ | 855 | 71 |
| | | | | 43 | 4 | 802 | 67 | 40 | 4 | 821 | 68 |
| 54 | 18 | $\frac{5}{16}$ | $\frac{1}{2}$ | 71 | 3 | 1173 | 98 | 59 | 3 | 1003 | 84 |
| | | | | 56 | $3\frac{1}{2}$ | 1094 | 91 | 48 | $3\frac{1}{2}$ | 962 | 80 |
| | | | | 43 | 4 | 980 | 82 | 40 | 4 | 924 | 77 |
| 60 | 12 | $\frac{5}{16}$ | $\frac{1}{2}$ | 71 | $3\frac{1}{2}$ | 907 | 75 | 56 | $3\frac{1}{2}$ | 742 | 62 |
| | | | | 54 | 4 | 804 | 67 | 46 | 4 | 704 | 59 |
| | | | | 43 | $4\frac{1}{2}$ | 733 | 61 | 36 | $4\frac{1}{2}$ | 634 | 53 |
| 60 | 14 | $\frac{5}{16}$ | $\frac{1}{2}$ | 71 | $3\frac{1}{2}$ | 1058 | 88 | 56 | $3\frac{1}{2}$ | 865 | 72 |
| | | | | 54 | 4 | 938 | 78 | 46 | 4 | 821 | 68 |
| | | | | 43 | $4\frac{1}{2}$ | 855 | 71 | 36 | $4\frac{1}{2}$ | 740 | 62 |
| 60 | 16 | $\frac{5}{16}$ | $\frac{1}{2}$ | 71 | $3\frac{1}{2}$ | 1209 | 101 | 56 | $3\frac{1}{2}$ | 989 | 82 |
| | | | | 54 | 4 | 1073 | 89 | 46 | 4 | 939 | 78 |
| | | | | 43 | $4\frac{1}{2}$ | 978 | 82 | 36 | $4\frac{1}{2}$ | 846 | 71 |
| 60 | 18 | $\frac{5}{16}$ | $\frac{1}{2}$ | 71 | $3\frac{1}{2}$ | 1360 | 113 | 56 | $3\frac{1}{2}$ | 1113 | 93 |
| | | | | 54 | 4 | 1207 | 101 | 46 | 4 | 1056 | 88 |
| | | | | 43 | $4\frac{1}{2}$ | 1100 | 92 | 36 | $4\frac{1}{2}$ | 952 | 79 |
| 66 | 16 | $\frac{3}{8}$ | $\frac{1}{2}$ | 90 | $3\frac{1}{2}$ | 1504 | 125 | 84 | $3\frac{1}{2}$ | 1416 | 118 |
| | | | | 68 | 4 | 1324 | 110 | 56 | 4 | 1122 | 94 |
| | | | | 56 | $4\frac{1}{2}$ | 1239 | 103 | 46 | $4\frac{1}{2}$ | 1051 | 88 |
| 66 | 18 | $\frac{3}{8}$ | $\frac{1}{2}$ | 90 | $3\frac{1}{2}$ | 1692 | 141 | 84 | $3\frac{1}{2}$ | 1593 | 133 |
| | | | | 68 | 4 | 1489 | 124 | 56 | 4 | 1263 | 105 |
| | | | | 56 | $4\frac{1}{2}$ | 1394 | 116 | 46 | $4\frac{1}{2}$ | 1113 | 93 |
| 72 | 16 | $\frac{3}{8}$ | $\frac{1}{2}$ | 108 | $3\frac{1}{2}$ | 1785 | 149 | 98 | $3\frac{1}{2}$ | 1638 | 137 |
| | | | | 82 | 4 | 1575 | 131 | 72 | 4 | 1407 | 117 |
| | | | | 64 | $4\frac{1}{2}$ | 1407 | 117 | 60 | $4\frac{1}{2}$ | 1331 | 111 |
| 72 | 18 | $\frac{3}{8}$ | $\frac{1}{2}$ | 108 | $3\frac{1}{2}$ | 2008 | 167 | 98 | $3\frac{1}{2}$ | 1843 | 154 |
| | | | | 82 | 4 | 1772 | 148 | 72 | 4 | 1584 | 132 |
| | | | | 64 | $4\frac{1}{2}$ | 1583 | 132 | 60 | $4\frac{1}{2}$ | 1498 | 125 |

**32. Corrugated Flues.**—Many flue boilers have the furnace flues made of corrugated sheets in order to give them greater strength to resist the crushing pressure to which they are subjected, and also to allow them to expand and contract without disturbing other parts of the boiler. The principal types of corrugated flues are illustrated in Figs. 29 and 30. The first is known as the Morison suspension flue and the second as the Fox corrugated flue.

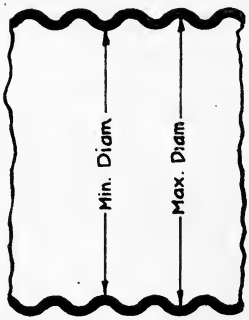



Fig. 29.—Morison suspension flue.

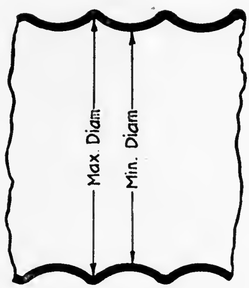



Fig. 30.—Fox corrugated flue.

Owing to the peculiar shape of the surface of these flues it is rather difficult to compute the area exactly. A simple method of estimating the heating surface of one of these tubes is to consider it as being a straight cylinder with a diameter equal to the mean, or average diameter of the corrugated flue; and then to add to the surface of this cylinder $14\frac{1}{2}$ per cent of its surface for the Morison flue or $9\frac{4}{10}$ per cent for the Fox flue.

To illustrate this, suppose we wish to find the heating surface contained in a Morison suspension furnace flue which has a maximum diameter of $39\frac{1}{8}$ in. and a minimum diameter of 36 in. and is 9 ft. 3 in. long. The mean diameter is

$$\frac{39\frac{1}{8}+36}{2}=37\frac{9}{16}\text{ in.}$$

Compute the area of a cylindrical flue having a diameter of $37\frac{9}{16}$ in. and a length of 9 ft. 3 in. The circumference is $3.1416\times37\frac{9}{16}=118$ in. The length is 9 ft. 3 in. $=111$ in. Therefore the surface is $118\times111=13{,}098$ sq. in. $13{,}098\div144=91$ sq. ft. Adding $14\frac{1}{2}$ per cent to this gives $91+(.145\times91)=91+13.2=104.2$ sq. ft. as the heating surface of the flue.

If the flue had been of the Fox corrugated type we would calculate its surface in the same way except that instead of adding $14\frac{1}{2}$ per cent, we would add $9\frac{4}{10}$ per cent; that is, its surface, considered as a cylinder having a diameter of $37\frac{9}{16}$ in., would be 91 sq. ft. as before. Adding $9\frac{4}{10}$ per cent to this gives $91+(.094\times91)=91+8.55=99.55$ sq. ft. as the heating surface of a Fox flue of the same dimensions.

**33. Strength of Shell.**—The force tending to burst a boiler shell may be computed from the formula

$$pD=2St \qquad (1)$$

in which $p$ is the pressure per square inch
$D$ is the diameter of shell in inches
$S$ is the stress in the metal per square inch
$t$ is the thickness of the shell in inches.

If there are any riveted joints and the efficiency of the joint is $e$, the above formula will have to be modified, and it will then become

$$pD=2Ste \qquad (2)$$

The efficiency of a joint is the relation of the strength of the joint to the strength of the solid plate.

The pressure per square inch required to burst the boiler will then be

$$p=\frac{2Ste}{D} \qquad (3)$$

in which $S$ is the breaking strength per square inch of metal in the shell.

**Example:** What pressure will burst a cylindrical boiler shell 72 in. in diameter, if the metal is 1/4 in. thick and has a strength of 60,000 lb. per square inch, and if it has a riveted joint whose efficiency is 70 per cent?

$$\textit{Solution:}\ p=\frac{2\times60{,}000\times.25\times.70}{72}=292 \text{ lb.}$$

The thickness of the shell to withstand a given pressure may be found from the formula

$$t=\frac{pD}{2Se} \qquad (4)$$

**Example:** What should be the thickness of the shell in the above example if it is to withstand a pressure of 500 lb. per square inch?

*Solution:* $t=\frac{500\times 72}{2\times 60{,}000\times .70}=.43$ in.

This boiler would presumably burst at a pressure of 500 lb.

In designing boilers it is necessary to make them stronger than the above formulas would indicate, and the number of times stronger that they are made is called the *factor of safety.* It is common practice to make the factor of safety for steam boilers from 4 to 6; that is, the boiler is made from four to six times as strong as necessary to actually withstand the pressure which it is to carry. When the factor of safety is known, the formula for strength becomes

$$pDf=2\,Ste \qquad (5)$$

where $f$ is the factor of safety.

The pressure which a boiler should carry then becomes

$$p=\frac{2\,Ste}{Df} \qquad (6)$$

And the thickness of shell to withstand any pressure will be

$$t=\frac{pDf}{2Se} \qquad (7)$$

**Example:** What should be the thickness of the shell of a 60-in. boiler which is to carry 150 lb. steam pressure, if the boiler is made of metal having a strength of 60,000 lb. per square inch and having riveted joints with an efficiency of 75 per cent, a factor of safety of 5 being allowed?

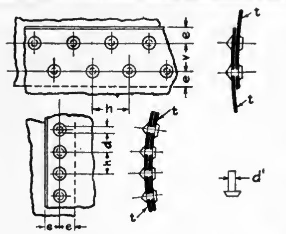
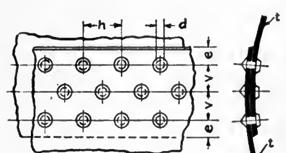
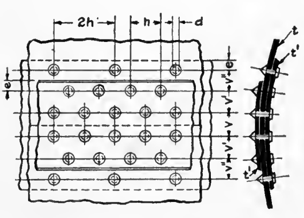
*Solution:* $t=\frac{150\times 60\times 5}{2\times 60{,}000\times .75}=0.5$ in.

*By the Efficiency of a Riveted Joint is meant the ratio of the strength of the riveted joint to the strength of the solid plate of metal.*

$$\text{Efficiency}=\frac{\text{Strength of joint}}{\text{Strength of plate}}$$

The Hartford Steam Boiler Inspection and Insurance Company have designed and recommended a number of riveted joints, and, as these include most of the joints used in boiler construction, the following table is given showing the dimensions of these joints together with their efficiencies. The ultimate tensile strength refers to the boiler plate, and the ultimate shearing strength refers to the rivets, as the plates will fail by tension while the rivets will fail by being sheared off.

PROPORTIONS OF RIVETED JOINTS

| Type of Joint | Position of Joint | t | t' | d' | d | h | v" | v' | v | e | Eff.% |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Longitudinal seam. Double-riveted lap joint. | 1/4 | | 11/16 | 3/4 | 2 7/8 | | | 1 15/16 | 1 1/8 | 73.9 |
| | | 5/16 | | 3/4 | 13/16 | 2 7/8 | | | 1 15/16 | 1 7/32 | 71.7 |
| | | 3/8 | | 7/8 | 15/16 | 3 1/4 | | | 2 3/16 | 1 13/32 | 71.1 |
| | | 7/16 | | 15/16 | 1 | 3 5/16 | | | 2 3/16 | 1 1/2 | 68.7 |
| | | 1/2 | | 1 | 1 1/16 | 3 5/16 | | | 2 5/16 | 1 19/32 | 67.7 |
| | Single-riveted girth seam used with above | 1/4 | | 11/16 | 3/4 | 2 1/16 | | | | 1 1/8 | 54.5 |
| | | 5/16 | | 3/4 | 13/16 | 2 1/8 | | | | 1 7/32 | 49.4 |
| | | 3/8 | | 7/8 | 15/16 | 2 3/8 | | | | 1 13/32 | 49.0 |
| | | 7/16 | | 15/16 | 1 | 2 7/16 | | | | 1 1/2 | 46.6 |
| | | 1/2 | | 1 | 1 1/16 | 2 1/2 | | | | 1 19/32 | 44.9 |
|  | Longitudinal seam. Triple-riveted lap joint | 1/4 | | 5/8 | 11/16 | 3 | | | 2 | 1 1/32 | 77.0 |
| | | 5/16 | | 11/16 | 3/4 | 3 1/8 | | | 2 1/16 | 1 1/8 | 76.0 |
| | | 3/8 | | 3/4 | 13/16 | 3 1/4 | | | 2 3/16 | 1 7/32 | 75.0 |
| | | 7/16 | | 7/8 | 15/16 | 3 3/4 | | | 2 1/2 | 1 13/32 | 75.0 |
| | | 1/2 | | 15/16 | 1 | 3 15/16 | | | 2 5/8 | 1 1/2 | 74.6 |
| | Single-riveted girth seam used with above | 1/4 | | 5/8 | 11/16 | 2 1/16 | | | | 1 1/32 | 45.6 |
| | | 5/16 | | 11/16 | 3/4 | 2 1/8 | | | | 1 1/8 | 41.9 |
| | | 3/8 | | 3/4 | 13/16 | 2 1/8 | | | | 1 7/32 | 41.2 |
| | | 7/16 | | 7/8 | 15/16 | 2 3/8 | | | | 1 13/32 | 42.0 |
| | | 1/2 | | 15/16 | 1 | 2 1/2 | | | | 1 1/2 | 39.8 |
|  | Longitudinal seam. Triple-riveted butt joint with double welt | 5/16 | 1/4 | 11/16 | 3/4 | 3 1/8 | 2 3/8 | 2 1/8 | 2 1/2 | 1 1/4 | 88.0 |
| | | 3/8 | 5/16 | 3/4 | 13/16 | 3 1/4 | 2 1/2 | 2 3/16 | 2 7/16 | 1 7/32 | 85.0 |
| | | 7/16 | 3/8 | 7/8 | 15/16 | 3 3/8 | 2 3/4 | 2 1/4 | 2 13/16 | 1 13/32 | 86.0 |
| | | 1/2 | 7/16 | 15/16 | 1 | 3 3/4 | 3 | 2 3/8 | 3 | 1 1/2 | 86.6 |
| | Single-riveted girth seam used with above | 5/16 | | 11/16 | 3/4 | 2 | | | | 1 1/8 | 44.6 |
| | | 3/8 | | 3/4 | 13/16 | 2 | | | | 1 7/32 | 43.8 |
| | | 7/16 | | 7/8 | 15/16 | 2 1/4 | | | | 1 13/32 | 44.0 |
| | | 1/2 | | 15/16 | 1 | 2 1/4 | | | | 1 1/2 | 44.2 |

Note:— Ultimate tensile strength of plate taken as 60,000 lbs. per sq. in.
" shearing " " rivets " " 38,000 " " " "

Formulas Nos. 1 to 7 in this chapter apply only to the strength of shell in a longitudinal direction, or along the sides of the shell. To calculate the strength of shell against bursting around the girth, the formula for the safe working pressure is

$$p = \frac{4\,Ste}{Df} \tag{8}$$

In this formula $e$ applies to efficiency of the girth joint. It will be seen by comparing formulas 3 and 8 that, for the same pressure, diameter, thickness, and factor of safety, the efficiency of the girth joint of a boiler need be only one-half that of the longitudinal joint. This explains why the longitudinal joints are always made the stronger of the two.

To illustrate the use of these formulas and their relations to each other, let us take the following example:

**Example:** Suppose we wish to calculate the safe working pressure for a fire-tube boiler 60 in. in diameter, 16 ft. long, having a shell 1/2 in. thick. The longitudinal seam is a triple-riveted butt joint with double welt, with size of rivets and spacing according to the table of riveted joints. The girth seam is a single-riveted lap joint with 15/16-in. rivets spaced $2\frac{1}{4}$ in. apart. The strength of the metal used in the plates is 60,000 lb. per square inch. Use a factor of safety of 5.

*Solution:* By referring to the table of riveted joints it will be seen that the efficiency of the girth joint is 44.2 per cent., therefore the safe working pressure, so far as the boiler bursting around the girth is concerned, is

$$p=\frac{4\ Ste}{Df}=\frac{4\times 60{,}000\times 0.5\times .442}{60\times 5}=177 \text{ lb. per square inch.}$$

The efficiency of the longitudinal riveted seam is, from the table, 86.6 per cent; therefore, the boiler can stand a safe working pressure, against bursting along the side, of

$$p=\frac{2\ Ste}{Df}=\frac{2\times 60{,}000\times 0.5\times .866}{60\times 5}=173 \text{ lb. per square inch.}$$

This latter value (173 lb.) should be the maximum pressure allowed in the boiler.

**34. Strength of Furnace Flues.**—The safe working pressure that may be allowed on corrugated flues, such as the Morison and the Fox, may be calculated from the following formula:

$$p=\frac{14{,}000t}{D}$$

in which $p$ = safe working pressure in pounds per square inch
$t$ = thickness of metal in inches
and $D$ = outside diameter of flue in inches.

The diameter of the flue should be measured at the bottom of the corrugations, thus giving the smallest outside diameter.

**Example:** What safe working pressure may be allowed on the Morison corrugated flue shown in Fig. 29, if the outside diameter is 37 in. and the thickness of the metal is .5 in.?

*Solution:* $p=\frac{14{,}000t}{D}=\frac{14{,}000\times .5}{37}=189$ pounds per square inch.

**35. Riveting.**—As riveted joints are the weakest points about a boiler and as they are likely to leak unless carefully made, the greatest care should be exercised in designing the joints and in doing the riveting.

Rivets are made of extra soft steel and can be bought in various lengths and sizes, with one head already formed. They can be bought in three different styles of heads—*button, cone,* and *countersunk.* The rounded heads in Fig. 34 are button heads, while the pan-shaped heads in the same figure are cone heads, being in reality only a part, or frustum of a cone. Countersunk heads are set into the plate so as to leave a smooth, or flush surface. Countersunk rivets should never be used, if possible to avoid it, as the countersinking weakens the plate and the countersunk head will pull through the plate rather easily.

Rivets are designated as to size by the diameter of the shank or body and by the length under the head, except that countersunk rivets are known by the length to the top of the head.

The rivet holes in the plates are made 1/16 in. larger than the diameter of the rivet, so the rivet may be inserted easily while hot. The holes are either punched, or drilled, or punched and reamed. If the plate is thin and of wrought iron or very soft steel, it may be punched without greatly injuring the metal. Ordinary boiler steel, especially the harder grades, *is* injured by punching, and this method of making the holes should never be allowed for power boilers. The injury by punching is not visible to the eye and all the more care should be taken to prevent the use of punched holes. Drilling is more accurate than punching, but it is slower and costs more. When the holes are drilled, the sharp edges left by the drill should be removed to prevent them from cutting the rivet. In drilling plates, it is best to bend them to shape and then clamp them together, when they may be drilled by a radial drill.

Sometimes the holes are punched to a smaller size than the rivet and then reamed to the proper size. When this is done, at least 1/16 in. of metal should be reamed off, in order to remove the metal that is injured by the punching process. When properly done, punching and reaming gives a very satisfactory joint and is cheaper than drilling.

When plates are punched, the end of the punch should be concave and a little larger than its shank, in order to secure a clean cut. The hole in the die is made slightly larger than the punch, to make the punching action easier. This gives a hole

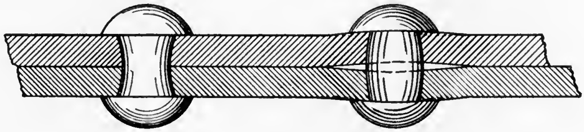


FIG. 31.

of slightly conical shape (see Fig. 31). When the plates are put together, the small ends of the holes in the two plates should be placed together as shown in Fig. 31 at the left. The bulging of the rivet will then press the plates closer together; otherwise, the plates will be forced apart by the rivet as shown by the right-hand rivet in Fig. 31.

Plates to be riveted should be champfered or planed off on the edge, as in Figs. 32 and 34, and after the rivets are driven the joint should be carefully caulked with a round-pointed caulking tool. A sharp-pointed tool should never be used as it is liable

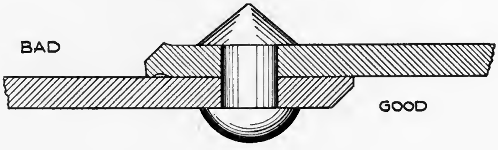



FIG. 32.

to form a groove which will increase rapidly by corrosion. An example of good and bad caulking is shown in Fig. 32.

In riveting a joint, the plates should be firmly clamped or bolted together. The rivets are heated and inserted in the holes with the heads on the inside. A head is then formed on the other end from the stock of the rivet which protrudes through the hole. The outer heads are usually formed by machinery, though occasionally hand riveting is necessary.

Machine riveting is better than hand riveting, as the pressure forces the shank to fill the hole in the plates completely. Riveting machines are operated by gearing, water pressure, steam, or air. The hydraulic machines give better results, as the force is applied to the rivets more steadily, causing them to swell gradually and fill the hole completely. With hydraulic, steam, or air machines, the pressure may be maintained on the rivet until it has cooled sufficiently to prevent stretching the shank by the springing apart of the plates, which might occur if the pressure be removed while the shank is hot. A pressure of 60 tons is considered sufficient for even the largest sizes of rivets used in boiler work.

In certain parts of boilers where space is small, and also in patching, hand riveting becomes necessary. The comparatively light blows of a riveting hammer affect but a small portion of

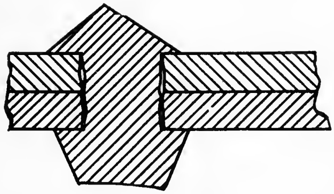


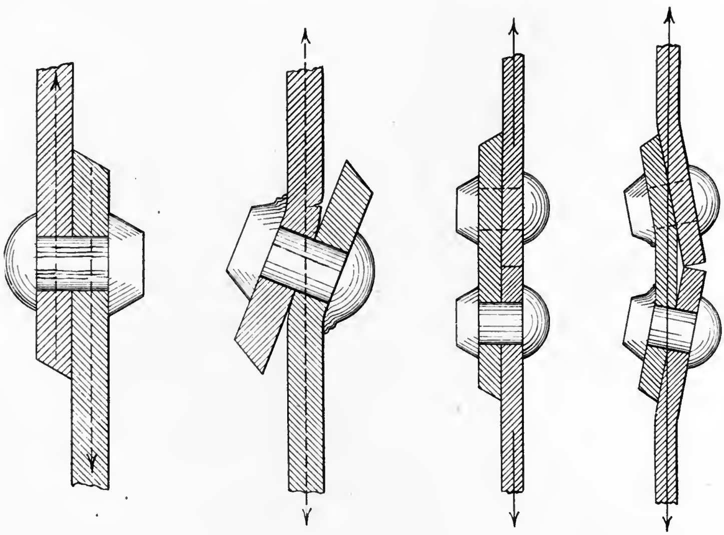
Fig. 33.

the metal of a rivet, and unless the rivet is at the proper temperature and is driven carefully, there is danger of forming the head without upsetting the shank to fill the hole in the plate. This condition results in a weak joint, as the holding powers of the rivets will then depend only on the grip of the heads on the plates, and the strength of the shank is not utilized. Fig. 33 shows another defect which may result from hand riveting. This shows an imperfectly formed head, that is, one which is centered to one side of the center lines of the shank, resulting in a loss of a part of the holding power of the head.

Steel rivets should be heated uniformly throughout their entire length and not merely at the point, as is sometimes done with iron rivets. This is important since most of the rivets now used are made of steel. As steel is easily burned, rivets made of this material should not be heated above a bright cherry-red nor should they be heated in a thin fire, especially in one having a forced blast, such as an ordinary blacksmith's fire. In such a fire there will be an excess of air which will attack the steel and cause it to burn.

The button head is the style generally made when the riveting is done by machinery. With hand riveting it is more common to make what is called a *steeple head,* having the shape of a full cone as shown in Figs. 32 and 33.

The height of the steeple head should be about three-fourths or seven-eighths the diameter of the rivet, and the greatest diameter about two times the diameter of the rivet. The height



*a* *b* *c* *d*

FIG. 34.—Forces acting upon riveted joints.

of the button or round head should be five-eighths or three-fourths the diameter of the rivet while the greatest diameter of the head should be one and three-fourths times the diameter of the rivet. For either type of head the allowance of extra length of shank for forming the head is $2\frac{1}{4}$ times the diameter of the shank for hand riveting; but for machine riveting, the allowance is from 1/16 to 1/8 in. greater. In addition to the above, there should be an allowance of 1/16 in. for each plate when more than two plates are to be joined together.

Rivets which are too long should not be used, as the cup die will form a ring around the head and this will have to be trimmed in order to present a good appearance. Neither should the rivet be too short, as the plate around the circumference of the head will be more or less nicked by the edge of the cup die, if the riveting is done by machine.

To test the tightness of the rivet, the thumb should be placed on the head and the forefinger on the plate. By striking the head with the hammer, any looseness of the rivet may be felt.

When steam is raised in a boiler, the pressure exerts a pull or tension in the metal of the shell. With a lap joint such as shown at *a* of Fig. 34 or a butt joint with a single cover plate such as shown at *c*, this tension will tend to pull the joints into the shapes shown at *b* and *d* of Fig. 34.

The bending action comes into play every time a boiler is fired up, the plates again straightening out when the boiler cools. This continual bending action in lapped joints and in single strapped butt joints often causes cracks to be formed in the plates beneath the laps. These cracks are widened by corrosion and, as they are hidden, are very dangerous. For this reason, if single straps are used, the straps should always be placed on the outside of the shell. Then, if cracks appear, they will be on the outside where they will not be acted upon by the water and where they may be detected.

# CHAPTER IV

## STAYS AND STAYING

**36. Principles of Staying.**—The pressure within a boiler tends to force the shell into a true cylindrical shape, if it is not already so. Likewise it tends to force the heads into a true hemispherical shape. This means that all surfaces under pressure, which do not have one of these forms, must be braced to prevent this change of shape.

Stays should fulfill three conditions. First, if the plate is flat or nearly so, they should be sufficient, both in number and size, to support the plate entirely, without regard to its stiffness. Second, they should be spaced so as to allow a free inspection of the boiler. Third, they should not interfere with the circulation of water.

A stay should pull at right angles to the surface which it supports, and should be fastened squarely to the plate instead of at an angle to it.

Stays should be fitted in their places tight enough to prevent shaking and should all pull equally. On the other hand, a stay should not be strained into place, as this is apt to overload it. All stays should be carefully fitted into place, as they are out of sight for considerable periods of time and there is no way of determining their efficiency except by the failure of the boiler.

**37. Stay Bolts.**—The simplest form of stay is used when two flat surfaces are near each other, as the sides of the water legs of a locomotive boiler which are stayed by means of stay bolts. These bolts are about 6 in. long and are threaded at both ends. The bolts are screwed into both plates and, if the plates have a thickness greater than half the diameter of the bolt, the ends are riveted over, as in Fig. 35. If the plates have a thickness less than half the diameter of the bolt, they are usually held by nuts and washers, as in Fig. 36. The heads of the stay bolts are upset so that they will be the same size at the root of the thread as the balance of the bolt. They are also made by threading the bolt throughout its length and then turning off the thread in the middle portion of the bolt. This is an excellent method as it gives a continuous thread and yet leaves the body of the bolt smooth, making it less liable to corrosion than if the threads are left on it. Sometimes a small hole (see Fig. 35) is bored in the center of the bolt, extending a little beyond the thread. When these bolts break, they usually do so near the plate which they are holding and, in case of a break, steam or water will flow through the hole in the bolt, giving warning of the break. Such bolts are called *safety stay bolts.*

The stay bolts described above are objectionable because of their stiffness. There is a considerable difference of temperature between the inner and outer sheets of the water leg of a locomotive type of boiler, where stay bolts are most used, and,

Fig. 35.

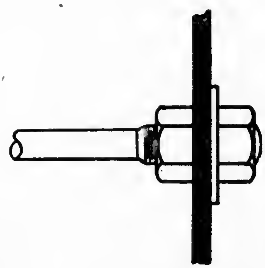


Fig. 36.

due to the greater expansion of one sheet over another, the rigid stay bolts are liable to break. To prevent the constant breaking of these bolts, many types of flexible stay bolts have been designed. One of the common types of these is shown in Fig. 37. This consists of a steel bolt threaded at one end and having a spherical head at the other. The spherical head rests in a cup-shaped collar which screws into the outer plate of the water leg. This collar is first screwed into the outer plate, after which the bolt is run through and screwed into the inner plate until the spherical head has a firm bearing against the collar. The bolt head is slotted to receive a large screw driver which is used in screwing it into the inner plate. The threaded end of the bolt may be riveted over after being screwed through the inner plate, or it may be fitted with a nut and washer to prevent the bolt working loose. A cap is screwed on the collar to cover the end of the bolt, giving it a neater appearance, preventing dirt from collecting between the bearing surfaces, and preventing the escape of any steam or water that may leak past the head of the bolt. This form of stay bolt allows considerable movement between the plates and at the same time main-

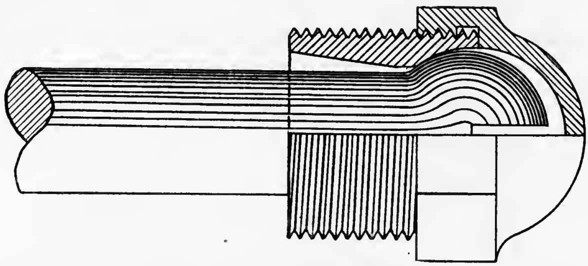


Fig. 37.—Flexible stay bolt.

tains a tight joint. It has the objection, however, that there may not always be enough space for the large cap in the location in which the bolt is most used. In addition to this, it is very difficult to remove a broken bolt unless it is fitted with a nut and washer on the threaded end, and these are objectionable in a fire box because they are liable to be burned.

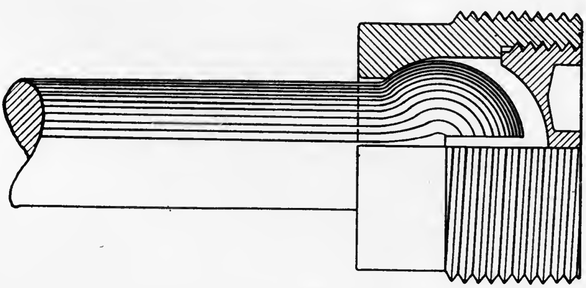


Fig. 38.—Flexible stay bolt.

To overcome the objection that the flexible stay bolt described above occupies too much space, the design shown in Fig. 38 has been made for use in those locations in which there is not enough space to accommodate the other type. In this design the bearing between the collar and bolt is in the bottom of the collar instead of near the top, and instead of an outer cap being used, a flat cap is screwed into the end of the collar. This type of stay bolt may be placed flush with the outer plate and thus occupy even less space than the ordinary form of rigid stay bolt.

A type of flexible stay bolt which is easier to remove than either of those described above is shown in Fig. 39. This bolt is threaded at both ends and the spherical head is in the form of a nut which screws on the bolt. This form of bolt has the further advantage that it may be readily tightened if it should become loose.

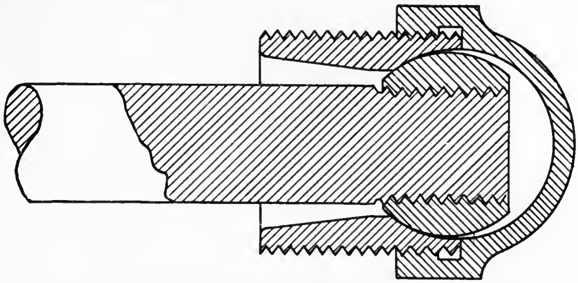


FIG. 39.—Flexible stay bolt.

**38. Boiler Heads.**—The pressure of the steam on a boiler head acts at right angles to the inner surface of the head. The heads of fire-tube boilers are necessarily flat, and flat plates begin to bulge out at very low pressures unless they are braced, as there is nothing to resist the bulging except the stiffness of the plate, which offers very little resistance. It is common practice in boiler construction to transfer these strains from the flat head to some part of the boiler shell. As this transference brings additional strains upon the shell, the fastenings for the stays must not be brought too near together, since the shell may then be weakened. Boiler heads may be braced either by diagonal stays extending from the head to the side of the boiler shell, or by means of long rods extending entirely through the boiler from one head to the other, the rods being threaded at the ends and screwed into the heads, or fitted with a washer and nut. Such a rod or, as it is more commonly called, a through stay is illustrated in Fig. 36.

The holding power of tubes expanded into the tube sheets is sufficient to brace this portion of the head against any ordinary pressure, unless the boiler is unusually large, as in the Scotch marine type. It is then sometimes desirable to use a few extra heavy tubes which are threaded and screwed into the heads to act as both tubes and braces.

Boiler heads are usually flanged and riveted to the shell. In case this is done, the flanging gives additional stiffness to the head so that no bracing need be applied nearer than 3 in. to the point where the curvature of the flange begins. In the same manner, the top row of tubes offers sufficient staying for a distance of 2 in. above this row of tubes. This leaves the unsupported area

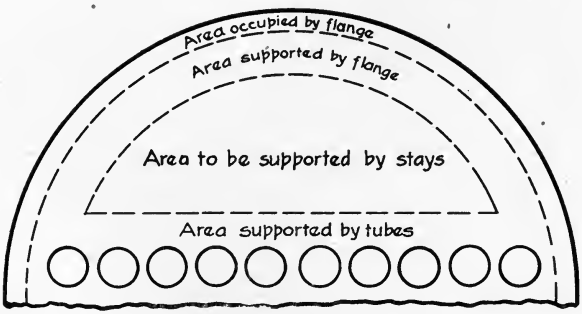



Fig. 40.

as shown in Fig. 40, and the stays or braces should be sufficient to support the pressure on this area, and they should be of uniform size and spacing so that all parts of this area will be supported equally.

**39. Diagonal Stays.**—Sometimes it is desirable to have the central part of the shell free from stays and, if such is the case, *diagonal stays* may be used to advantage to stay the heads of boilers. Diagonal stays are fastened to the head of the boiler and to the shell, as in Fig. 41. A stay exerts a pull on the head in the direction *ab*, Fig. 41, but only the horizontal component or projection of this, as represented by the line *ac*, is effective for resisting the pressure to be supported by the stay. Fig. 42 shows four of the most common types of diagonal stays. The lower ends in the figure show the methods of attaching to the head. The other ends are riveted solidly to the shell. An illustration of the application of diagonal stays is shown in Fig. 7

where the heads of the return fire-tube portable boiler shown there are braced by this means.

**40. Girder Stays.**—These are used for supporting the crown-sheet or top of the combustion chamber in locomotive and in

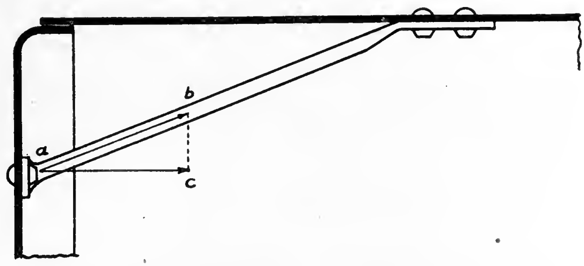



FIG. 41.—Forces in diagonal stay.

Scotch marine boilers. This form of stay acts as a beam or girder resting on the side sheets of the combustion chamber and supporting the crown-sheet by means of bolts passing through it and through the girder stay as shown in Figs. 43 and 44. An

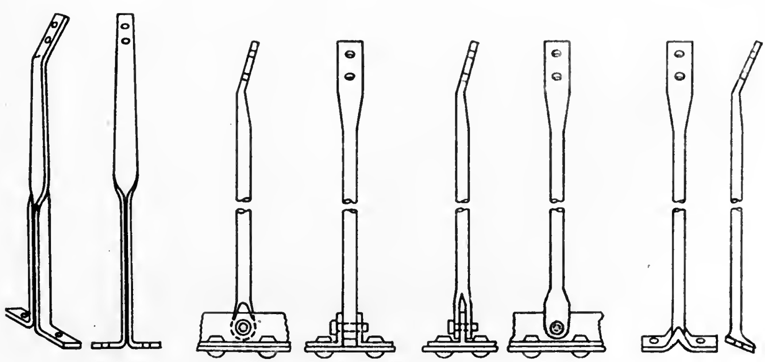


FIG. 42.—Types of diagonal stays.

open space is left between the crown-sheet and the girder to permit free circulation of the water.

The girder should be chipped and filed until it sets perfectly, resting not only on the edge of the side sheets, but also on the curved edge of the crown-sheet. Two forms of girders are illustrated here: The one shown in Fig. 44 consisting of two parallel girders formed from steel plates, which is the older and more common form; and the other, shown in Fig. 43, consisting of a single forged or cast girder, with holes for the bolts bored through enlarged portions of it. The bolts used to support the crown-sheet are plain round bolts threaded at one end only, and

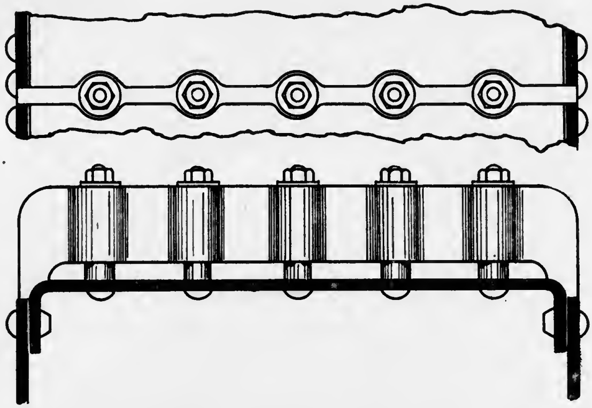


FIG. 43.—One-piece girder stay.

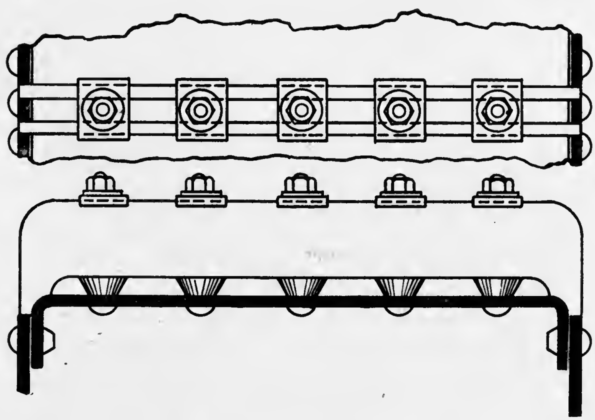


FIG. 44.—Two-piece girder stay.

with round heads. The bolts pass up through the crown-sheet and girder and are fastened on top by a nut which bears against a washer resting on top of the girder. Thimbles or distance pieces are placed between the girder and crown-sheet, and the nuts are screwed up till the crown-sheet rests against them.

This stiffens the crown-sheet and forms a steam- and water-tight joint.

In locomotive boilers, the girder stay is sometimes so long that it must be supported differently. This is done by having short stays, called *sling stays,* fastened to the girder and to the top sheet of the boiler. If this were not done, the girder would have to be so large, in order for it to have sufficient stiffness, that it would interfere seriously with the circulation. In this way, the girder is supported by the top sheet, and the crown-sheet is

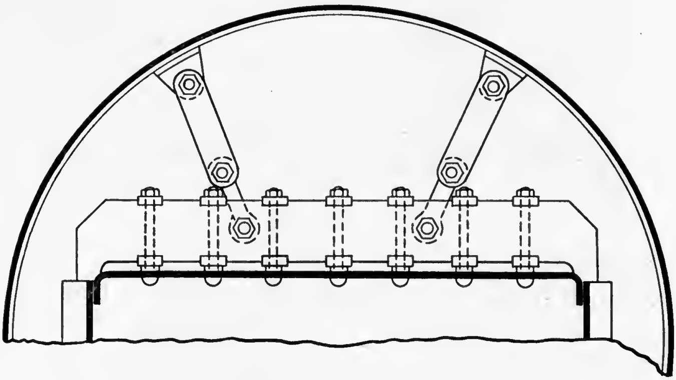


Fig. 45.—Sling stay.

supported by the girder. This is equivalent to having through stays from the crown-sheet to the top sheet of the boiler, except that this arrangement is more flexible. A crown-sheet supported by a girder and sling stays is illustrated in Fig. 45. The use of a girder stay to support the top of the combustion chamber of a Scotch marine boiler is illustrated in Fig. 14.

Girder stays are not used as extensively now for supporting the crown-sheet of locomotive boilers as they were a few years ago. This method of support is being replaced by the use of radial stays. These are in the form of bolts threaded at both ends like a stay bolt, and screwed into both crown-sheet and shell of the boiler and then riveted over. By using the proper number and size of radial stays, the crown-sheet is supported equally at all points, and as they are placed in regular rows they do not interfere seriously with the circulation. The use of radial stays in supporting the crown-sheet of a locomotive boiler is shown in Figs. 9 and 10.

**41. Gusset Stays.**—Gusset stays are a form of diagonal stay, but are made from plates and are attached to angles which are riveted to the head and to the sides of the boiler, as shown in Fig. 46. They are quite commonly used in Cornish and Lancashire boilers, but have the faults that they are exceedingly rigid, take up considerable space, and the determination of stresses in them is difficult.

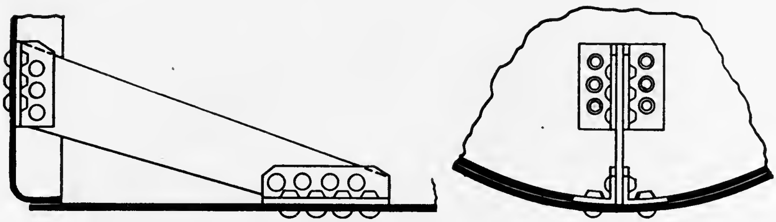


Fig. 46.—Gusset stay.

**42. Stay Tubes.**—Boiler tubes also act as stays if the ends are properly beaded over and, where they are used, no other stays are needed to hold the tube sheets. The surface of the head above the tubes must, however, be stayed. In marine boilers, some of the tubes are made extra heavy and have the ends upset and screwed into the heads for the purpose of giving extra support. These are called stay tubes.

**43. Radial Stays.**—These are used between two surfaces which have different radii of curvature, such as the crown-sheet and

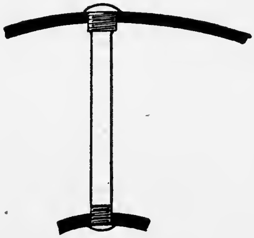


Fig. 47.

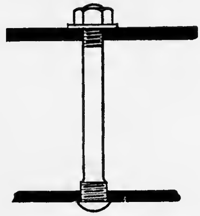


Fig. 48.

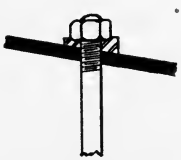


Fig. 49.

top of a locomotive fire box. Fig. 47 shows a common form of radial stay. One of the threaded ends is upset to a size 1/8 in. larger than the other in order to allow the small end to be passed through without screwing. The ends of the stay are riveted over after it is screwed into place. Fig. 48 is another type of bolt for the same purpose. This requires a copper washer, which should be not less than 1/8 in. thick, under the nut. Where this bolt is used at an angle to the plates, the head and nut must be faced off to a wedge shape, and the copper washers made to fit, as in Fig. 49.

**44. Through Stays.**—Such stays are made of round rods, as in Fig. 36, threaded at both ends and supplied with washers and nuts on each side of the plate to stiffen it. The ends of the stays are upset in order to make the threaded portion as strong as other parts of the rod. Through stays are used to connect together the two heads of a boiler and are used chiefly on marine boilers. Fig. 14 illustrates their use for the latter purpose.

**45. Dished Heads.**—The internal pressure of a boiler acting on a flat head tends to bulge it out into a spherical shape. Therefore if a boiler head is made of a spherical shape it will require no bracing, as it is already in the shape which the pressure tends to make it. It is impossible to make the heads of fire-tube boilers in this shape as the tubes must be placed in them at right angles to the head in order to bead them over properly, but when steam drums are used on water-tube boilers, the heads of these are practically always made of a spherical shape. Heads shaped to this form are called "*cambered,*" *dished,*" or "*bumped*" heads. If they are dished to twice the radius of the shell, the head and shell will be equally strong to resist bursting.

When heads are made they are usually flanged to fit inside the shell and are then riveted, a single riveted joint being used.

**46. Tube Setting.**—When for any reason it becomes necessary to renew a tube in a boiler, the old tube must be carefully removed. The old tube may be quickly removed by first crushing the ends of the tube with a cold chisel and hammer to release the beading from the tube plate. During this process great care should be exercised to prevent injury to the hole in the plate. If it is desired to preserve the tube this method is objectionable because the tube is very liable to be split and ruined.

If it is desired to preserve the tube, either of two methods may be employed. First, a tube cutter may be used to cut the tube where it is expanded in the heads and at a point about two-thirds through the thickness of the head. This leaves both the tube and a short nipple remaining in the head. The nipple may now be crushed with a cold chisel and removed. In order to remove the tube it will be necessary to make its ends smaller by passing an oyster chisel around it between the tube and the head, when the tube may be easily slipped out. This method cannot be used if there is a bead on the tube just inside the head, like that shown in Fig. 53, which is left by some kinds of tube expanders. The second method mentioned above may be employed in this case. By this method, the tube is cut inside the head by means of a tube cutter. The nipple remaining in the head is crushed and removed and the tube slipped out.

As there is always more or less irregularity in every tube plate it will be necessary to measure each tube separately. This can best be done by means of a small gas pipe of sufficient length, as it is quite stiff for its weight and, being small, it is easily caught at the farther end. The measuring pipe should be held flush with the far end by a helper while being marked close against the plate at the near end. A block of wood held over the hole at the far end by the helper will assist in keeping the measuring pipe flush with the tube plate. A slate pencil is useful in marking the measuring pipe and avoids the confusion which is likely to result from scratches on the pipe which cannot be removed.

When the distance between the tube plates has been obtained in the way described above, the measuring pipe may be removed and laid alongside the tube, and this marked to the proper length. Enough extra length of tubing should be measured off to allow for beading. A length at each end of from two to two and one-half times the thickness of the walls of the tube is sufficient to allow for beading.

If copper ferrules are to be used on the ends of the tubes, the tubes have to be swaged to admit the ferrule. If this is not done it will be necessary to enlarge the hole in the tube sheet, and usually the holes are so close together as not to permit of this. The ferrules should not project beyond the tube sheet more than enough to give them a hold and allow the tubes to be beaded over.

In placing the tubes, they are run through the front sheet, while the helper catches them with a short rod at the far end, directing this end into place. The excess length of tube should now be divided so that an equal amount projects beyond each tube sheet. While setting one end of the tube the other end should be held to its proper position by the helper. For this purpose a block of iron with a recess in it, such as shown in Fig. 50, will be found convenient.

If the tube has been cut off by a cutter which works on the inside of the tube, it is now ready for expanding in the head. Cutting off the tube in this way leaves a bevelled edge, the bead being turned outward, which makes it easy to bead.

A thin steel tube can be expanded in a bored hole so as to make a steam- and water-tight joint by means of a tool called a tube expander. It is not practical to expand tubes having a greater diameter than 5 in. Tubes larger than this are commonly riveted to flanged holes in the tube sheet.

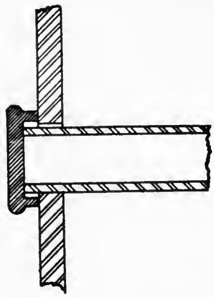


Fig. 50.

There are two types of tube expanders in common use, known as the Prosser expander, illustrated in Fig. 51, and the Dudgeon expander, shown in Fig. 52. The Prosser expander consists of a number of steel segments held together by a spring steel band, or by a rubber ring, the segments being of such size that when the expander is collapsed it is of smaller size than the tube, and may be inserted into it. A tapered steel pin passes through the center of these steel segments and, by driving this tapered pin in, the segments are separated and bear against the tube. By gradually driving in the pin, then slacking and turning it and driving again, the tube is expanded until it completely fills the hole in the tube sheet. Tubes which are put in by this method are expanded on both sides of the tube sheet and act as braces to stiffen it.

The Dudgeon expander is designed to expand the tube by the continuous pressure of steel rollers turning inside the tube. It consists of a hollow cylinder provided with openings to receive three or more steel rollers. A tapered steel mandrel is placed in a hole in the center of the cylinder and bears against the steel rollers. By revolving the expander and at the same time hitting the mandrel with a wooden mallet the rollers are gradually forced outward and this expands the tube. If the expander is run by power, the motor will stall when the tube has been

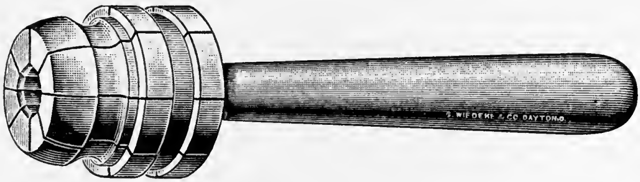


FIG. 51.—Prosser tube expander.

expanded and there will be no danger of rolling it too thin. If the expander is run by hand, it will pull so tightly when the tube has been expanded that the workman will stop of his own accord.

By placing the steel rolls of a Dudgeon expander at an angle, as shown in Fig. 52, the expander is made self-feeding and it is not necessary for the workman to drive the mandrel. When

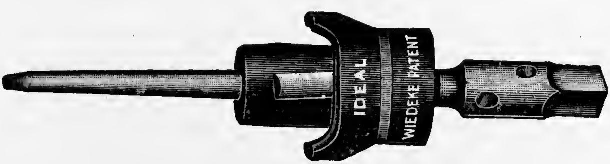



FIG. 52.—Dudgeon tube expander.

the tube has been expanded sufficiently, it is only necessary to turn it backward to loosen it. These expanders are made to be operated by either hand or power and they are provided with extra long rolls which may be reversed after one end has become worn, thus greatly lengthening the life of the expander.

After the tube has been expanded by either of the methods described above, the ends of the tube that project beyond the tube sheet should be neatly beaded over by means of a beading tool called a "boot," which is illustrated in Fig. 53. The tool should be held greatly inclined to the tube at first, as shown by the dotted lines, until the end of the tube is well flared out. After this is done, the tool may be held nearly parallel with the flue, as illustrated, and the beading finished neatly.

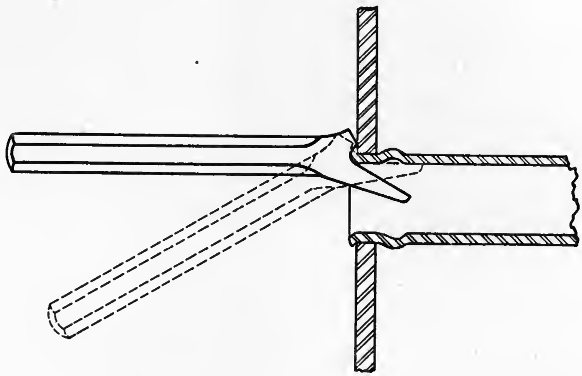


FIG. 53.—Boot.

**47. Manholes and Handholes.**—Any boiler which has a steam or water space large enough to admit a man should be provided with a manhole. There is no standard size for manholes but most of them are 11 in. × 15 in., which is large enough to admit a good-sized man. The best location for a manhole is in the end of a boiler above the tubes for fire-tube boilers or in the end of the steam drum of a water-tube boiler. It is often impractical to place the manhole in the end of a fire-tube boiler, as the head is flat and requires stays which may have to come at the point which the manhole would occupy. In this case they have to be placed in the top of the shell, but the latter location is not so good unless the boiler is large, because of the difficulty a man has in straightening himself out in the small height between the top of the tubes and the top of the shell.

Unless the manhole is flanged, it should be strengthened by a ring of steel or wrought iron riveted to the inside of the shell. This will restore the strength lost by cutting so much metal out of the sheet. There is a disadvantage, however, in the use of such a strengthening ring in that the rivets come where the manhole cover rests, and for this reason only countersunk rivets can be used.

A later and better practice is to flange the manhole, the flanges being on the inside. This flange gives the additional strength needed and, by facing off the flange, it forms a good seat for the cover. The cover is usually stamped out of steel

FIG. 54.—Lukens manhole and cover.

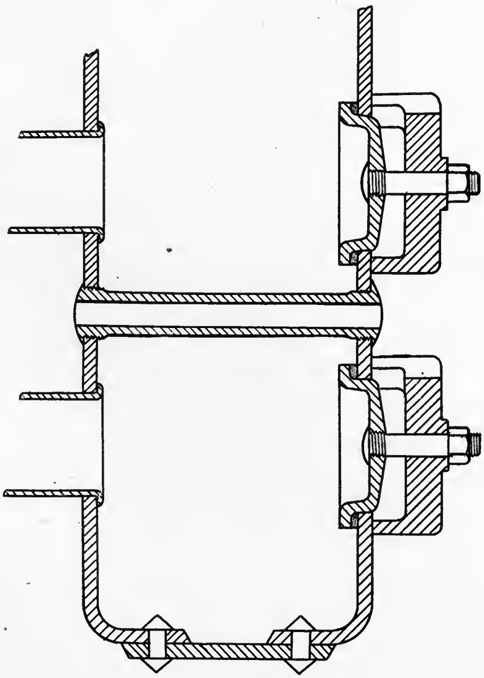


FIG. 55.—Handhole for water-tube boiler.

and goes inside the boiler, being kept firmly to its seat by a bolt which passes through the cover and through a steel yoke which bridges across the manhole on the outside. A manhole and cover constructed in this manner is illustrated in Fig. 54, which shows a Lukens manhole and cover. A gasket which is not affected by either heat or water should be placed between the manhole cover and its seat.

Handholes are shaped like manholes but are smaller in size. They are used in front of the tubes of water-tube boilers and below the tubes in small fire-tube boilers. In the larger sizes of fire-tube boilers a manhole is placed below the tubes instead of a handhole. Fig. 55 shows a handhole such as is usually placed in front of a tube in a water-tube boiler. The cover is fitted with a gasket to make a steam- and water-tight joint and the cover is of such shape as to prevent the gasket from being blown out. The cover is held by a single bolt screwed through the cover and then riveted over. The bolt then passes through a steel yoke and is held in place by a nut on the outside.

## CHAPTER V

### HEAT AND WORK

**48. Changing Heat into Work.**—Since a boiler is a device for making steam from water by the application of heat it is essential that we have a thorough understanding of the nature of heat, how it acts and how steam is formed. We must keep in mind always that it is the heat which does the work and not the steam. From this property of heat by which it is able to do work we say that heat is a form of energy, for energy is the ability to do work.

In a steam power plant we start with a coal fire on the grate and with water in the boiler and finally get mechanical energy or electric current to be sent out from the plant. The coal is burned, and the heat thus liberated is used to evaporate water and supply steam under pressure. The steam goes to the engine, where part of its heat is transformed into mechanical energy. We see, then, that the fuel is the starting-point and is the real source of energy. We will now study the process by which the energy of the fuel is utilized in a power plant.

Consider the elementary power plant illustrated in Fig. 56 which shows all the apparatus needed to convert heat energy into mechanical work. The coal is fed into the furnace, where a small part of it is lost by dropping through the grate in the form of small particles of unburned coal. The larger part of the coal is burned and, of the total heat generated thereby, one part is lost out of the stack and another part passes into the water in the boiler to form steam.

Of the heat which enters the boiler a very small portion is lost through radiation from the exposed portions of the boiler, but by far the larger portion enters the water, raises its temperature and causes the water to boil and form steam. The steam thus formed passes out of the boiler through the steam pipe, part going to the engine cylinder and part going to the pumps. A small amount of heat will be lost by radiation from the hot steam pipes and from the hot cylinder of the engine and pump. The

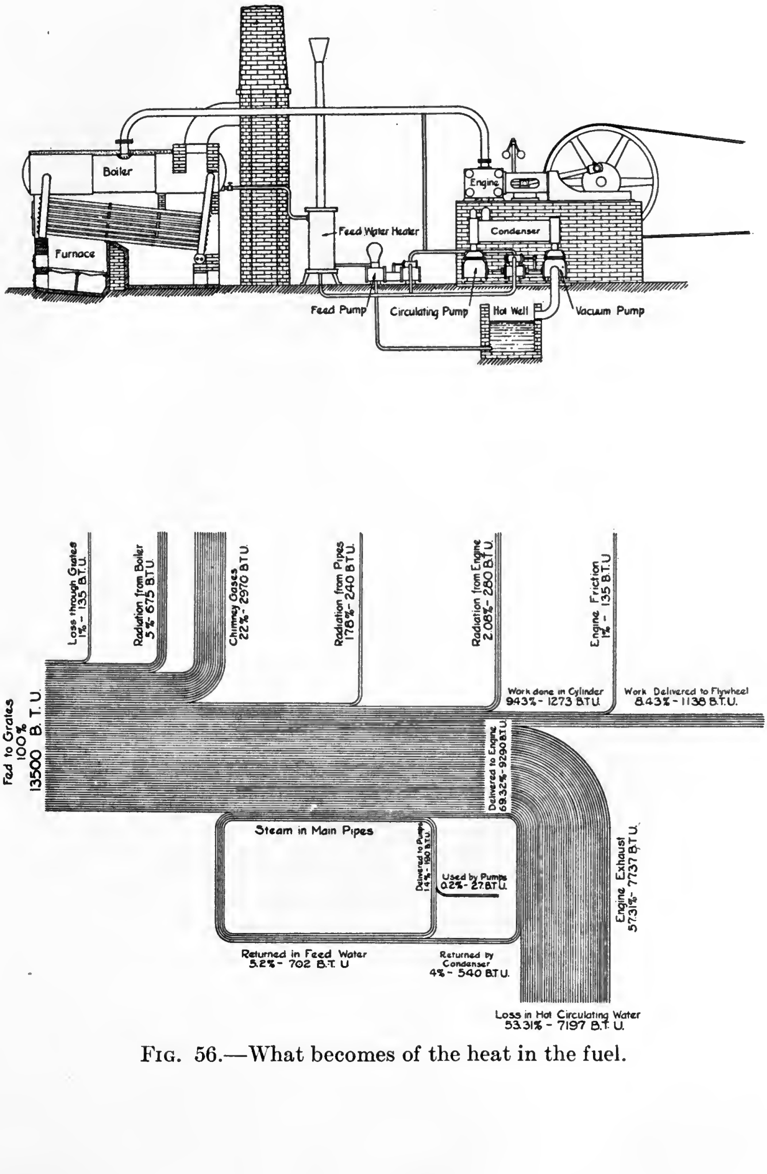



FIG. 56.—What becomes of the heat in the fuel.

remaining portion which enters the engine cylinder causes the piston to move, at the same time losing its pressure. The motion of the piston is transferred to the flywheel where the energy may be taken off by belts.

Only a small part of the heat energy delivered to the cylinder reaches the flywheel. A small part of it is lost in friction in the moving parts of the engine and a far greater part is exhausted from the cylinder in the form of exhaust steam. Upon leaving the cylinder, the exhaust steam passes to a condenser, where it is changed back into water and in doing so gives up its heat to the water which condenses it, and thereby raises the temperature of the condensing water. A portion of this water is fed into the boiler to take the place of the steam used in running the engine and pumps. The remaining hot water is wasted.

A small amount of steam is used in the boiler-feed pump, where it does work in pumping water into the boiler, but, as in the case of the engine, the larger part of the steam taken by the pump is lost in the exhaust. We see from the above description that the water used in a boiler passes through a regular cycle of events whereby it takes up heat and carries it to the engine, where a portion of the heat is turned into work and another portion is wasted, the water returning to the boiler in the form of water and leaving it in the form of steam.

**49. Work.**—The prime object of any power plant is to do *work*. By work we mean the overcoming of resistance and the producing of motion. When the steam in an engine cylinder exerts a sufficient force to overcome the resistance of the load and to cause the piston to move, work is done. There are two parts or factors to work; *the force used* and *the distance moved.* The same force will do more work in moving a body a long distance than in moving it a short distance. Also, for the same distance, a large force will do more work than a small one. Work is, therefore the product of the moving force and the distance, and is generally expressed in *foot-pounds.*

One Foot-pound is the work done when a force of 1 lb. is exerted for a distance of 1 ft. If a weight of 80 lb. is lifted 1 ft., the force required will be 80 lb., because we measure a force by the weight it can lift. If this force lifts the weight through a distance of 4 ft. the work done will be $4 \times 80 = 320$ foot-pounds. It will require the same amount of work to lift 40 lb. 8 ft. or 16 lb. 20 ft. If the piston of an engine travels 750 ft. in a minute and the average pressure on the piston during this time is 10,000 lb., the work done during one minute will be $750 \times 10{,}000 = 7{,}500{,}000$ foot-pounds. Remember that no work can be done by a force unless it succeeds in producing motion. A man might tug all day at a weight but unless he succeeded in raising it he would do no work. Likewise if the pressure on the piston of a steam engine is not great enough to overcome the load and turn the engine, there will be no work done.

**50. Power.**—Power is the *rate* of doing work. To lift a stone weighing 10,000 lb. to a height of 7 ft. will require 70,000 foot-pounds of work. If one hoisting engine can do this in half the time that another one can, the first engine is twice as *powerful* because it must do the work twice as fast. We see, then, that in calculating power, time must be considered. The engine which can do the most work in a minute has the greatest power.

**51. Horse-power.**—The engineer's standard of power is the horse-power. This standard was established by James Watt, who estimated that an average horse was able to work continuously at the rate of 33,000 foot-pounds per minute. One horse-power is therefore a rate of working of 33,000 foot-pounds per minute (or 550 foot-pounds per second).

If a force of 18,000 lb. is required to move a train of 30 cars, the work required to move it 1 mile will be $18{,}000 \times 5280 = 95{,}040{,}000$ foot-pounds. An engine that could do this in 2 minutes would do $95{,}040{,}000 \div 2 = 47{,}520{,}000$ foot-pounds per minute; and its horse-power would be $47{,}520{,}000 \div 33{,}000 = 1440$ horse-power. If another engine required 4 minutes to haul the train 1 mile it would only do half as much work in a minute and its horse-power would be only half as great, or 720 horse-power.

**52. Energy.**—Energy is *ability* to do work. Heat can be made to do work through a steam engine or gas engine and, therefore, heat is energy. Electricity also can do work by means of an electric motor; therefore, electricity is energy. The energy of a body in motion, as, for instance, the energy of a revolving flywheel is called mechanical energy. Light is still another form of energy, because we can turn heat or electricity into light and, if they are forms of energy, light must also be energy. The various forms of energy with which we may have to deal in a power plant are: heat, mechanical energy, electricity, and light. Heat is liberated from the coal and given to the water in forming steam; the engine takes heat from the steam and changes it to mechanical energy; the dynamo changes this mechanical energy to electricity; the electricity is transmitted through wires to some distant point and there transformed to heat and light by electric lamps, or to mechanical energy by an electric motor.

Energy cannot be destroyed nor created but, as has been shown, can be readily changed from one form to another. There are many cases where it appears on first thought as if energy were lost but on close examination we find that such is not the case. In a long line shaft we may not get as much mechanical energy at one end as was put in at the other end but we find that what has apparently been lost has really been changed into heat in overcoming the friction of the bearings. The mechanical energy expended in cutting a piece of steel is also changed to heat and we find that the steel and also the tool used will become warmer during the process.

**53. Heat.**—Although heat and its effects have been observed and studied for many hundreds of years it was only in the past century (the nineteenth) that scientists completely formulated our present theory as to its nature and effects. Formerly heat was supposed to be an actual substance which entered a body when that body became hot, and left it when it became cold. We now believe heat to be a form of energy which can be changed to work, electricity, or any of the other forms of energy. These changes of form can be seen in numerous cases, some of which have already been mentioned.

It is generally accepted that heat exists in bodies as a very rapid invisible motion of the fine particles or molecules of the bodies. Each particle is supposed to have a violent to-and-fro motion and the greater the amount of heat energy in a body the greater must be the energy of each molecule and, hence, the greater will be the rapidity of this molecular motion. The application of this theory can be extended to all of the phenomena of heat. For example, the melting of solids into liquids and the evaporation of liquids into gases is explained as follows: There is a force of attraction known as *cohesion* which tends to hold the particles of any substance together and which, in a solid, is strong enough to hold the body in a certain shape. Heat causes the particles to move to and fro and thus exerts a force opposite to cohesion, tending to separate the particles. As heat is applied and the particles are separated the force of cohesion acts more and more feebly until finally the particles are able to move among each other, though still held together slightly. This is the *liquid* state. As the liquid is further heated a point is reached where the motion of the particles becomes so great that they will tend to fly apart and try to separate. Cohesion is then entirely overcome and we have a *gas*.

**54. Energy of Fuels.**—When a fuel is burned, it brings into existence a certain amount of heat. This energy must exist in the fuel in some form before combustion occurs, if we are to believe that energy cannot be created or destroyed. We know that prior to combustion the energy of the coal is not heat and yet the only way we can make it available for use is to turn it into heat. Consequently, we often designate it by the name of "*Potential Heat.*" "Fuel Energy" and "Chemical Energy," are other names that can be rightly applied to energy in this form; but, since in our work we think of it only as "stored up" heat and use it only after turning it into the heat form, we will use the term Potential Heat. If we investigate the origin of our natural deposits of fuels, such as coal, petroleum, and natural gas, we can readily understand the idea of fuel energy being "stored up" heat. The sun is the source of all our heat energy and all the daily manifestations of energy, as in wind or water powers or the heat from a fire, are but exhibitions of energy that came originally from the sun. Because of the sun's heat forests grow and give us wood for fuel. In a similar manner the coal was formed ages ago. The earth's surface was at one time covered with a dense growth of vegetation, which became covered with rock and soil, and, by the action of heat and pressure, this vegetation underwent a gradual change until we find it at present in the form of coal.

**55. Sensible and Latent Heat.**—The first impression we get of heat is that caused by its effect on our sense of feeling. We touch an object and say that it is hot or cold according to its effect on our senses. Heat which can thus be felt is called "*Sensible Heat.*" But heat can exist in other forms not noticeable to our sense of feeling. When we melt a piece of ice, considerable heat is required to make the change, and yet the ice water formed, is just as cold as the ice. Similarly, the steam formed when we boil water is no hotter than the water which is boiling, but a large amount of heat is required to change the water into steam. Heat which is thus utilized in changing the state of a substance without effecting any change of temperature is called "*Latent Heat.*"

**56. Temperature.**—The impression which sensible heat makes on our senses we call *temperature.* Temperature is a measure of the intensity of heat in a body. It is not true, as is often said, that temperature indicates the amount of heat. A quart of water may have more heat than a pint of water and yet be colder. A pound of iron will have far less heat than a pound of water at the same temperature, because water has a greater capacity for heat than iron. Likewise a pound of ice water will contain more heat than a pound of ice although they will be at the same temperature.

**57. Measuring Temperatures.**—The common method of measuring temperature is by means of an instrument known as a thermometer, which usually consists of a glass tube partially filled with mercury or some other substance which will expand or contract as the temperature rises or falls and thus will indicate the temperature.

**58. Thermometer Scales.**—There are two kinds of thermometer scales in common use; the Centigrade, abbreviated C., and the Fahrenheit, abbreviated Fahr. or F. On the Centigrade thermometer the space between the freezing-point of water and the boiling-point at atmospheric pressure is divided into 100 equal parts called degrees, the freezing-point being marked zero (0) and the boiling-point 100°. The balance of the scale is then divided into spaces of equal length below zero and above 100° in order that temperatures higher than 100° and lower than zero may be read.

On the Fahrenheit scale the freezing-point of water is marked 32° and the boiling-point 212°, and the space between is divided into 180 degrees. This scale is also marked with divisions below 32° and above 212° in order to make the thermometer read through a wider range. The Fahrenheit thermometer is used more commonly in the United States than the Centigrade, which is used extensively in Europe. In this work the Fahrenheit scale will be used exclusively and where temperatures are given without any reference to the scale it will be understood to be the Fahrenheit.

In Fig. 57 the two scales are shown side by side and the student can see at a glance the relation between them. Since the same interval of temperature is divided into 100 parts in the

Centigrade scale and 180 parts in the Fahrenheit scale the Centigrade degree is $\frac{180}{100}$ or $\frac{9}{5}$ of the Fahrenheit degree. Similarly, the Fahrenheit degree is five-ninths of the Centigrade degree. In changing a reading on one thermometer to the corresponding reading on the other it must be borne in mind that

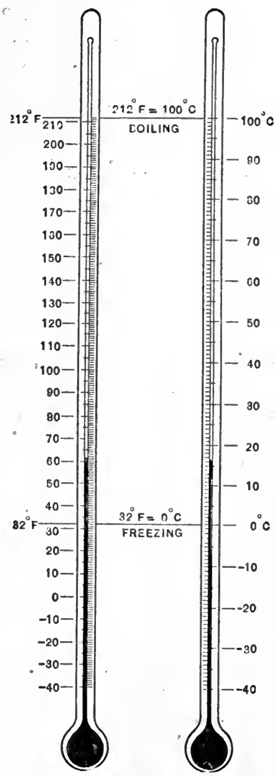



FIG. 57.

their zeros are not at the same point but are 32 Fahrenheit degrees apart.

Hence: *To reduce from the Fahrenheit to the Centigrade scale, first find how many Fahrenheit degrees the given temperature is above or below freezing and then multiply this by five-ninths.*

*To reduce from the Centigrade to the Fahrenheit scale, first multiply by nine-fifths to find how many Fahrenheit degrees the* *given temperature is above or below freezing. Then make the necessary change for the fact that the Fahrenheit zero is thirty-two Fahrenheit degrees below freezing.*

These rules may be stated briefly by the following formulas:

$$C=(F-32)\times\frac{5}{9}$$

$$F=\frac{9}{5}C+32$$

where $F$ represents degrees above zero Fahrenheit and

$C$ represents the corresponding reading above zero Centigrade. Thus if it is desired to change 26° C. to F.:

$$F=\frac{9}{5}\times 26+32$$
$$=46.8+32=78.8$$

Hence 26° C. = 78.8° F.

Likewise to change 170° F. to Centigrade we have:

$$C=(170-32)\times\frac{5}{9}$$

$$=138\times\frac{5}{9}=76.6+$$

Hence 170° F. = 76.6° + C.

Many people make the mistake of adding or subtracting the number 32 in cases where they should not. For example, suppose the mercury in a Centigrade thermometer rises 20 degrees on a certain day and we want to find the equivalent rise in Fahrenheit degrees. Each degree on the C. scale equals nine-fifths degree on the F. scale.

$$20\times\frac{9}{5}=36$$

Hence a Fahrenheit thermometer would show a *rise* of 36° on the same day. In this case the fact that the zero points are not the same has no connection with the problem, since we are dealing only with *changes* in temperature and not with readings from the zero points.

**59. Thermometers and Pyrometers.**—Mercury freezes at 39°

below zero Fahrenheit (−39° F.) and consequently cannot be used for temperatures below this point. Temperatures lower than this are usually measured with thermometers containing alcohol, since the freezing-point of alcohol is −202° F.

As mercury boils at 680° F. it is not suitable for use in thermometers which are to indicate very high temperatures and for this purpose other devices must be used. Such devices are called pyrometers. As the mercury thermometer is ordinarily made, it should not be used for temperatures above 500°, but by filling the glass tube above the mercury with an inactive gas, such as nitrogen, under high pressure the boiling-point of the mercury will be raised and a thermometer can be made that may be read up to 900°. Constructed in this way it forms one of the best instruments for determining stack temperatures in boiler plants.

Devices for indicating very high temperatures are called Pyrometers. One of the simplest forms of pyrometer depends for its operation on the fact that some metals expand more than others when heated to the same temperature. It is well known that a metal rod will expand when it is heated. Brass will expand much more than iron and this difference in expansion can be used to indicate temperatures. In form, such a pyrometer looks like an ordinary steam gage with a straight piece of pipe about 2 ft. long connected to it. The pipe is closed at the outer end and contains a brass or copper rod, one end of which is fastened to the outer end of the pipe. The other end is connected by a suitable mechanism to a hand on the dial of the instrument. As the tube and rod are heated, the difference in expansion causes the hand to move over the dial, which is graduated to read in degrees.

In order to obtain an accurate determination of the temperature the iron and brass must be at the same temperature throughout their lengths. The difficulties of securing this and of avoiding lost motion in the gears make this form of pyrometer somewhat unreliable. A peculiarity of these expansion pyrometers is that when the temperature starts to fall, the pointer will move up and, also, when the temperature starts to rise the pointer will move backward. This is because the brass strip is enclosed in an iron tube and the heat affects the iron before it does the brass. As soon as the heat penetrates to the brass and a uniform temperature is attained the pointer will take up its correct position.

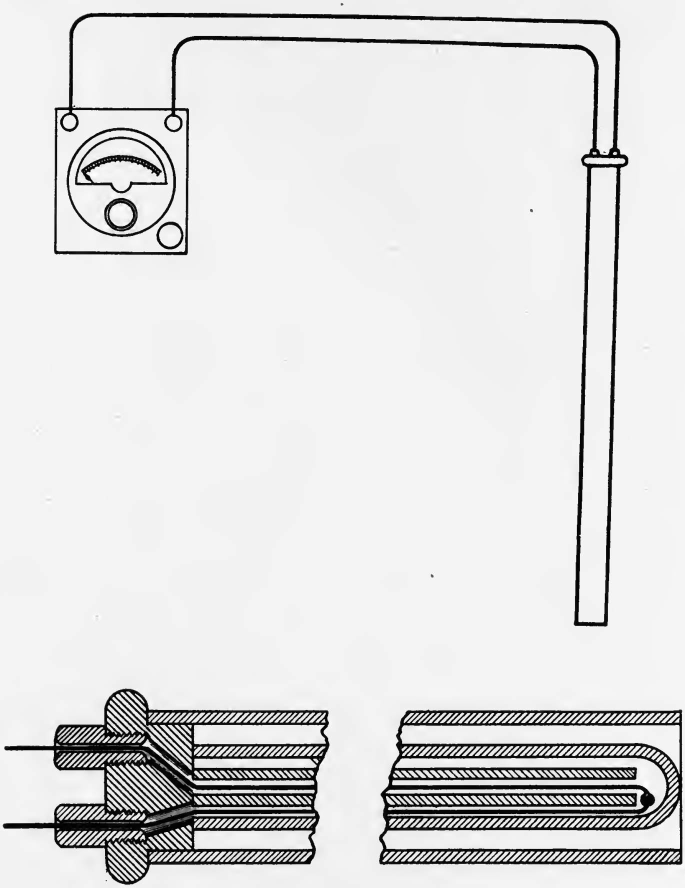


Fig. 58.—Le Chatelier pyrometer.

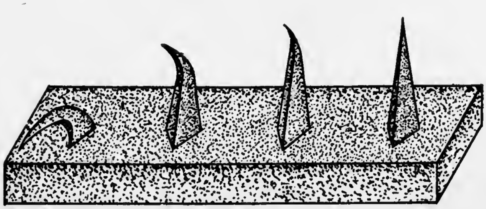


Fig. 59.—Clay cone pyrometer.

Another form of pyrometer, far more delicate than the above, is one called the Le Chatelier. It is made by joining two dissimilar metals and connecting the joint to a galvanometer by wires. Such a joint has the property, when heated, of generating a current of electricity, and the strength of the current is proportional to the temperature of the joint. The galvanometer measures the strength of the current and thus indicates the temperature of the joint. It may be placed at a distance from the point where the heat is applied and is, therefore, a very convenient instrument for certain cases. The joints, or elements as they are called, are enclosed in porcelain tubes to protect them from injury. The metals used in making these pyrometers are usually platinum and an alloy of platinum and rhodium. These metals will stand exceedingly high temperatures, but for such work are usually protected by porcelain or clay tubes. When constructed in this manner these pyrometers can be used for taking the temperatures of furnaces or of molten metals. A Le Chatelier pyrometer is shown in Fig. 58.

Another common method of determining furnace temperatures is by the use of small cones of clay composition such as shown in Fig. 59. The composition of these cones is such that they will melt at certain known temperatures. By placing in a furnace a number of these cones having different melting-points and by observing which ones melt and which stand erect we can tell very closely the temperature within the furnace. The dealers in these cones furnish with them a table of temperatures at which they melt.

High temperatures can be judged approximately by color but the results will depend on the eye of the observer and on the degree of illumination under which the observations are made. A piece of steel that would be red-hot in a darkened room would be black-hot in broad daylight. The following table from Kent's Handbook gives the colors and their corresponding temperatures:

| Color | Degree F. |
|---|---|
| Incipient red heat | 977 |
| Dull red heat | 1292 |
| Incipient cherry-red heat | 1472 |
| Cherry-red heat | 1652 |
| Clear cherry-red heat | 1832 |

| Color | Degree F. |
|---|---|
| Deep orange heat | 2021 |
| Clear orange heat | 2192 |
| White heat | 2372 |
| Bright white heat | 2552 |
| Dazzling white heat | 2732 to 2912 |

**60. The Unit of Heat.**—The most common way of measuring heat is to observe its effect in raising the temperature of a quantity of water. Consequently, it is but natural that we should take as our unit of heat the quantity of heat that is necessary to raise the temperature of 1 lb. of water 1 degree on the Fahrenheit thermometer. This unit is called the British Thermal Unit (B.t.u.) and it is most often designated simply by the letters B.t.u. instead of by the full name. The quantity of heat required to raise the temperature of a pound of water 1 degree is not exactly the same at different temperatures and for this reason it is necessary to specify the temperatures at which the B.t.u. is defined. To be exact, we have taken as 1 B.t.u. the amount of heat required to change the temperature of 1 lb. of pure water from 62° F. to 63° F., these temperatures being used because they are easily obtained. As a general rule it is sufficiently accurate to figure that 1 B.t.u. is transferred when a pound of water is raised 1 degree at *any* ordinary temperature. If 7 lb. of water are heated through 5 degrees the heat given to the water is the product of 7 and 5 or 35 B.t.u.

The method used to determine the heating value of coal is to burn a small sample so that the heat will all be given to a certain known quantity of water. By observing the change in the temperature of the water the heat can be calculated. The apparatus used for this purpose is called a *calorimeter*. Suppose we burned .003 lb. of coal in a calorimeter and find that it heats 7 lb. of water, causing a rise in temperature of 6° F. The heat given to the water is

$$7 \times 6 = 42 \text{ B.t.u.}$$

This heat came from only .003 lb. of the coal so 1 lb. of the coal would therefore yield

$$42 \div .003 = 14{,}000 \text{ B.t.u.}$$

**61. Relation of Heat and Work.**—Since heat and work are both forms of energy, there must be some definite relation between the units of heat and of work, that is, between the B.t.u. and the foot-pound. It has been found by actual experiment that, if a quantity of work is tranformed into heat, it requires 778 foot-pounds to give 1 B.t.u. On the other hand, if 1 B.t.u. is entirely transformed to work it will give 778 foot-pounds. This quantity (778) is what is termed "*The Mechanical Equivalent of Heat*" and also is sometimes called "Joules Equivalent" because Joule was the first to establish a relation between these quantities. The value found by Joule (772) was, however, afterward proved to be too low.

As an example of this relation let us take the case of an engine that loses 10 h.p. in friction. Since 1 h.p. equals 33,000 foot-pounds a minute this engine will lose 330,000 foot-pounds a minute in friction. This work that is lost in friction is really turned into heat and, since 330,000 foot-pounds $=330{,}000 \div 778 = 424$ B.t.u., we find that the heat generated in the bearings and rubbing surfaces of this engine amounts to 424 B.t.u. per minute.

It is impossible for an engine to receive a quantity of heat and transform all of it into work. A steam engine receives heat in the steam and transforms *part* of this heat into work but the exhaust from the engine carries off a large percentage of the heat that is supplied. If an engine were able to transform all of the heat it receives into work we would only need to supply $33{,}000 \div 778 = 42.42$ B.t.u. per minute for each horse-power, or 2545 B.t.u. per hour per horse-power. The best steam engines only transform into work about 20 to 25 per cent of the heat supplied them and many can do no better than 4 or 5 per cent.

**62. Heat Cycle of a Steam Power Plant.**—A study of the heat diagram shown in the lower part of Fig. 56 will show what becomes of the heat supplied in the form of fuel to the boiler furnace. In this diagram the small branches which lead off from the main diagram show the various losses, while those branches which return to the main diagram show the portions of heat that are saved.

If we consider a single pound of fuel having a heating value of 13,500 B.t.u. fed into the furnace, the first loss of heat occurs by unburned fuel dropping through the grate, amounting to about 1 per cent or 135 B.t.u. out of the total of 13,500. It must be understood that all of the values given in this diagram are only approximate, and will vary with different plants. They are given here simply to indicate in a general way the amount of heat lost in various ways.

The remainder of the heat which leaves the grate, amounting to about 99 per cent, divides, about 72 per cent passing into the boiler and the remaining 27 per cent or 2970 B.t.u. passing out of the chimney in the hot flue gases. The heat which passes into the boiler heats the water and forms steam and also heats the shell, which radiates some heat to the atmosphere. This amounts to about 5 per cent of the total, or 675 B.t.u.

The remaining 72 per cent of the heat is carried into the pipes by the steam. About 1.78 per cent or 240 B.t.u. is lost by radiation from the hot pipes and the remainder passes on to the engine. Here another 2.08 per cent or 280 B.t.u. are lost by radiation from the heated portions of the engine, while about 9.43 per cent or 1273 B.t.u. are turned into work in the cylinder. Not all of this 9.43 per cent is in the form of useful work, however, as about 1 per cent is used to overcome the friction in the moving parts of the engine. The remainder, 8.43 per cent or 1138 B.t.u. is delivered to the flywheel in the form of useful work. This may seem like a very small portion of the total heat to be utilized, yet it is as much as may be expected under the ordinary conditions.

The larger part of all the heat, amounting to about 57.31 per cent or 7738 B.t.u., passes out of the engine in the exhaust without doing any useful work. All of this would be lost if the engine was run non-condensing, but in the power plant shown here, the exhaust steam is condensed and this furnishes a supply of hot feed water. By doing this, about 4 per cent or 540 B.t.u. is saved and returned to the boiler. The remaining 53.31 per cent or 7197 B.t.u. passes off in the hot circulating water from the condenser and is lost.

The feed pump also takes about 1.4 per cent or 190 B.t.u. and of this, uses about 0.4 per cent or 54 B.t.u. to pump the water, while the remainder, 1 per cent or 135 B.t.u. may be used to further heat the feed water and thus be saved. This accounts for all the heat supplied to the grates. These various losses are tabulated below.

WHAT BECOMES OF THE HEAT IN THE COAL

| | | |
|---|---|---|
| Lost through the grates | 1.00 per cent | 135 B.t.u. |
| Lost by radiation from boiler | 5.00 per cent | 675 B.t.u. |
| Lost in chimney gases | 22.00 per cent | 2970 B.t.u. |
| Lost by radiation from pipes | 1.78 per cent | 240 B.t.u. |
| Delivered to pumps | 1.40 per cent | 190 B.t.u. |
| Lost by radiation from engine | 2.08 per cent | 280 B.t.u. |
| Lost in engine friction | 1.00 per cent | 135 B.t.u. |
| Lost in engine exhaust | 57.31 per cent | 7738 B.t.u. |
| Useful work delivered to flywheel | 8.43 per cent | 1137 B.t.u. |
| | 100.00 per cent | 13500 B.t.u. |

# CHAPTER VI

## EFFECTS OF HEAT

**63. Expansion of Solids.**—Nearly all substances expand when heat is applied to them and contract when heat is removed. This phenomenon is greatest in gases and least in solids, but even in solids is of enough moment so that it must be considered in the design and installation of boilers.

When a solid body is heated it, of course, expands in all directions if free to do so; but, as a rule, we are concerned only with the change of one dimension and not with the change in volume. Thus, in the case of a steam pipe, we do not care especially about the change in thickness or in diameter but we are concerned with the change in length.

The amount of linear expansion which a body undergoes depends upon the kind of material, upon the amount of the temperature change and, of course, upon the original length.

**64. Coefficients of Expansion.**—The Coefficient of Linear Expansion of a substance is that part of its original length which a body will expand for each degree change in temperature. Coefficients for different metals have been determined for our use by careful experiments and can be found in handbooks or tables under the head of "Coefficients of Expansion." A few of the most common are given here:

COEFFICIENTS OF EXPANSION

| Metal | Coefficient |
|---|---|
| Aluminum | .00001234 |
| Brass | .00001 |
| Cast iron | .0000055 to .000006 |
| Wrought iron and machine steel | .0000065 |
| 36 per cent nickel steel | .0000003 |

The above values are based on a temperature rise of 1° F. For 1 Centigrade degree the coefficients would be 9/5 of those just given. The student is not expected to memorize these values. Where exact calculations are not necessary the value "five zeros-six" (.000006) for cast iron can be easily carried in mind. For steel or wrought iron annex a 5, making it .0000065. For copper, brasses, and bronzes a value of "four zeros-one" (.00001) is easily carried in mind. Remember that if the length is given in feet the expansion calculated will be in feet and if the length is in inches the expansion will be obtained in inches. The increase in length of a body due to expansion may be expressed by the following formula:

$$e = t\,C\,L$$

where $e$ is the *change* in length
$t$ is the *change* in temperature
$C$ is the coefficient of linear expansion
$L$ is the original length of the body.

The same formula applies to contraction when a body is cooled.

**Example:** What will be the expansion of a steam pipe 200 ft. long when subjected to a temperature of 300°, if erected when the temperature was 60°? *Note:* The pipe used for steam lines is generally of steel though some people prefer wrought iron when it can be obtained.

*Solution:* The change in temperature is $300 - 60 = 240°$ and the coefficient for steel is .0000065

$$e = 240 \times .0000065 \times 200$$
$$= .312 \text{ ft. or } 3\tfrac{3}{4} \text{ in., nearly.}$$

A good working knowledge of the effect of heat on metals is of great importance to the engineer. A failure to provide for expansion in steam piping has caused many leaks and some serious accidents. In turbine work, change in position of parts due to heating will seriously affect the alignment. The erecting engineer makes use of expansion and contraction when putting links in a flywheel rim or shrinking bolts in the hub. In setting a boiler, provision must be made for expansion and contraction.

**65. Expansion of Liquids.**—The expansion of mercury and alcohol under increase of temperature has already been referred to under the discussion of thermometers. Water also expands when heated, except as follows: A given weight of water occupies the least volume at 39.2° F. and if cooled below this temperature will expand until it freezes at 32° F. The density of water is, therefore, the greatest at 39.2° F. As a very important result of this, we note that ice forms on the surface of water because after water is cooled below 39.2° the coldest water will rise to the surface and the warmest will descend.

**66. Expansion of Gases.**—Gases likewise will expand when heated. However, an added complication is introduced in considering the expansion of gases, owing to the fact that the volume of a gas is readily reduced by increasing the pressure on

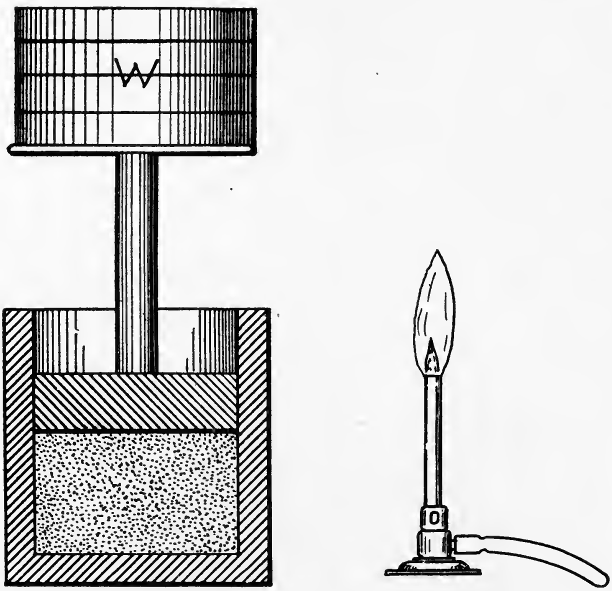



Fig. 60.

it and is increased by reducing the pressure. Fig. 60 shows a certain weight of gas held within the cylinder and maintained at a certain pressure by the weights W. If we remove part of the weights, the pressure on the gas will be reduced, the gas will force the piston upward, and the volume will increase accordingly.

In studying the effect of heat on gases, let us imagine that a flame is applied to the bottom of the cylinder in Fig. 60. The gas will be heated and, as the energy of the particles of the gas is thus increased, they tend to vibrate in a wider space and thus the gas expands and raises the piston and occupies a larger volume. In this case, the gas has been heated "at constant pressure" (the weights remaining the same) and it will be found that gases so heated obey a regular law in expanding. It is of course possible, by fastening the piston or by adding weights gradually, to prevent the volume from increasing as the temperature is increased. In this case the gas is heated "at constant volume" and the pressure increases regularly as the temperature rises.

**67. Absolute Zero.**—By experiment it has been found that 1 cu. ft. of a gas at 32° will expand to 1.366 cu. ft. when heated to 212° under a constant pressure. This means that for each degree rise in temperature the gas expands $\frac{.366}{180}=\frac{1}{492}$ of its original volume at 32° F. and we find that this expansion is uniform throughout the range of temperature. Now, let us imagine what would happen if this cubic foot of gas were cooled below 32° F. At 0° F. it would occupy only $\frac{460}{492}$ cu. ft. and if the temperature could be reduced to 460° below zero the gas would have *no volume whatever.* This means that, according to our theory of heat, the heat energy has been entirely removed and the particles cease to vibrate and, therefore, that –460° F. is the lowest possible temperature and is *absolute zero.* As a matter of fact the different gases all liquefy before this temperature is reached, but scientists have reached as low as –436° F. Air liquefies at about –300° F.

Absolute temperature is temperature calculated above absolute zero and is obtained by adding 460 to the reading on the ordinary Fahrenheit thermometer. Thus 40° F. equals $40+460=500$ degrees absolute.

It has been shown above that, *when a gas is heated or cooled while the pressure remains constant, its volume increases or decreases in proportion to its absolute temperature.* If the cylinder mentioned above had contained 1 cu. ft. of gas at a temperature of 70° F. or 530° absolute, and had been heated at constant pressure to 300° F. or 760° absolute, its volume would have increased to $1\times\frac{760}{530}=1.43$ cu. ft.

*If a gas is heated while its volume remains constant, its pressure will increase or decrease in proportion to its absolute temperature.*

Thus if a certain volume of gas at a temperature of 60° F. or 520° absolute and a pressure of 100 lb. per square inch is heated at constant volume to 200° F. or 660° absolute its pressure will increase to

$$100 \times \frac{660}{520} = 127 \text{ lb. per square inch.}$$

**68. Transmission of Heat.**—One of the most important things in studying heat in connection with steam-boiler operation is the manner of transferring heat from one body to another. There are three methods of heat transfer, namely: *Radiation, Conduction,* and *Convection.*

**69. Radiation.**—Radiation is the transmission of heat through an intervening space in the same manner that light is transmitted. We sometimes speak of feeling the "glow" from a fire when at some distance from it. This glow is really the radiant heat from the fire. That part of a boiler shell which is directly over the fire receives the radiant heat from the fire and, as this heat is very intense at such a short distance, the shell heating surface is very effective in raising steam.

**70. Conduction.**—When a silver spoon is placed in a cup of hot tea or coffee the handle soon becomes warm. The bowl of the spoon receives the heat and transmits it to the hand by a process which we call *conduction.* According to our theory of heat, conduction must consist simply in the transfer of motion from one molecule to the next. Some metals, we find by experience, will conduct heat faster than others. Silver is the best conductor and copper is almost as good, while brass will only transmit heat at about one-fourth the rate of silver and, even then, it is nearly twice as good a conductor of heat as iron. The following table gives the relative conductivities of some common substances, that of silver being taken as 100. It will be noticed that even though there is a wide difference in the conductivities of the metals they are all greater than those of other substances.

RELATIVE HEAT CONDUCTIVITIES

| | | | |
|---|---|---|---|
| Silver | 100 | Lead | 8.5 |
| Copper | 90 | Glass | .15 |
| Aluminum | 50 | Wood | .01 |
| Brass | 25 | Magnesia | .007 |
| Steel and Iron | 15 | Asbestos | .007 |

The low values for magnesia and asbestos explain why these and similar substances are used for pipe coverings.

When the hot gases from a boiler furnace come in contact with the shell and the tubes, some of the heat of the gases is transferred to the metal. The transfer is made by conduction, the molecules of the gases transferring some of their energy to the molecules of iron on the surface of the metal. This heat is next transmitted through the shell from the outer to the inner surface by conduction and is then given to the water lying on the inside by the same process. The radiant heat received by the metal directly from the fire is likewise transmitted through the metal to the water by conduction.

From the table of conductivities it would appear as if there were several metals better suited for boiler construction than iron or steel. Iron and steel are, as we know, both cheap and strong and we find in practice that these conductivities are not so important as they seem. The tubes and plates of a boiler are comparatively thin and the difference in temperature between the outside and inside is so great that the kind of metal does not make a great deal of difference. Their importance is also reduced by the fact that thinner plates of steel can be used than of other metals because of its greater strength. There is undoubtedly some difference, however, and we find brass and copper tubes used in many fire-engine boilers and in large numbers of European locomotives.

**71. Convection.**—Liquids and gases are very poor conductors, but they have another method of transferring heat that is very effective. Fill a bottle or a test-tube with water and, grasping it near the bottom, hold the upper end in a gas flame as illustrated in Fig. 61. The water will soon boil at the surface but the lower end of the bottle will remain quite cool. It will be evident from this that water is a poor conductor of heat.

Again filling the tube, hold it by the top and apply the flame to the base as in Fig. 62. As fast as the water receives heat at the bottom it will rise to the top and the upper end of the tube will be practically as hot as the bottom. The heat in this case is transferred from one end of the tube to the other by a current in the water, and this method of transferring heat is called *convection.*

In boiler operation the movement of water from one part of the boiler to another, caused by heat, is spoken of as *circulation.*

The water lying next to the heating surface of a boiler receives heat from the metal. This water expands as it becomes warmer and therefore rises, while the cooler water, being denser, descends to the bottom. By the circulation thus set up, the heat is distributed throughout the entire body of water and, if the circulation is rapid, the entire contents of the boiler will be at the same temperature.

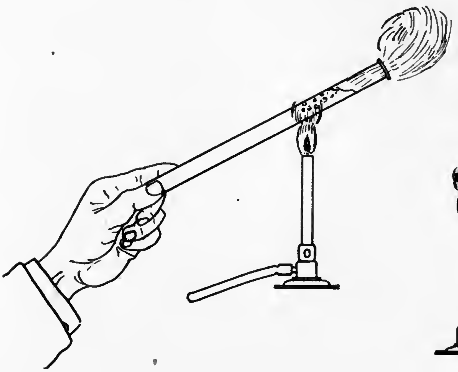


Fig. 61.

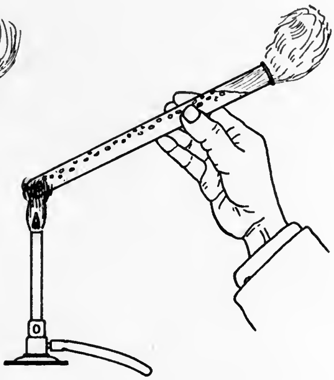


Fig. 62.

**72. Circulation.**—The circulation in a boiler is a most important item and should be facilitated as much as possible. The capacity of a boiler depends largely upon the character of the circulation. The metal parts of the boiler, such as the shell and tubes, will transmit heat very fast, much faster, in fact, than is generally supposed and, in order to take advantage of this ability to transmit heat rapidly, it is necessary to have water sweeping over the metal with a strong rapid movement so as to keep the steam bubbles swept from the surface. Steam is an even poorer conductor of heat than water, and, if allowed to collect in pockets next to metal which is transmitting a large quantity of heat, the steam will be unable to conduct the heat away fast enough and the metal will be overheated and burned. It has been found by experiment that as long as water flows freely along a boiler tube it is impossible to burn the tube, even with the most intense heat, but if steam is allowed to remain in contact with the surface, it may be melted quickly.

Overheating of the metal in spots will also cause unequal expansion in different parts of the boiler, and the strains thus set up may cause serious damage. A boiler having a rapid circulation will respond quicker to changes in load, and steam may be raised more readily than in one in which the circulation is poor.

A rapid circulation also serves to sweep away any films of air that may separate from the water and collect on the surface. Air which separates from water in a boiler is very injurious as it causes rapid corrosion. In the same way, rapid circulation prevents the accumulating of grease and oil on the heating surface; this is especially true where the water sweeps rapidly over the surface as in a small tube of a water-tube boiler. By reason of the cleansing action of a rapid current of water, deposits of mud and sediment are not likely to settle as thickly in the tubes of water-tube boilers as in those portions where the current is less rapid.

The circulation in a boiler depends largely upon the form of the heating surface and, as circulation is so important, a great deal of attention is given in designing boilers, to have them of such shape as to aid the circulation. In a return fire-tube boiler the water will rise in the front end over the furnace, move toward the back end near the surface of the water and will then pass to the bottom near the rear end and along the bottom toward the front. Of course all the water does not follow this path, as some of it is rising from all parts of the tubes and all along the bottom of the shell. In water-tube boilers the direction of the circulation will depend largely on the position of the tubes. In inclined water-tube boilers, such as the B. & W., the circulation is from rear to front through the tubes, then up the front header to the steam drum, through the steam drum to the rear header and down the rear header to the tubes.

In order to aid circulation and avoid bringing cold water in contact with heated surfaces of the boiler, the feed water should be discharged into the boiler only after it has become heated, and even then it should be discharged in the same direction as the circulation. In a return fire-tube boiler this result can best be secured by introducing the feed pipe through the front head a few inches below the surface of the water and near one side. The pipe should then pass straight back to within a few inches of the rear head, then across the boiler to the other side and discharge downward among the tubes. The pipe may be perforated where it passes across at the back but the perforations should discharge toward the rear head or downward. Introducing the feed water in this way will allow it to become heated in the feed pipe before it is discharged against any hot surfaces. In no case should a feed pipe end as soon as it enters the shell, unless the water is pumped into the boiler by means of an injector, which will heat it to about the same temperature as exists in the boiler.

**73. Formation of Steam.**—Since heat is necessary to effect the transformation of water into steam, it follows that the steam will be formed from water in immediate contact with the heating surface of a boiler. In the hottest parts of the boiler we therefore have a mixture of hot water and bubbles of steam. As these bubbles occupy a much larger volume than the water from

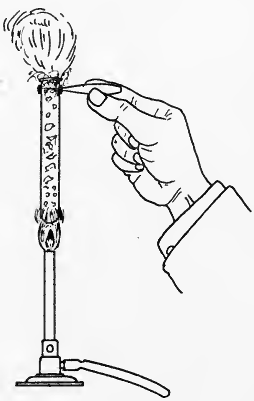


Fig. 63.

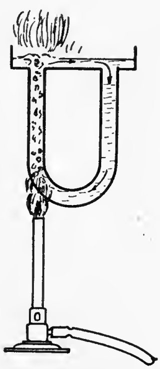


Fig. 64.

which they were formed, they are lighter and tend to rise to the surface with the heated water. Each bubble of steam is under a pressure equal to that on the surface of the water plus the weight of the water above the bubble. As it rises toward the surface the pressure becomes less and the steam inside the bubble expands. At the same time, the velocity with which it is rising increases as it approaches the surface and when the bubble reaches the surface it bursts the film of water which encloses it. The finely divided particles of water are thrown up into the steam above the water and, as these particles of water are very small, they remain suspended in the steam just as moisture remains suspended in air during a fog. This water is not in the form of steam but is merely water in mechanical suspension. This causes the steam to be wet or moist. When a boiler delivers wet steam into the steam pipes it is said to *prime.* It can be readily seen that the faster steam is formed or the more the boiler is forced, the greater will be the priming. The character of the circulation greatly affects the tendency to prime. A boiler having a strong positive circulation can be forced much harder without priming than can one with a poor circulation. This can be readily appreciated by reference to Figs. 63 and 64. If water is boiled in a vertical tube as in Fig. 63, the steam will form at the bottom of the tube in large bubbles. The rising steam opposes the downward passage of the water and if the heat is intense the entire contents of the tube may be thrown out with almost explosive violence. Now observe how smoothly and positively the circulation would occur in a system such as shown in Fig. 64, and therefore how much faster the evaporation could occur without any excessive priming action.

**74. Disengagement Surface.**—The Disengagement Surface or Disengagement Area refers to the surface of the water from which the steam escapes into the steam space above. It is important that this area should be large, especially in flue or fire-tube boilers where there is not a positively defined circulation. If too much steam escapes from a small area, it will keep the surface of the water in violent agitation and cause priming and may even cause the water gage to indicate a false water level.

**75. Steam Space.**—The amount of steam space in a boiler also affects the possibility of priming. If the steam space is too small the steam will be drawn off before it has time to deposit its moisture. With an ample steam space the moisture thrown up will have an opportunity to settle back upon the surface of the water before it enters the steam main. This explains the reason for placing domes on many fire-tube boilers. For instance, in a locomotive, where the formation of steam is very rapid, the main steam pipe is taken from the top of the dome in order to have the entrance of the pipe as far removed from the surface of the water as possible. When a dome is not provided, the moisture is separated from the steam by either a dry pipe or by a baffle plate which prevents the moisture from being carried into the steam line.

# CHAPTER VII

## PROPERTIES OF STEAM

**76. Atmospheric Pressure.**—The atmosphere which surrounds the earth exerts a pressure on all bodies on the earth's surface. Air has weight and, since it extends upward from the earth's surface a distance usually estimated at about 50 miles, the weight of this air presses on any object on the earth's surface.

At the level of the ocean (or "sea level," as it is called) the pressure of the atmosphere averages 14.7 lb. on each square inch of surface, although it varies according to the weather. Moist air is lighter than dry air; therefore, the atmospheric pressure will be less on a damp day than on a dry one.

In other parts of the country the atmospheric pressure is less than at sea level, because, being above sea level, the column of air which produces the pressure is not so high. The decrease in pressure is about 1/2 lb. for each 1000 ft. above sea level. This figure is usually sufficiently accurate up to 2 miles above sea level, but, since the air gradually becomes rarer as we go upward, the pressure decreases less rapidly at high altitudes. Since the actual atmospheric pressure depends upon weather conditions as well as upon altitude, the only reliable method of ascertaining the pressure at a particular time and place is to measure it with a barometer.

**77. Barometers.**—A barometer is a device for measuring the pressure of the atmosphere. The simplest form of barometer is made as follows: Take a glass tube about 3 ft. long having one end sealed, and completely fill it with mercury. Place the finger over the open end and invert the tube. Place the open end, still covered with the finger, in a cup of mercury and then remove the finger. The mercury in the tube will descend until it stands at a height $h$, Fig. 65, which indicates the atmospheric pressure. The atmosphere presses on the surface of the mercury in the cup, but there is *no* pressure on the surface of the mercury in the tube. Therefore, the mercury in the tube must stand at such a height that the pressure at the bottom of the column will balance the pressure of the atmosphere.

One cubic inch of mercury weighs .4908 lb., and, therefore, each inch of mercury in the tube above the level in the cup will represent an atmospheric pressure of .4908 lb. per square inch. At sea level we find a mercury barometer will usually stand at 30 in., indicating a pressure of


Fig. 65.

$$30 \times .4908 = 14.724 \text{ lb. per square inch.}$$

The commonly used figure 14.7, corresponds to 29.92 in. or an elevation of 69 ft. above sea level. Although 30 in. and 14.7 lb. do not exactly agree, they are both used as representing the pressure at sea level. Barometers are made in other ways than by the use of mercury, but they are usually graduated so as to read in "inches of mercury." If water were used instead of mercury, it would require a tube over 34 ft. long, since water weighs .036 lb. per cubic inch.

**78. Gage Pressures.**—The ordinary steam gage used on boilers indicates the difference between the steam pressure within the boiler and that of the atmosphere on the outside. The steam exerts a certain pressure outward against the walls of the boiler and the atmosphere exerts a certain pressure inward against the walls. Owing to the construction of the steam gage, it indicates the amount by which the steam pressure inside the boiler is greater than the atmospheric pressure on the outside. This is called *Gage Pressure.*

**79. Absolute Pressure.**—The true way to measure pressure is from an entire absence of pressure (or absolute zero pressure). The absolute pressure in a boiler is the sum of the pressure indicated by the gage and the pressure of the atmosphere as indicated by the barometer. In the absence of any barometer, we generally assume that 14.7 lb. per square inch is the atmospheric pressure and add this to the pressure indicated by the gage, unless we have some more definite idea as to the average barometric pressure in our locality. For example, suppose the steam gage on a boiler reads 120 lb. The absolute pressure in the boiler will be $120 + 14.7 = 134.7$ lb. per square inch, if we consider the atmospheric pressure as being 14.7 lb. per square inch. Suppose we knew that a barometer at this locality read 28.5 in., the absolute pressure would then be $120 + (.4908 \times 28.5) = 120 + 13.99 = 133.99$ lb. per square inch.

**80. Vacuum.**—A vacuum is a space from which all matter (including the air) is removed and, therefore, is indicated by a zero absolute pressure. If we have a cylinder of air at atmospheric pressure and then pump out part of the air so that the pressure is less than that of the surrounding atmosphere, we have in the cylinder a *partial vacuum*. If we were able to remove all of the air, we would then have a *total or absolute vacuum*. The chief use of vacuums in power-plant work is in condensers. By cooling and thus condensing the exhaust steam from an

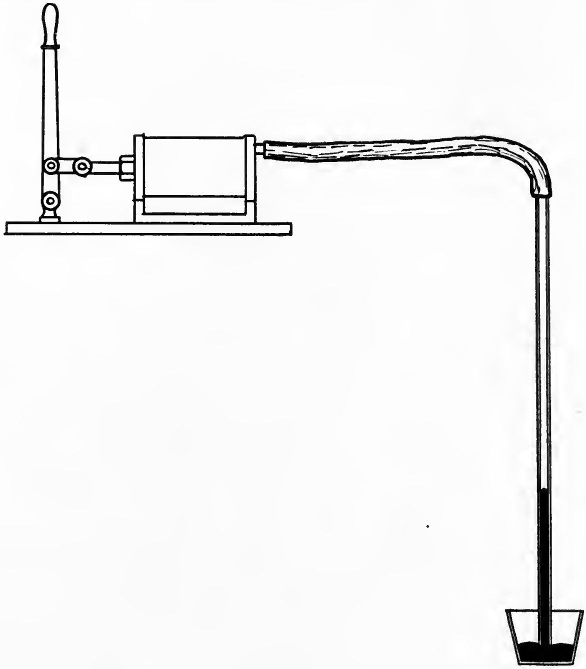


Fig. 66.

engine, the change in volume when the steam is turned to water is so great that a high vacuum is obtained in the exhaust pipe and the condenser.

Vacuums are usually measured by the reduction of the pressure below that of the surrounding atmosphere. If the top of the glass tube in Fig. 65 were opened to the atmosphere, the mercury would immediately drop to the level of that in the cup, because the pressure on the mercury in the tube would then be the same as that on the mercury in the cup. If now we were to connect the top of the tube with a suction pump, as in Fig. 66, and draw out the air, the difference in pressure would cause the mercury to rise in the tube. The more we pumped, the higher would the mercury rise, and the height of the mercury would indicate the difference in pressure between the atmosphere and the pump cylinder. As previously explained, this can be reduced to pounds per square inch by multiplying the inches of mercury by .4908. Vacuum gages do not always make use of the mercury column, but nevertheless are nearly always graduated to read in "inches of mercury below atmosphere." The absolute pressure corresponding to a certain vacuum can be obtained by finding the difference between the reading of the barometer and the reading of the vacuum gage. To illustrate this, suppose the vacuum gage on a condenser indicates 24 in. of vacuum on a day when the barometer reads 28.5 in. The difference between the atmospheric pressure and the pressure in the condenser is

$$28.5 - 24 = 4.5 \text{ in.}$$

$$4.5 \times .4908 = 2.21 \text{ lb. per sq. in.}$$

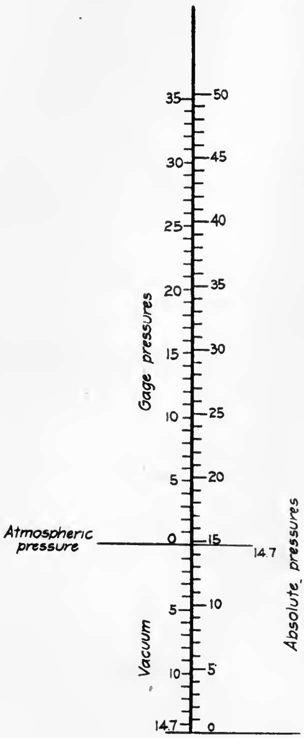


Fig. 67.

Because of the difference in atmospheric pressures at different altitudes, a vacuum that is readily obtained in some places is very difficult or impossible to obtain in other places. At sea level a vacuum of 28 in. is readily maintained in condensers because the atmospheric pressure is about 30 in., which would leave an absolute pressure of 2 in. of mercury or .98 lb. per square inch. On the other hand, this same vacuum is unattainable in some of the western cities because the altitude is such that even the barometer does not stand this high. If the barometer stands at only 26 in., a vacuum gage in order to have the same absolute pressure of 2 in. would record only 24 in. of vacuum. Remember that the barometer and vacuum gage read in opposite directions, the barometer indicating the absolute pressure of the atmosphere while the vacuum gage indicates the reduction in pressure below that of the atmosphere.

Fig. 67 shows the relation between absolute pressure, gage pressure, and vacuum, all expressed in pounds, with an atmospheric pressure of 14.7 lb. per square inch. If the atmospheric pressure were 14 lb. per square inch the gage pressure and vacuum scales would be lowered so that their zero reading would be opposite 14 lb. absolute.

**81. Evaporation.**—If we take an ordinary tea-kettle or pan containing water and place it over a fire we will observe the following changes: At first the water will merely rise in temperature, but after it has reached a temperature somewhere near 212° F. boiling begins and steam is given off. If we continue to apply heat after the boiling-point is reached we notice that the temperature remains stationary. If less heat is applied the water boils slowly and if more heat is added the water boils faster; but in either case the temperature remains constant until all the water is evaporated.

If the water is boiled in a closed vessel under a pressure above that of the atmosphere, a higher temperature than 212° F. is necessary to start boiling. On the other hand, if a pressure less than atmospheric is maintained in the vessel by means of a vacuum pump or otherwise, the water boils at a much lower temperature. Experiments show also that the amount of heat required to change the water to steam after the boiling temperature is reached is different for different pressures.

It is thus seen that for each pressure at which the steam is formed there is a definite corresponding temperature at which evaporation occurs. If the pressure is great the corresponding temperature is high and if the pressure is low the temperature is low. The temperature of steam formed at a certain pressure may be further increased without increasing its pressure if it is taken away from the presence of water and heated; but an attempt to increase the temperature of steam while it is in contact with water results only in boiling the water faster and forming more steam. If an attempt is made to lower the temperature of the steam, a portion of it will be condensed.

In order to make boiler tests or to study in any other way the operation of a boiler, it is necessary to know the exact amount of heat used in generating each pound of steam. In calculating the size of a steam line, it is desirable to know just how much space is occupied by 1 lb. of steam and how much a cubic foot of steam weighs. All such quantities are called "Properties of

Steam." These have been observed and recorded for our use by various scientists, and the results of their observations have been arranged in tables which we call, for short, *Steam Tables.* Numerous formulas have been devised that will give more or less accurately the different properties, but it is much easier and more accurate to use the tables. With this chapter is included a Steam Table for the use of the student in this course and in his future work. *The values given in the tables are for* 1 *lb. of water or steam.*

**82. Saturated Steam.**—It will be noticed that the table is headed. "Properties of Saturated Steam" and the question naturally arises, "What is meant by *saturated* steam?" By saturated steam we mean steam that is at the evaporation temperature corresponding to its pressure. As steam is formed in a boiler and rises from the surface of the water, it is saturated and will remain so as long as it is in contact with water. So long as the steam is in a boiler or in close communication with water, it cannot be other than saturated. Any attempt to heat the steam higher will fail, as it will merely transmit the heat to the water and cause further evaporation. To effect superheat, the steam must be removed from close communication with water. Steam is *superheated* by heating it, away from water, to a higher temperature than its boiling-point, without changing the pressure.

Saturated steam may be "dry" or "wet." Dry steam is as clear and transparent as air and is not visible to the eye. The steam which we see in the exhaust from an engine is wet steam and the visible part consists of particles of water, or condensed steam.

Do not get the idea that saturated steam necessarily means wet steam. Saturated steam may be perfectly dry. One may show this clearly by taking a small glass bottle, partially filling it with water, and placing it loosely corked on the stove. When the water boils, no mist is seen, such as we usually imagine to be the appearance of steam. The bottle will remain perfectly transparent just as if filled with air. The exhaust from an engine is visible only because of the water which it contains. This water is divided into fine particles and is suspended in the steam just as water is suspended in the air during a fog. When a boiler is blown off, or when a whistle is blown, it will be noticed that steam is not visible until it is about 3 or 4 in. from the end of the pipe, where some of it has been condensed by the colder air.

Whenever steam is mentioned *saturated* steam is meant. If the steam is superheated it is spoken of as *superheated steam.*

**83. Steam Tables.**—The steam tables should be studied very carefully, as any one working problems relating to steam will be using them constantly, and it requires considerable study to become proficient in their use.

All steam tables are made out for 1 lb. weight of steam and the quantities given in them, such as the Heat of the Liquid, Latent Heat of Evaporation, Specific Volume, etc., are the quantities of heat or volume of 1 *lb. weight of dry steam* (the steam formed from 1 lb. of water). To find these quantities for a given weight of steam, it is necessary to multiply the figures given in the steam table by the weight of the steam in pounds. The column giving the density or weight per cubic foot of steam is, of course, an exception to the statement that the tables give only values for 1 lb. of steam.

**84. Pressures.**—The properties of steam depend on the absolute pressure to which the steam is subjected. The pressure offers a certain resistance to the expansion of the water into steam, and it is the amount of this resistance that determines the temperature of evaporation and the other quantities. Consequently, the absolute pressure is the first item to be given in the tables.

For convenience, the corresponding gage pressures are given in the second column, assuming an atmospheric pressure of 14.7 lb. per square inch. In case the barometer shows an atmospheric pressure very different from this, it is best to add the barometer and gage pressures and thus get the absolute pressure, which should then be used for finding the properties of the steam. In using properties of steam at pressures below atmospheric, it is especially desirable to calculate the absolute pressure from barometer and vacuum gage readings rather than to use the vacuum reading in the gage pressure column of the table. An example will show readily what a difference this may make.

Suppose a vacuum gage on a condenser shows a vacuum of 27 in. and we want to find the temperature at which the steam is condensing. Without knowing the barometer reading we would say that

$$27 \times .4908 = 13.25+$$

and that at a vacuum of 13.25 lb. (−13.25 lb. gage), which corresponds to an absolute pressure of 1.45 lb. per sq. in., water boils or condenses at a little less than 115.9° F., say about 115°. This assumes that the barometer reading is 29.92 in.

Now, suppose that we first look at a barometer and find that it stands at only 28 in. Our condenser has more of a vacuum than we thought it had. The absolute pressure in the condenser is

$$(28-27)\times .4908=.4908 \text{ lb. per sq. in.}$$

or not quite .5 lb. per sq. in. absolute, and we find that the temperature of the steam and water in the condenser is a little less than 79° F., instead of being 115°.

**85. Temperature of Evaporation.**—The third column in the table gives the temperatures at which water evaporates when under the pressures given in the first and second columns. These temperatures are also the temperatures of saturated steam at the given pressures and are likewise the temperatures at which steam under the given pressures will condense.

When water is heated in an open vessel under atmospheric pressure (14.7 lb. absolute), it boils at 212° F. If the pressure is reduced, the resistance to the formation of steam is diminished and evaporation takes place at a lower temperature. For example, in a vacuum of 28 in. (.943 lb. absolute pressure) water will boil at 100° F. and if the absolute pressure is reduced to .089 lb., water will evaporate at 32° F. On the other hand, if water is under a pressure greater than that of the atmosphere, it will require a temperature higher than 212° F. to cause it to boil. This is the condition which usually exists in the common steam boiler. If the absolute pressure in a boiler is 144 lb. (129.3 lb. gage), the temperature of both the water and the steam in the boiler is 355° F. A thermometer placed in a boiler would serve as a pressure gage but perhaps would not be as convenient for the fireman.

Formulas have been worked out by which we can get the boiling temperature for a certain pressure, or *vice versa.* One of the simplest of these is:

$$t=\frac{2900}{6.17-\log P}-368.0$$

and in which $t$ is the temperature of the steam in degrees Fahrenheit, and $\log P$ is the logarithm of the absolute pressure.

**Example:** What is the temperature of steam having an absolute pressure of 100 lb. per sq. in.?

The logarithm of 100 is 2.

$$t=\frac{2900}{6.17-2}-368=327.4°$$

which is within 0.2 degrees of the temperature given in the steam table.

However, it would be necessary to consult a table of logarithms in order to make use of this formula, and, since steam tables are just as easily consulted as logarithm tables, this formula is of little practical use.

The absolute pressure in pounds per square inch may be found approximately from the following formula:

$$P=\frac{\left(\frac{t+100}{100}\right)^6}{62.66}$$

in which $t$ is the temperature of the steam in degrees Fahrenheit.

**Example:** What will be the pressure of steam having a temperature of 300°?

$$P=\frac{\left(\frac{300+100}{100}\right)^6}{62.66}=\frac{4^6}{62.66}=\frac{4096}{62.66}=65.4 \text{ lb.}$$

while the steam table gives 67.2 lb.

This is not a very accurate way to find the pressure but the method of calculating it accurately is very complicated. This formula gives results which do not vary more than 2 1/2 lb. from the values given in the steam table, and at pressures near that of the atmosphere, the results given by the formula do not vary more than 0.1 lb. from those given in the table.

**86. Heat of the Liquid.**—In the formation of steam, the water must first be raised to the boiling temperature. The heat it then contains, measured from 32° F., is called the *Heat of the Liquid.* In other words, the heat of the liquid is the amount of heat which is required to raise the temperature of 1 lb. of the water from 32° F. to the boiling-point. Approximately, the value of the heat of the liquid per pound is the difference between the boiling temperature and 32° F., since the specific heat of water is about 1. Written as a formula:

$$h=t-32$$

in which $h$ is the heat of the liquid, and $t$ is the boiling temperature of the water. For rough calculations this is close enough, but for accurate work, steam tables should be used since the specific heat of water is not exactly 1 at all temperatures, but varies slightly.

At atmospheric pressure the temperature of evaporation is

212° F. Obtaining the heat of the liquid by difference in temperatures, $h=212-32=180$ B.t.u. If we refer to steam tables, we find the exact value to be 180.8 B.t.u. or an increase of 0.45 per cent over the first number. At 165 lb. absolute (150.3 lb. gage), the evaporation temperature is 365.9° F. This would give by difference in temperatures a value of $365.9-32=333.9$ B.t.u. for the heat of the liquid, while the actual value is 332.4 B.t.u., an increase of over 1 per cent. Whenever possible the values from a steam table should be used as they are the results of accurate measurements.

**87. Latent Heat.**—After water is raised to the boiling-point, heat must be added to change it into steam. This heat, called *latent heat,* varies in amount, being 1091.7 B.t.u. for each pound of steam formed at 32° F. and 965.8 B.t.u. for each pound formed at 212° F. The whole amount of the latent heat will be absorbed only when the whole pound of water has been evaporated. If the water is being evaporated at 212° F. and after reaching the evaporation temperature only one-half of 965.8 or 482.9 B.t.u. are applied, then only one-half of a pound of water will be evaporated, and conversely, if we extract 482.9 B.t.u. from a quantity of steam at 212° F., only one-half of a pound will be condensed.

The latent heat of steam, unlike the other properties so far studied, decreases as the pressure is increased. At 32° F. the latent heat is 1091.7 B.t.u., the same as the total heat at this temperature, since there would be no heat of the liquid above 32° F. if the water boiled at 32° F. It seems almost incredible that steam can be formed at 32°, the freezing temperature of water, but such is the case. It can be done, however, only in a very high vacuum (.089 lb. per sq. in. absolute pressure) when the resistance to the expansion is practically all removed. Under such conditions it is possible to have steam rising directly from a block of ice.

The decrease of the latent heat, as the pressure (and consequently the temperature) increases, amounts to .695 B.t.u. per degree and, therefore, the latent heat per pound can be expressed by the formula:

$$L=1091.7-.695\ (t-32)$$

where $t$ is the temperature of the steam, and $L$ is the corresponding latent heat. This formula gives only approximately correct results. It is much better to find the value of the latent heat in a steam table if one is at hand.

It must be firmly impressed on the mind that the addition of the latent heat of evaporation and the consequent transformation of water into steam has no effect on temperature and, consequently, the steam when formed, is at the same temperature as the boiling water.

**88. Total Heat of Steam.**—Steam, as we know, is the vapor formed from water by the addition of heat. The water must first be heated to a certain temperature, depending on the pressure which is exerted on it, and, after reaching this point, more heat must be added to effect the change of state from water into steam. The heat required for the generation of saturated steam is thus divided into two distinct parts: First, the *Heat of the Liquid,* which is the heat that the water must have above a temperature of 32° F. in order to bring it to the boiling-point; and second, the *Latent Heat,* which is the heat required to effect the change from water to steam without change of temperature. The sum of these two quantities is the *Total Heat* of 1 lb. of dry steam, and is given in the fourth column of the table.

The total heat of steam is calculated from 32° as a basis, and includes all of the heat which must be added to a pound of water at 32° in order to bring it to the boiling temperature and then evaporate it into steam.

A study of the steam tables will reveal the fact that the total heat varies but little for even a large variation of pressure. There is a difference of only 44.6 B.t.u. between the total heat of steam at atmospheric pressure and at a pressure of 150 lb. absolute.

The total heat can be expressed in terms of the temperature by a very simple formula. A study of the table reveals the fact that the total heat increases approximately .305 B.t.u. for each degree rise in the temperature of evaporation. At 32° F. the total heat is 1091.7 B.t.u. The total heat ($H$) can, therefore, be expressed by the formula:

$$H = 1091.7 + .305\ (t - 32)$$

where $t$ is any temperature of evaporation and $H$ is the corresponding total heat of steam. The term $(t - 32)$ gives the temperature of the steam above 32° F. The total heat of steam is the sum of the two items *heat of the liquid* and *latent heat,* and as we often find use for one or both of these two items separately, columns giving each of them are found in the tables.

**89. Density of Steam.**—There are two remaining columns of the tables. The information contained in these is of especial use in calculations concerning the flow of steam or the sizes of piping. The density of steam (or its weight per cubic foot) is, of course, directly dependent on the pressure and temperature the same as any other gas. An approximate formula for the density of steam is:

$$D = \frac{1.775\,P}{T}$$

where $P$ is the absolute pressure

$T$ is the absolute temperature ($= t + 460$)

and $D$ is the corresponding density in pounds per cubic foot.

**90. Specific Volume.**—The specific volume is the space in cubic feet occupied by 1 lb. weight of steam. This is the reciprocal of the density, that is, it is 1 divided by the density. Some steam tables do not give both the density and specific volume, since they are so closely related. If the specific volume of steam at atmospheric pressure is 26.39 cu. ft. per pound, the density is $1 \div 26.39 = .0379$ lb. per cubic foot. Likewise, reversing the same example, if the density is given as .0379, the specific volume is $1 \div .0379 = 26.39$ cu. ft. per pound.

**91. Expansion of Water into Steam.**—Some steam tables give a column showing how many times water expands in changing into steam. This is not of much practical use, and if wanted, can be easily obtained from the specific volume column. One cubic foot of water weighs 62.4 lb., or 1 lb. occupies $\frac{1}{62.4}$ cu. ft. Then the specific volume of steam multiplied by 62.4 will give the number of expansions that take place when water is turned to steam.

**Example:** How many cubic feet of steam at atmospheric pressure are formed from a cubic foot of water?

1 lb. of steam = 26.39 cu. ft. (from steam table)

1 cu. ft. of water = 62.4 lb.

1 cu. ft. of water will make $62.4 \times 26.39 = 1647$ cu. ft. of steam. Thus, water evaporated under atmospheric pressure expands 1647 times in turning into steam. The greater the pressure under which the steam is formed, the less will be the number of expansions which it undergoes.

**92. Allowance for Feed Water Temperatures.**—All the quantities of heat given in the steam table are calculated from water at 32° F. and generally it is necessary, in practical problems, to make allowance for the fact that the feed water is at some other temperature. Thus, if we wish to know how much heat must be supplied to 1 lb. of feed water having a temperature of 170° in order to turn it into steam having a pressure of 150 lb. absolute pressure, we must remember that the water already contains

$$170-32=138 \text{ B.t.u.}$$

Now, since the total heat of steam at 150 lb. pressure absolute is 1191.2 B.t.u. there will have to be supplied to the water in the boiler only

$$1191.2-138=1053.2 \text{ B.t.u.}$$

in order to turn it into steam. Since the heat of the liquid at 150 lb. pressure is 329.6 B.t.u., only 329.6 − 138 = 191.6 B.t.u. need be supplied to the water to bring it to the boiling temperature, but the entire latent heat, 861.6 B.t.u., has to be supplied in order to evaporate it into steam.

Some people obtain the part of the heat of the liquid that must be supplied in the boiler by subtracting the feed-water temperature from the temperature of evaporation. This is not as accurate as the method just outlined, because the specific heat of water is not as near 1 at high temperatures as at low temperatures.

**93. Interpolation from Tables.**—*Interpolation* refers to the method used to find values between those given in the tables, as for example, finding the latent heat at 44½ lb. absolute pressure. The table gives $L$ for 44 lb. and for 45 lb. but not for 44½ lb., and we *interpolate* to get the value for 44½ lb. which would be halfway between 922.8 and 921.8, or just 922.3. Suppose we wish to find the heat of the liquid at 120 lb. gage pressure. The table gives 119.3 lb. and 120.3 lb., the corresponding values of $h$ being 320.5 and 321.1. For 1 lb. change in pressure, $h$ changes 321.1 − 320.5 = .6. Now 120 is .7 lb. more than 119.3, or .3 lb. less than 120.3. We can, therefore, add .7 of .6 to 320.5, or subtract .3 of .6 from 321.1. Either way we get 320.9 as the value of $h$ at 120 lb. gage pressure.

In interpolating, remember that $L$ and $v$ *decrease* as the pressure increases and that all other items in the table increase. For most calculations it is sufficiently accurate to take the nearest value given in the table without bothering to interpolate.

PROPERTIES OF SATURATED STEAM

| Absolute pressure in lb. per sq. in. | Gage pressure in lb. per sq. in. | Temperature, Fahrenheit | Total heat above 32° | | Latent heat, H-h. | Weight of 1 cu. ft. of steam in lb. | Volume of 1 lb. of steam in cu. ft. $=\frac{1}{w}$ |
|---|---|---|---|---|---|---|---|
| | | | In the steam | In the water | | | |
| p | | t | H | h | L | w | v |
| 0.089 | −14.611 | 32.0 | 1091.7 | 0.0 | 1091.7 | .00030 | 3333.3 |
| 0.5 | −14.2 | 79.9 | 1106.3 | 47.9 | 1058.4 | .00157 | 636.9 |
| 1 | −13.7 | 102.0 | 1113.1 | 70.0 | 1043.1 | .0030 | 333.3 |
| 1.5 | −13.2 | 115.9 | 1117.3 | 84.0 | 1033.3 | .0044 | 227.3 |
| 2 | −12.7 | 126.3 | 1120.5 | 94.4 | 1026.1 | .0058 | 172.4 |
| 2.5 | −12.2 | 134.6 | 1123.0 | 102.8 | 1020.2 | .0071 | 140.8 |
| 3 | −11.7 | 141.6 | 1125.1 | 109.8 | 1015.3 | .0085 | 117.6 |
| 3.5 | −11.2 | 147.7 | 1127.0 | 116.0 | 1011.0 | .0098 | 102.0 |
| 4 | −10.7 | 153.1 | 1128.6 | 121.5 | 1007.1 | .0111 | 90.09 |
| 4.5 | −10.2 | 157.9 | 1130.1 | 126.3 | 1003.8 | .0124 | 80.65 |
| 5 | − 9.7 | 162.3 | 1131.4 | 130.7 | 1000.7 | .0137 | 72.99 |
| 5.5 | − 9.2 | 166.4 | 1132.7 | 134.8 | 997.9 | .0150 | 66.67 |
| 6 | − 8.7 | 170.1 | 1133.8 | 138.6 | 995.2 | .0163 | 61.35 |
| 6.5 | − 8.2 | 173.6 | 1134.9 | 142.1 | 992.8 | .0176 | 56.82 |
| 7 | − 7.7 | 176.9 | 1135.9 | 145.4 | 990.5 | .0189 | 52.91 |
| 7.5 | − 7.2 | 180.0 | 1136.8 | 148.5 | 988.3 | .0202 | 49.50 |
| 8 | − 6.7 | 182.9 | 1137.7 | 151.5 | 986.2 | .0214 | 46.73 |
| 8.5 | − 6.2 | 185.7 | 1138.6 | 154.3 | 984.3 | .0227 | 44.05 |
| 9 | − 5.7 | 188.3 | 1139.4 | 156.9 | 982.5 | .0239 | 41.84 |
| 9.5 | − 5.2 | 190.8 | 1140.1 | 159.4 | 980.7 | .0252 | 39.68 |
| 10 | − 4.7 | 193.2 | 1140.9 | 161.8 | 979.1 | .0264 | 37.88 |
| 10.5 | − 4.2 | 195.6 | 1141.6 | 164.2 | 977.4 | .0276 | 36.23 |
| 11 | − 3.7 | 197.8 | 1142.3 | 166.5 | 975.8 | .0288 | 34.72 |
| 11.5 | − 3.2 | 199.9 | 1142.9 | 168.6 | 974.3 | .0301 | 33.22 |
| 12 | − 2.7 | 202.0 | 1143.6 | 170.7 | 972.9 | .0313 | 31.95 |
| 12.5 | − 2.2 | 204.0 | 1144.2 | 172.7 | 971.5 | .0326 | 30.67 |
| 13 | − 1.7 | 205.9 | 1144.7 | 174.7 | 970.0 | .0338 | 20.59 |
| 13.5 | − 1.2 | 207.8 | 1145.3 | 176.6 | 968.7 | .0350 | 28.57 |
| 14 | − 0.7 | 209.6 | 1145.9 | 178.4 | 967.5 | .0362 | 27.62 |
| 14.7 | 0.0 | 212.0 | 1146.6 | 180.8 | 965.8 | .0379 | 26.39 |
| 15 | + 0.3 | 213.0 | 1146.9 | 181.8 | 965.1 | .0386 | 25.91 |
| 16 | 1.3 | 216.3 | 1147.9 | 185.2 | 962.7 | .0410 | 24.39 |
| 17 | 2.3 | 219.4 | 1148.9 | 188.3 | 960.6 | .0434 | 23.04 |
| 18 | 3.3 | 222.4 | 1149.8 | 191.3 | 958.5 | .0458 | 21.83 |
| 19 | 4.3 | 225.2 | 1150.6 | 194.1 | 956.5 | .0482 | 20.75 |
| 20 | 5.3 | 227.9 | 1151.4 | 196.8 | 954.6 | .0506 | 19.76 |
| 21 | 6.3 | 230.5 | 1152.2 | 199.5 | 952.7 | .0530 | 18.87 |
| 22 | 7.3 | 233.1 | 1153.0 | 202.1 | 950.9 | .0553 | 18.08 |
| 23 | 8.3 | 235.5 | 1153.8 | 204.5 | 949.3 | .0577 | 17.33 |
| 24 | 9.3 | 237.8 | 1154.5 | 206.8 | 947.7 | .0601 | 16.64 |
| 25 | 10.3 | 240.0 | 1155.1 | 209.1 | 946.0 | .0624 | 16.03 |
| 26 | 11.3 | 242.2 | 1155.8 | 211.3 | 944.5 | .0648 | 15.43 |
| 27 | 12.3 | 244.3 | 1156.5 | 213.4 | 943.1 | .0671 | 14.90 |
| 28 | 13.3 | 246.3 | 1157.1 | 215.5 | 941.6 | .0695 | 14.39 |
| 29 | 14.3 | 248.3 | 1157.7 | 217.5 | 940.2 | .0718 | 13.93 |

PROPERTIES OF SATURATED STEAM—*Continued*

| Absolute pressure in lb. per sq. in. | Gage pressure in lb. per sq. in. | Tempera-ture, Fahren-heit | Total heat above 32° F. In the steam | Total heat above 32° F. In the water | Latent Heat H-h. | Weight of 1 cu. ft. of steam in lb. | Volume of 1 lb. of steam in cu. ft. $=\frac{1}{w}$ |
|---|---|---|---|---|---|---|---|
| p | | t | H | h | L | w | v |
| 30 | 15.3 | 250.3 | 1158.3 | 219.5 | 938.8 | .0741 | 13.50 |
| 31 | 16.3 | 252.2 | 1158.9 | 221.4 | 937.5 | .0764 | 13.09 |
| 32 | 17.3 | 254.0 | 1159.4 | 223.2 | 936.2 | .0787 | 12.71 |
| 33 | 18.3 | 255.8 | 1160.0 | 225.0 | 935.0 | .0810 | 12.35 |
| 34 | 19.3 | 257.5 | 1160.5 | 226.8 | 933.7 | .0833 | 12.00 |
| 35 | 20.3 | 259.2 | 1161.0 | 228.5 | 932.5 | .0856 | 11.68 |
| 36 | 21.3 | 260.9 | 1161.5 | 230.2 | 931.3 | .0879 | 11.38 |
| 37 | 22.3 | 262.5 | 1162.0 | 231.9 | 930.1 | .0902 | 11.09 |
| 38 | 23.3 | 264.1 | 1162.5 | 233.5 | 929.0 | .0925 | 10.81 |
| 39 | 24.3 | 265.6 | 1162.9 | 235.0 | 927.9 | .0948 | 10.55 |
| 40 | 25.3 | 267.1 | 1163.4 | 236.5 | 926.9 | .0971 | 10.30 |
| 41 | 26.3 | 268.6 | 1163.9 | 238.0 | 925.9 | .0993 | 10.07 |
| 42 | 27.3 | 270.1 | 1164.3 | 239.5 | 924.8 | .1016 | 9.843 |
| 43 | 28.3 | 271.5 | 1164.7 | 241.0 | 923.7 | .1039 | 9.625 |
| 44 | 29.3 | 272.9 | 1165.2 | 242.4 | 922.8 | .1062 | 9.416 |
| 45 | 30.3 | 274.3 | 1165.6 | 243.8 | 921.8 | .1085 | 9.217 |
| 46 | 31.3 | 275.7 | 1166.0 | 245.2 | 920.8 | .1108 | 9.025 |
| 47 | 32.3 | 277.0 | 1166.4 | 246.6 | 919.8 | .1130 | 8.850 |
| 48 | 33.3 | 278.3 | 1166.8 | 247.9 | 918.9 | .1152 | 8.681 |
| 49 | 34.3 | 279.6 | 1167.2 | 249.2 | 918.0 | .1175 | 8.511 |
| 50 | 35.3 | 280.9 | 1167.6 | 250.5 | 917.1 | .1197 | 8.354 |
| 51 | 36.3 | 282.1 | 1168.0 | 251.8 | 916.2 | .1220 | 8.197 |
| 52 | 37.3 | 283.3 | 1168.3 | 253.0 | 915.3 | .1242 | 8.052 |
| 53 | 38.3 | 284.5 | 1168.7 | 254.2 | 914.5 | .1264 | 7.911 |
| 54 | 39.3 | 285.7 | 1169.1 | 255.4 | 913.7 | .1287 | 7.770 |
| 55 | 40.3 | 286.9 | 1169.4 | 256.6 | 912.8 | .1309 | 7.639 |
| 56 | 41.3 | 288.1 | 1169.8 | 257.8 | 912.0 | .1332 | 7.508 |
| 57 | 42.3 | 289.2 | 1170.1 | 259.0 | 911.1 | .1354 | 7.386 |
| 58 | 43.3 | 290.3 | 1170.5 | 260.1 | 910.4 | .1376 | 7.267 |
| 59 | 44.3 | 291.4 | 1170.8 | 261.2 | 909.6 | .1398 | 7.153 |
| 60 | 45.3 | 292.5 | 1171.2 | 262.3 | 908.9 | .1420 | 7.042 |
| 61 | 46.3 | 293.6 | 1171.5 | 263.4 | 908.1 | .1443 | 6.930 |
| 62 | 47.3 | 294.7 | 1171.8 | 264.5 | 907.3 | .1465 | 6.826 |
| 63 | 48.3 | 295.7 | 1172.1 | 265.6 | 906.5 | .1487 | 6.725 |
| 64 | 49.3 | 296.8 | 1172.5 | 266.7 | 905.8 | .1509 | 6.627 |
| 65 | 50.3 | 297.8 | 1172.8 | 267.7 | 905.1 | .1531 | 6.532 |
| 66 | 51.3 | 298.8 | 1173.1 | 268.7 | 904.4 | .1553 | 6.439 |
| 67 | 52.3 | 299.8 | 1173.4 | 269.7 | 903.7 | .1575 | 6.349 |
| 68 | 53.3 | 300.8 | 1173.7 | 270.7 | 903.0 | .1597 | 6.262 |
| 69 | 54.3 | 301.8 | 1174.0 | 271.7 | 902.3 | .1619 | 6.177 |
| 70 | 55.3 | 302.7 | 1174.3 | 272.7 | 901.6 | .1641 | 6.094 |
| 71 | 56.3 | 303.7 | 1174.6 | 273.7 | 900.9 | .1663 | 6.013 |
| 72 | 57.3 | 304.6 | 1174.8 | 274.7 | 900.1 | .1685 | 5.935 |
| 73 | 58.3 | 305.6 | 1175.1 | 275.7 | 899.4 | .1707 | 5.858 |
| 74 | 59.3 | 306.5 | 1175.4 | 276.6 | 898.8 | .1729 | 5.784 |

PROPERTIES OF SATURATED STEAM—*Continued*

| Absolute pressure in lb. per sq. in. | Gage pressure in lb. per sq. in. | Temperature, Fahrenheit. | Total heat above 32° F. In the steam | Total heat above 32° F. In the water | Latent heat, H-h. | Weight of 1 cu. ft. of steam in lb. | Volume of 1 lb. of steam in cu. ft. $=\frac{1}{w}$ |
|---|---|---|---|---|---|---|---|
| p | | t | H | h | L | w | v |
| 75 | 60.3 | 307.4 | 1175.7 | 277.5 | 898.2 | .1751 | 5.711 |
| 76 | 61.3 | 308.3 | 1176.0 | 278.4 | 897.6 | .1773 | 5.640 |
| 77 | 62.3 | 309.2 | 1176.2 | 279.3 | 896.9 | .1795 | 5.571 |
| 78 | 63.3 | 310.1 | 1176.5 | 280.2 | 896.3 | .1817 | 5.504 |
| 79 | 64.3 | 311.0 | 1176.8 | 281.1 | 895.7 | .1839 | 5.438 |
| 80 | 65.3 | 311.8 | 1177.0 | 282.0 | 895.0 | .1860 | 5.376 |
| 81 | 66.3 | 312.7 | 1177.3 | 282.9 | 894.4 | .1882 | 5.313 |
| 82 | 67.3 | 313.5 | 1177.6 | 283.7 | 893.9 | .1904 | 5.252 |
| 83 | 68.3 | 314.4 | 1177.8 | 284.6 | 893.2 | .1926 | 5.192 |
| 84 | 69.3 | 315.2 | 1178.1 | 285.5 | 892.6 | .1948 | 5.133 |
| 85 | 70.3 | 316.0 | 1178.3 | 286.3 | 892.0 | .1970 | 5.076 |
| 86 | 71.3 | 316.8 | 1178.6 | 287.1 | 891.5 | .1991 | 5.023 |
| 87 | 72.3 | 317.7 | 1178.8 | 288.0 | 890.8 | .2013 | 4.968 |
| 88 | 73.3 | 318.5 | 1179.1 | 288.8 | 890.3 | .2035 | 4.914 |
| 89 | 74.3 | 319.3 | 1179.3 | 289.6 | 889.7 | .2056 | 4.864 |
| 90 | 75.3 | 320.1 | 1179.6 | 290.4 | 889.2 | .2078 | 4.812 |
| 91 | 76.3 | 320.8 | 1179.8 | 291.2 | 888.6 | .2100 | 4.762 |
| 92 | 77.3 | 321.6 | 1180.0 | 292.0 | 888.0 | .2122 | 4.713 |
| 93 | 78.3 | 322.4 | 1180.3 | 292.8 | 887.5 | .2143 | 4.666 |
| 94 | 79.3 | 323.1 | 1180.5 | 293.6 | 886.9 | .2165 | 4.619 |
| 95 | 80.3 | 323.9 | 1180.7 | 294.4 | 886.3 | .2186 | 4.575 |
| 96 | 81.3 | 324.6 | 1180.9 | 295.1 | 885.8 | .2208 | 4.529 |
| 97 | 82.3 | 325.4 | 1181.2 | 295.9 | 885.3 | .2229 | 4.486 |
| 98 | 83.3 | 326.1 | 1181.4 | 296.6 | 884.8 | .2251 | 4.442 |
| 99 | 84.3 | 326.9 | 1181.6 | 297.4 | 884.2 | .2273 | 4.399 |
| 100 | 85.3 | 327.6 | 1181.9 | 298.1 | 883.8 | .2294 | 4.359 |
| 101 | 86.3 | 328.3 | 1182.1 | 298.8 | 883.3 | .2316 | 4.318 |
| 102 | 87.3 | 329.0 | 1182.3 | 299.6 | 882.7 | .2337 | 4.279 |
| 103 | 88.3 | 329.7 | 1182.5 | 300.3 | 882.2 | .2359 | 4.239 |
| 104 | 89.3 | 330.4 | 1182.7 | 301.0 | 881.7 | .2380 | 4.202 |
| 105 | 90.3 | 331.1 | 1182.9 | 301.7 | 881.2 | .2402 | 4.163 |
| 106 | 91.3 | 331.8 | 1183.1 | 302.4 | 880.7 | .2423 | 4.127 |
| 107 | 92.3 | 332.5 | 1183.4 | 303.1 | 880.3 | .2445 | 4.909 |
| 108 | 93.3 | 333.2 | 1183.6 | 303.8 | 879.8 | .2466 | 4.055 |
| 109 | 94.3 | 333.9 | 1183.8 | 304.5 | 879.3 | .2488 | 4.019 |
| 110 | 95.3 | 334.5 | 1184.0 | 305.2 | 878.8 | .2509 | 3.986 |
| 111 | 96.3 | 335.2 | 1184.2 | 305.9 | 878.3 | .2530 | 3.933 |
| 112 | 97.3 | 335.9 | 1184.4 | 306.6 | 877.8 | .2552 | 3.918 |
| 113 | 98.3 | 336.5 | 1184.6 | 307.3 | 877.3 | .2573 | 3.887 |
| 114 | 99.3 | 337.2 | 1184.8 | 308.0 | 876.8 | .2595 | 3.854 |
| 115 | 100.3 | 337.8 | 1185.0 | 308.6 | 876.4 | .2616 | 3.823 |
| 116 | 101.3 | 338.5 | 1185.2 | 309.3 | 875.9 | .2637 | 3.792 |
| 117 | 102.3 | 339.1 | 1185.4 | 309.9 | 875.5 | .2659 | 3.761 |
| 118 | 103.3 | 339.8 | 1185.6 | 310.6 | 875.0 | .2680 | 3.731 |
| 119 | 104.3 | 340.4 | 1185.8 | 311.2 | 874.6 | .2702 | 3.701 |

PROPERTIES OF SATURATED STEAM—*Continued*

| Absolute pressure in lb. per sq. in. | Gage pressure in lb. per sq. in. | Temperature, Fahrenheit | Total heat above 32° F. In the steam | Total heat above 32° F. In the water | Latent heat, H-h. | Weight of 1 cu. ft. of steam in lb. | Volume of 1 lb. steam in cu. ft. $= \frac{1}{w}$ |
|---|---|---|---|---|---|---|---|
| p | | t | H | h | L | w | v |
| 120 | 105.3 | 341.0 | 1185.9 | 311.9 | 874.0 | .2723 | 3.672 |
| 121 | 106.3 | 341.7 | 1186.2 | 312.6 | 873.6 | .2744 | 3.644 |
| 122 | 107.3 | 342.3 | 1186.3 | 313.2 | 873.1 | .2765 | 3.617 |
| 123 | 108.3 | 342.9 | 1186.5 | 313.8 | 872.7 | .2787 | 3.588 |
| 124 | 109.3 | 343.5 | 1186.7 | 314.4 | 872.3 | .2808 | 3.561 |
| 125 | 110.3 | 344.1 | 1186.9 | 315.0 | 871.9 | .2829 | 3.535 |
| 126 | 111.3 | 344.7 | 1187.1 | 315.6 | 871.5 | .2850 | 3.509 |
| 127 | 112.3 | 345.3 | 1187.3 | 316.3 | 871.0 | .2872 | 3.482 |
| 128 | 113.3 | 345.9 | 1187.4 | 316.9 | 870.5 | .2893 | 3.457 |
| 129 | 114.3 | 346.5 | 1187.6 | 317.5 | 870.1 | .2914 | 3.432 |
| 130 | 115.3 | 347.1 | 1187.8 | 318.1 | 869.7 | .2935 | 3.407 |
| 131 | 116.3 | 347.7 | 1188.0 | 318.7 | 869.3 | .2957 | 3.382 |
| 132 | 117.3 | 348.3 | 1188.2 | 319.3 | 868.9 | .2978 | 3.358 |
| 133 | 118.3 | 348.8 | 1188.3 | 319.9 | 868.4 | .2999 | 3.334 |
| 134 | 119.3 | 349.4 | 1188.5 | 320.5 | 868.0 | .3020 | 3.311 |
| 135 | 120.3 | 350.0 | 1188.7 | 321.1 | 867.6 | .3042 | 3.287 |
| 136 | 121.3 | 350.6 | 1188.9 | 321.7 | 867.2 | .3063 | 3.265 |
| 137 | 122.3 | 351.1 | 1189.0 | 322.3 | 866.7 | .3084 | 3.243 |
| 138 | 123.3 | 351.7 | 1189.2 | 322.9 | 866.3 | .3105 | 3.221 |
| 139 | 124.3 | 352.3 | 1189.4 | 323.5 | 865.9 | .3126 | 3.199 |
| 140 | 125.3 | 352.8 | 1189.5 | 324.0 | 865.5 | .3147 | 3.178 |
| 141 | 126.3 | 353.4 | 1189.7 | 324.6 | 865.1 | .3169 | 3.156 |
| 142 | 127.3 | 353.9 | 1189.9 | 325.1 | 864.8 | .3190 | 3.135 |
| 143 | 128.3 | 354.5 | 1190.1 | 325.7 | 864.4 | .3211 | 3.114 |
| 144 | 129.3 | 355.0 | 1190.2 | 326.3 | 863.9 | .3232 | 3.094 |
| 145 | 130.3 | 355.6 | 1190.4 | 326.9 | 863.5 | .3253 | 3.074 |
| 146 | 131.3 | 356.1 | 1190.6 | 327.4 | 863.2 | .3274 | 3.054 |
| 147 | 132.3 | 356.7 | 1190.7 | 328.0 | 862.7 | .3295 | 3.035 |
| 148 | 133.3 | 357.2 | 1190.9 | 328.5 | 862.4 | .3316 | 3.016 |
| 149 | 134.3 | 357.7 | 1191.0 | 329.0 | 862.0 | .3337 | 2.997 |
| 150 | 135.3 | 358.2 | 1191.2 | 329.6 | 861.6 | .3358 | 2.978 |
| 151 | 136.3 | 358.8 | 1191.4 | 330.2 | 861.2 | .3379 | 2.959 |
| 152 | 137.3 | 359.3 | 1191.5 | 330.7 | 860.8 | .3400 | 2.941 |
| 153 | 138.3 | 359.8 | 1191.7 | 331.2 | 860.5 | .3421 | 2.923 |
| 154 | 139.3 | 360.3 | 1191.8 | 331.7 | 860.1 | .3442 | 2.905 |
| 155 | 140.3 | 360.8 | 1192.0 | 332.2 | 859.8 | .3463 | 2.888 |
| 156 | 141.3 | 361.4 | 1192.2 | 332.8 | 859.4 | .3484 | 2.870 |
| 157 | 142.3 | 361.9 | 1192.3 | 333.3 | 859.0 | .3504 | 2.854 |
| 158 | 143.3 | 362.4 | 1192.5 | 333.9 | 858.6 | .3525 | 2.837 |
| 159 | 144.3 | 362.9 | 1192.6 | 334.4 | 858.2 | .3546 | 2.820 |
| 160 | 145.3 | 363.4 | 1192.8 | 334.9 | 857.9 | .3567 | 2.803 |
| 161 | 146.3 | 363.9 | 1192.9 | 335.4 | 857.5 | .3588 | 2.787 |
| 162 | 147.3 | 364.4 | 1193.1 | 335.9 | 857.2 | .3609 | 2.771 |
| 163 | 148.3 | 364.9 | 1193.2 | 336.4 | 856.8 | .3630 | 2.755 |
| 164 | 149.3 | 365.4 | 1193.4 | 336.9 | 856.5 | .3651 | 2.739 |
| 165 | 150.3 | 365.9 | 1193.5 | 337.4 | 856.1 | .3672 | 2.723 |
| 166 | 151.3 | 366.3 | 1193.7 | 337.9 | 855.8 | .3693 | 2.708 |
| 167 | 152.3 | 366.8 | 1193.8 | 338.4 | 855.4 | .3714 | 2.693 |

PROPERTIES OF SATURATED STEAM—*Continued*

| Absolute pressure in lb. per sq. in. | Gage pressure in lb. per sq. in. | Temperature, Fahrenheit | Total heat above 32° F. | | Latent heat H-h. | Weight of 1 cu. ft. of steam in lb. | Volume of 1 lb. steam in cu. ft. $=\frac{1}{w}$ |
|---|---|---|---|---|---|---|---|
| | | | In the steam | In the water | | | |
| p | | t | H | h | L | w | v |
| 168 | 153.3 | 367.3 | 1194.0 | 338.9 | 855.1 | .3734 | 2.678 |
| 169 | 154.3 | 367.8 | 1194.1 | 339.4 | 854.7 | .3755 | 2.663 |
| 170 | 155.3 | 368.3 | 1194.3 | 339.9 | 854.4 | .3776 | 2.648 |
| 171 | 156.3 | 368.7 | 1194.4 | 340.4 | 854.0 | .3797 | 2.634 |
| 172 | 157.3 | 369.2 | 1194.5 | 340.9 | 853.6 | .3818 | 2.619 |
| 173 | 158.3 | 369.7 | 1194.7 | 341.4 | 853.3 | .3839 | 2.605 |
| 174 | 159.3 | 370.1 | 1194.8 | 341.8 | 853.0 | .3860 | 2.591 |
| 175 | 160.3 | 370.6 | 1195.0 | 342.3 | 852.7 | .3880 | 2.577 |
| 176 | 161.3 | 371.1 | 1195.1 | 342.8 | 852.3 | .3901 | 2.563 |
| 177 | 162.3 | 371.5 | 1195.2 | 343.3 | 851.9 | .3922 | 2.550 |
| 178 | 163.3 | 372.0 | 1195.4 | 343.8 | 851.6 | .3943 | 2.536 |
| 179 | 164.3 | 372.5 | 1195.6 | 344.3 | 851.3 | .3963 | 2.523 |
| 180 | 165.3 | 372.9 | 1195.7 | 344.7 | 851.0 | .3984 | 2.510 |
| 181 | 166.3 | 373.4 | 1195.8 | 345.2 | 850.6 | .4005 | 2.497 |
| 182 | 167.3 | 373.8 | 1195.9 | 345.7 | 850.2 | .4026 | 2.484 |
| 183 | 168.3 | 374.3 | 1196.1 | 346.2 | 849.9 | .4047 | 2.471 |
| 184 | 169.3 | 374.7 | 1196.2 | 346.6 | 849.6 | .4067 | 2.459 |
| 185 | 170.3 | 375.2 | 1196.4 | 347.1 | 849.3 | .4088 | 2.446 |
| 186 | 171.3 | 375.6 | 1196.5 | 347.5 | 849.0 | .4109 | 2.434 |
| 187 | 172.3 | 376.0 | 1196.6 | 348.0 | 848.6 | .4130 | 2.421 |
| 188 | 173.3 | 376.5 | 1196.8 | 348.5 | 848.3 | .4151 | 2.409 |
| 189 | 174.3 | 376.9 | 1196.9 | 348.9 | 848.0 | .4171 | 2.398 |
| 190 | 175.3 | 377.4 | 1197.0 | 349.4 | 847.6 | .4192 | 2.385 |
| 191 | 176.3 | 377.8 | 1197.2 | 349.8 | 847.4 | .4213 | 2.374 |
| 192 | 177.3 | 378.3 | 1197.3 | 350.3 | 847.0 | .4234 | 2.362 |
| 193 | 178.3 | 378.7 | 1197.4 | 350.7 | 846.7 | .4254 | 2.351 |
| 194 | 179.3 | 379.1 | 1197.6 | 351.2 | 846.4 | .4275 | 2.339 |
| 195 | 180.3 | 379.6 | 1197.7 | 351.7 | 846.0 | .4296 | 2.328 |
| 196 | 181.3 | 380.0 | 1197.8 | 352.1 | 845.7 | .4317 | 2.316 |
| 197 | 182.3 | 380.4 | 1198.0 | 352.5 | 845.5 | .4338 | 2.305 |
| 198 | 183.3 | 380.8 | 1198.1 | 352.9 | 845.2 | .4359 | 2.294 |
| 199 | 184.3 | 381.3 | 1198.2 | 353.4 | 844.8 | .4380 | 2.283 |
| 200 | 185.3 | 381.7 | 1198.4 | 353.8 | 844.6 | .4400 | 2.273 |
| 205 | 190.3 | 383.8 | 1199.0 | 356.0 | 843.0 | .4504 | 2.220 |
| 210 | 195.3 | 385.8 | 1199.6 | 358.1 | 841.5 | .4608 | 2.170 |
| 215 | 200.3 | 387.8 | 1200.2 | 360.2 | 840.0 | .4712 | 2.122 |
| 220 | 205.3 | 389.8 | 1200.8 | 362.2 | 838.6 | .4816 | 2.076 |
| 225 | 210.3 | 391.7 | 1201.4 | 364.2 | 837.2 | .4920 | 2.033 |
| 230 | 215.3 | 393.6 | 1202.0 | 366.2 | 835.8 | .5024 | 1.990 |
| 240 | 225.3 | 397.3 | 1203.1 | 370.1 | 833.0 | .5231 | 1.912 |
| 250 | 235.3 | 400.9 | 1204.2 | 373.8 | 830.4 | .5439 | 1.839 |
| 260 | 245.3 | 404.4 | 1205.3 | 377.5 | 827.8 | .5646 | 1.771 |
| 270 | 255.3 | 407.8 | 1206.3 | 381.0 | 825.3 | .5854 | 1.708 |
| 280 | 265.3 | 411.1 | 1207.3 | 384.4 | 822.9 | .6061 | 1.650 |
| 290 | 275.3 | 414.3 | 1208.3 | 387.8 | 820.5 | .6268 | 1.595 |
| 300 | 285.3 | 417.4 | 1209.2 | 391.0 | 818.2 | .6475 | 1.544 |
| 325 | 310.3 | 424.8 | 1211.5 | 398.7 | 812.8 | .6990 | 1.431 |
| 350 | 335.3 | 431.8 | 1213.6 | 406.0 | 807.6 | .7505 | 1.332 |

# CHAPTER VIII

## ACTUAL AND EQUIVALENT EVAPORATION

**94. Wet Steam.**—When heat is applied to a boiler slowly the temperature of the water contained in it is raised gradually until it reaches the boiling-point. If the application of heat is continued the water begins to boil slowly. Under these conditions the bubbles of steam formed next to the heating surface are small and, as they become detached from the heating surface, rise slowly to the surface of the water. Upon reaching the surface, the bubbles burst and empty their steam into the space above the surface of the water. Steam formed in this manner will be dry saturated steam.

If, on the other hand, heat is supplied to the water so rapidly as to cause it to boil violently, the steam bubbles formed on the heating surface will be large and, when they become detached, will rise to the surface more rapidly. As the steam bubbles reach the surface they burst violently and the water which forms the film around them is thrown into the steam space in the form of very small particles of water. These particles of water are so small and light that they remain suspended in the mass of steam and cause it to be wet. Thus a boiler may form either dry or wet steam depending upon the rate at which the steam is formed.

The importance of a large disengagement surface may now be understood. If the disengagement surface is small in proportion to the amount of steam formed, a great many steam bubbles will burst in a small area, keeping the surface of the water in violent commotion and causing more of it to be thrown into the steam. But if the disengagement area is large, a smaller number of steam bubbles will burst in a given area and the surface of the water will not be disturbed very much.

If the water is boiling so violently as to throw large quantities of water into the steam space, or if the water foams, the boiler is said to "prime." Foaming is usually caused by the presence of some impurity in the water which causes a scum to form over its surface. The presence of a scum over the surface prevents the steam from being discharged readily into the steam space, hence it collects under the layer of scum until enough is present to raise large portions of it into the steam space, where the rapidly moving current of steam carries it into the steam pipes leading from the boiler.

The moisture which is suspended in wet steam is not in the form of vapor since it has not been evaporated, but it still exists in the form of water which is at the temperature of the steam. Wet steam is thus composed of two parts, one of saturated steam and the other of water.

That part of wet steam which is in the form of water has received only enough heat to raise its temperature to the boiling-point. If its temperature was originally 32° it has, therefore, received the "heat of the liquid." That part of the wet steam which is in the form of saturated vapor or steam has received enough heat to not only raise its temperature to the boiling-point, but also enough to evaporate it. If the water from which it was formed was originally at 32° it contains the "total heat" as given in the steam table.

To illustrate the way in which the heat contained in wet steam is divided between the moisture and the steam, consider 1 lb. of wet steam formed under a pressure of 120 lb. per sq. in. absolute, and suppose the pound of wet steam to consist of 1/5 or 0.2 of a pound of moisture and 4/5 or 0.8 of a pound of saturated steam. The 0.2 of a pound of moisture has received enough heat to raise its temperature to the boiling-point. If its original temperature was 32°, each pound will receive 311.9 B.t.u. which is the heat of the liquid corresponding to a pressure of 120 lb. per sq. in. absolute. The 0.2 of a pound of moisture will, therefore, contain $0.2 \times 311.9 = 62.38$ B.t.u. The 0.8 of a pound of saturated steam has received not only enough heat to bring it to the boiling-point but also enough to evaporate it. The amount of heat required to bring it to the boiling-point is $0.8 \times 311.9 = 249.52$ B.t.u. and the amount required to evaporate it will be 0.8 of the latent heat of 1 lb. or $0.8 \times 874 = 699.2$ B.t.u. Therefore, the 1 lb. of wet steam contains $62.38 + 249.52 + 699.2 = 1011.1$ B.t.u.

Since the whole pound of water must be heated to the boiling point while only a fraction of the pound has to receive the latent heat of evaporation, the above calculation may be combined into the following formula

$$H_w = h + qL$$

in which $H_w$ is the number of B.t.u. in a pound of wet steam,

$h$ is the heat of the liquid,
$L$ is the latent heat of evaporation,
$q$ is the fraction of the whole pound which is dry saturated steam.

Applying this formula to the above problem

$$H_w = h + qL$$
$$H_w = 311.9 + 0.8 \times 874$$
$$= 311.9 + 699.2 = 1011.1 \text{ B.t.u.}$$

which is the same result as obtained before.

Comparing the amount of heat contained in a pound of the wet steam specified above with that contained in a pound of dry steam we see that the wet steam contains only 1011.1 B.t.u. while, if it had been dry, it would contain 1185.9 B.t.u. In other words, the wet steam contains 174.8 less heat units than the dry steam, and the more moisture there is suspended in steam the fewer heat units each pound of it will contain.

Since a pound of wet steam contains less heat than a pound of dry steam there is a disadvantage in operating a boiler in such a manner as to produce wet steam, because a greater weight of steam must be handled in order to transfer a certain number of heat units from the boiler to the engines. This involves larger apparatus and the handling of more feed water. If the amount of moisture in the steam becomes excessive, that is, if the boiler primes, there is danger of flooding the engine cylinder and of damaging the piping by water-hammer.

**95. Quality of Steam.**—The factor $q$ in the above formula for finding the heat contained in wet steam is called the *quality factor*. The quality of steam (sometimes called the dryness of the steam) is the portion of the total weight of steam which is in the form of steam or vapor, as distinguished from that portion which is in the form of moisture. The quality is expressed as a per cent of the total weight. Thus in the example given above the quality or dryness, $q$, is .80 or 80 per cent. If one-half of the pound of steam had been water, the other half being in the form of steam, the quality would have been .50 or 50 per cent, and if the steam had contained 1/4 water and 3/4 steam its quality would have been .75 or 75 per cent. If the steam had been perfectly dry, all of it would have been in the form of vapor or steam and its quality would, therefore, be 1.00 or 100 per cent. The wetness of steam is 100 per cent minus the per cent of dryness or $(100-q)$.

*In applying the quality factor to the heat contained in steam it should be remembered that the quality does not apply to the total heat as given in the steam table but only to the latent heat.* The heat of the liquid is the same whether the steam is wet or dry but the latent heat of a pound of steam will be less if the steam is wet than if it is dry. For this reason the formula for the heat in a pound of wet steam must take the form

$$H_w = (h + qL)$$

Under ordinary operating conditions, power boilers will generate steam having a quality from 97 to 100 per cent. If forced above their rated loads the quality may fall considerably below this, depending upon how hard the boilers are forced. Steam which has a quality of not less than 98 per cent is called "commercially dry" steam.

**96. Steam Calorimeters.**—The quality of steam may be measured by means of an instrument called a steam calorimeter. There are two forms of steam calorimeters called respectively the *Separating Calorimeter* and the *Throttling Calorimeter.*

**97. Separating Calorimeter.**—The separating calorimeter shown in cross-section in Fig. 68 separates the water from the steam mechanically, collecting the water at one place and allowing the steam, now free of moisture, to pass off at another. Since water is heavier than an equal volume of steam, if the direction in which a mixture of steam and water is flowing is suddenly changed, the particles of water will be thrown out of the steam. The water being heavy, tends to continue in a straight line, while the steam being lighter, can have its directions of flow changed more readily. This principle is made use of in the separating calorimeter.

The body of the separating calorimeter consists of a double walled hollow chamber with a steam pipe connection leading through the top into the inner chamber. A metal basket with perforated sides is suspended in the upper part of the inner chamber with its bottom a short distance below the end of the steam connection. The inner chamber is connected to the outer one through an opening located at the top of the perforated metal basket. The outer chamber, located between the two walls of the body of the calorimeter, has an outlet to the atmosphere through a small hole in the bottom.

In operating the calorimeter, the steam to be tested enters through the tube in the top and discharges against the bottom of the perforated metal basket. The steam, in seeking an outlet, is forced to make a sharp turn as it leaves the tube, thus separating the moisture from it. The steam, which is now dry,

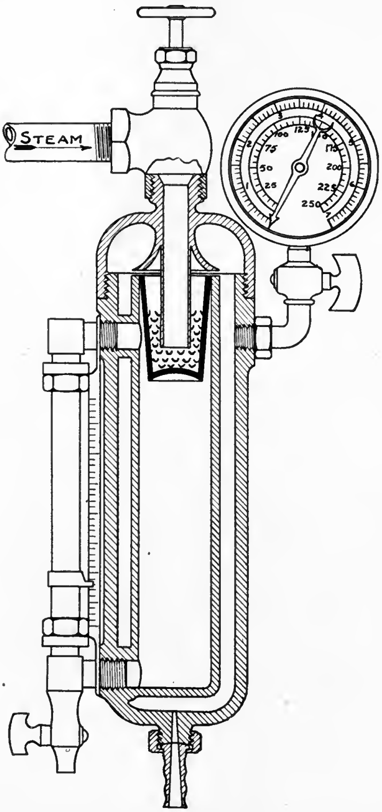



FIG. 68.—Separating calorimeter.

passes the sides of the metal basket and through the opening into the outer chamber. The moisture is separated from the steam and passes through the perforations in the basket, collecting in the bottom of the inner chamber. The amount of water collected in the inner chamber is indicated in a glass gage located outside the body of the calorimeter and connected at top and bottom to the inner chamber. This gage is fitted with a marker which passes over a graduated scale. The scale is usually graduated to read in hundredths of a pound.

The dry steam passes into the outer chamber and out through the opening in the bottom. A gage, resembling a steam gage, is connected to the outer chamber of the calorimeter. The dial of this gage has two sets of graduations; the inner one showing the pressure of the steam in the calorimeter in pounds per square inch above atmospheric pressure, and the other showing the weight of steam flowing through the small opening in the bottom during a period of 10 minutes. The gage is rather unreliable and for this reason, it is better to obtain the weight of steam passing through the calorimeter by weighing it. This may be done by connecting a rubber tube to the bottom of the calorimeter and passing the steam into a tub or bucket of cold water, where it will be condensed. By weighing the tub or bucket of water before and after passing the steam into it, its increase in weight may be obtained. This increase in weight represents the weight of dry steam that has passed through the calorimeter.

To obtain the quality of steam with a separating calorimeter, the valve at the top is opened wide and steam allowed to flow through the instrument until it becomes hot. The glass gage is then drained through the drain cock of any water which it may contain. After waiting a few seconds until water again appears in the gage glass, a reading of the height of the water in the gage glass is taken and at the same instant the end of the rubber tube connected to the bottom of the calorimeter is quickly placed in a tub or bucket of water which has previously been weighed and placed near the calorimeter. The water and condensed steam are collected in this manner for 10 or 15 minutes, when the height of the water in the gage glass is again read and at the same instant the end of the rubber tube is removed from the tub or bucket of water. The weight of water collecting in the calorimeter may then be read from the gage glass and the weight of dry steam passing through the calorimeter obtained by weighing the tub or bucket of water.

The calculation of quality of steam from the readings taken with a separating calorimeter is very simple, since the weight of water and of steam are obtained directly. If $W$ represents the weight of water removed from the steam, as indicated on the glass gage, and $W_1$ represents the weight of dry steam obtained by condensation in a tub or bucket of water, then the total weight of the wet steam is $W+W_1$ and the quality or dryness will be

$$\frac{W_1}{W+W_1} \text{ or } q=\frac{W_1}{W+W_1}$$

**Example:** Suppose the glass gage shows that the calorimeter has collected .12 lb. of water in a certain time, and during the same time the tub of water has increased in weight 2 lb. 4½ oz. What is the quality of the steam?

$$4\tfrac{1}{2} \text{ oz.}=\frac{4.5}{16}= .281 \text{ lb.}$$

Therefore, 2 lb. 4½ oz. $=2.281$ lb. $=W_1$

$$q=\frac{W_1}{W+W_1}=\frac{2.281}{.12+2.281}=\frac{2.281}{2.401}=.95=95 \text{ per cent.}$$

In this form of calorimeter, radiation from the outer walls, which causes condensation of a portion of the steam, does not affect the accuracy of the results, as condensation can take place only in the outer chamber and will, therefore, affect only steam from which the moisture has already been separated.

The separating calorimeter is especially useful in determining the quality of steam which contains considerable moisture. If the quality of the steam is so low that one calorimeter will not remove all the moisture, two calorimeters may be connected so the first one discharges into the second, thus forcing the steam to pass through both. The moisture which passes the first calorimeter will be separated by the second. The separating calorimeter does not give as accurate results as the throttling calorimeter to be described next, but it can be used with steam having a lower quality.

**98. Throttling Calorimeter.**—The throttling calorimeter operates on an entirely different principle from that of the separating calorimeter just described. This form of calorimeter takes its name from the fact that the steam, whose quality is to be determined, is forced to pass through a very small opening, thereby throttling it, or causing its pressure to be reduced.

Two forms of throttling calorimeters are shown in Figs. 69 and 71. The one shown in Fig. 69 is very simple and is in common use. It consists of a hollow cylindrical shell with a thermometer well extending down its center, and with an opening into the atmosphere at the bottom. Steam is led into the calorimeter through a sampling tube and valve and through a nozzle which has an opening of only about .03 of an inch in diameter. An opening is placed in the shell of the calorimeter directly opposite the nozzle and leading to one branch of a manometer, or glass "U" tube partly filled with mercury and provided with a scale divided into inches.

The theory of a throttling calorimeter is as follows: The steam drawn from the steam pipe by the nozzle is saturated

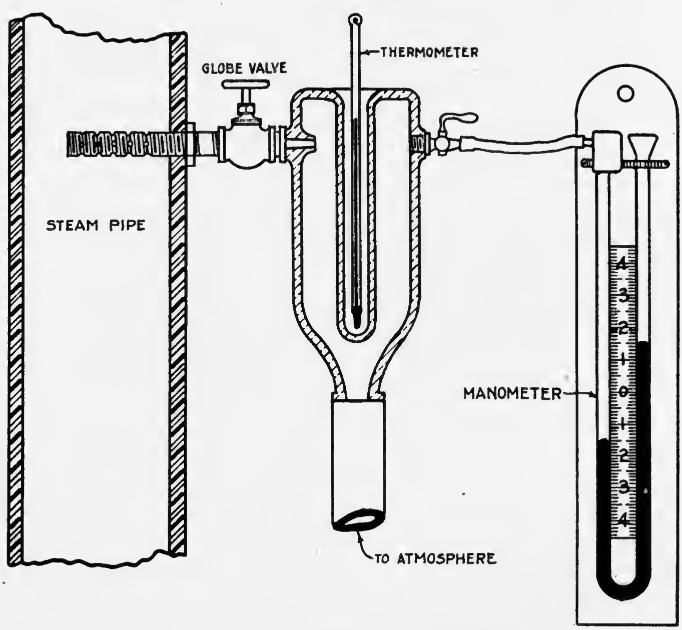



FIG. 69.—Throttling calorimeter.

and under a high pressure. Upon flowing through the nozzle into the chamber of the calorimeter, which is open to the atmosphere, the pressure of the steam will be reduced to approximately atmospheric pressure. A study of the steam table will show that high pressure saturated steam contains a greater number of heat units per pound than low pressure saturated steam. The steam taken from the steam pipe cannot gain any heat, since there is no source of heat present. Neither can it lose heat except by radiation and, since the calorimeter is small, the small amount of heat lost in this way may be neglected. Therefore, as far as practical results are concerned, the steam in the calorimeter contains the same number of heat units per pound as the steam in the pipe from which the sample is taken. Since the low pressure steam in the calorimeter requires less heat to saturate it than high pressure steam, there will be more heat in the calorimeter than is required to saturate the steam after its pressure has been reduced. As this excess heat cannot escape, it is absorbed by the steam in the calorimeter thereby raising its temperature, or *superheating* it. A numerical example will make this plain. Suppose the steam in the main pipe has a pressure of 150 lb. per sq. in. absolute and a quality of 98 per cent. The number of B.t.u. per pound in this steam will be

$$\begin{aligned}\text{B.t.u.} &= h+qL\\ &=329.6+.98\times 861.6\\ &=329.6+844.37\\ &=1173.97\end{aligned}$$

and this is the amount of heat which enters the calorimeter per pound of steam. If the steam inside the calorimeter has a pressure of 15 lb. per sq. in. absolute and is merely saturated, it would contain only 1146.9 B.t.u. per pound. Therefore, there will be 1173.97 − 1146.9 = 27.07 B.t.u. inside the calorimeter in excess of that required to saturate the steam and, as this 27.07 B.t.u. cannot escape, it is absorbed by the steam inside the calorimeter, thereby superheating it.

The amount of heat required to raise the temperature of 1 lb. of any substance may be found by multiplying the specific heat of that substance by the difference in temperature through which the substance is raised. The specific heat of superheated steam, when near atmospheric pressure, is commonly taken as 0.48, therefore the 27.07 B.t.u. of excess heat mentioned above is sufficient to raise the temperature of the steam in the calorimeter an amount equal to $T$ in the following formula

$$27.07=0.48T$$

$$\text{or } T=\frac{27.07}{0.48}=56.4 \text{ degrees.}$$

Since saturated steam at a pressure of 15 lb. per sq. in. has a temperature of 213° F. the excess heat in the calorimeter is sufficient to raise the temperature of the steam in the calorimeter to $213+56.4=269.4°$ F. and, under the conditions stated above, this is the temperature which a thermometer placed in the well of the calorimeter would indicate.

In operating the throttling calorimeter, the valve in the sampling tube between the main steam pipe and the calorimeter, is opened wide in order to prevent the steam from being throttled in passing through it.

The thermometer well should be filled with a heavy oil, such as cylinder oil, and a thermometer capable of reading to about 300° F. immersed in it. The manometer is filled about half full of mercury, and attached by a rubber tube to the calorimeter. The valve in the manometer connection is opened. When the calorimeter has become heated and the temperature as indicated by the thermometer has become stationary the readings may be taken.

The readings to be taken for determining the quality of the steam are: First, the pressure of the steam in the pipe from which the sample is taken, for which purpose a steam gage should be attached to the steam pipe; second, the temperature inside the calorimeter, as indicated on the thermometer in the well; and third, the pressure inside the calorimeter as indicated by the manometer. The atmospheric pressure as indicated by a barometer should also be read. The readings of pressure and temperature should be taken at the same time.

The method of calculating the quality is illustrated with the following set of readings as taken from the calorimeter:

Gage pressure in steam pipe 130 lb. per sq. in.

Temperature in calorimeter $=249.25°$ F.

Pressure in calorimeter above atmospheric pressure (manometer reading) $=$ 3 in. of mercury $=1.47$ lb. per sq. in.

Barometer reading $=28.4$ in. of mercury $=$ 13.94 lb. per sq. in.

*Calculations:*

Absolute pressure in steam pipe $=130+13.94=143.94$ lb. per sq. in.

Absolute pressure in calorimeter $= 1.47 + 13.94 = 15.41$ lbs. per sq. in.

Heat in 1 lb. of steam in pipe $= h+qL$, the quantities $h$ and $L$ being for a pressure of 143.94 lb. per sq. in.

Heat in calorimeter $=H+.48(t_s-t)$, in which

$H$ = the total heat in 1 lb. of saturated steam at the pressure which exists in the calorimeter.

$t_s$ = temperature of the superheated steam in the calorimeter as indicated by the thermometer.

$t$ = temperature of saturated steam at the pressure which exists in the calorimeter.

Now as shown before

$$h+qL=H+.48(t_s-t)$$

or

$$q=\frac{H+.48(t_s-t)-h}{L}$$

From the observations and the steam table we know that

$$H=1147.3$$
$$t_s=249.25$$
$$t=214.35$$
$$h=326.08$$
$$L=863.93$$

Therefore,

$$q=\frac{H+.48(t_s-t)-h}{L}$$

$$=\frac{1147.3+.48(249.25-214.35)-326.08}{863.93}$$

$$=\frac{1147.3+(.48\times 34.9)-326.08}{863.93}$$

$$=\frac{1147.3+16.75-326.08}{863.93}$$

$$=\frac{837.97}{863.93}=.969=96.9 \text{ per cent.}$$

When the throttling calorimeter is used as directed above and results are calculated by the method used in the example, the quality is determined very accurately. It is not suitable, however, for use with steam having a quality less than 96 per cent, as there will not then be enough excess heat in the calorimeter to superheat the steam. Any one using a throttling calorimeter may know when it is not superheating the steam by reading the thermometer. If the temperature in the calorimeter is not greater than that corresponding to the temperature of saturated steam at the pressure in the calorimeter, then the steam is not being superheated and the quality cannot be determined by this method. For example, if the thermometer had not indicated a temperature higher than 214.35° F. in the example given above, it would show that the steam was not being superheated and the quality could not have been obtained from this data.

Where it is not desired to obtain as accurate results as may be obtained by the method illustrated above, the manometer pressure may be neglected and the pressure in the calorimeter assumed to be 14.7 lb. per square inch. Using the data of the example above and assuming the pressure in the calorimeter to be 14.7 lb. per square inch the quality will be

$$q=\frac{1147.3+48(249.25-212)-326.08}{863.93}$$
$$=.971=97.1 \text{ per cent}$$

which is a difference of only .2 per cent from the result obtained before.

A common method of using the throttling calorimeter is to neglect both the manometer and the barometer readings, considering the atmospheric pressure and also the pressure in the calorimeter to be 14.7 lb. per square inch absolute. Applying this method to the data given above would give

$$q=\frac{1146.3+.48(249.25-212)-326.7}{863.62}=.97=97 \text{ per cent.}$$

A chart for obtaining the quality by this latter method is shown in Fig. 70 and may be used with considerable accuracy in this locality (Wisconsin) because, while the pressure of the atmosphere is a little less than 14.7 lb. per sq. in., the pressure in the calorimeter will be a little greater than atmospheric pressure and these two discrepancies partially balance each other. To find the quality from this chart, the gage pressure is located on the left-hand side of the chart, and the temperature inside the calorimeter is located on the bottom. By following the lines from these points to the point where they meet, the quality may be read from the diagonal lines. For example, suppose the steam gage on the pipe read 150 lb. per sq. in. and the thermometer read 250° F. Following these two points to their intersection we see the per cent of moisture lies between 3.25

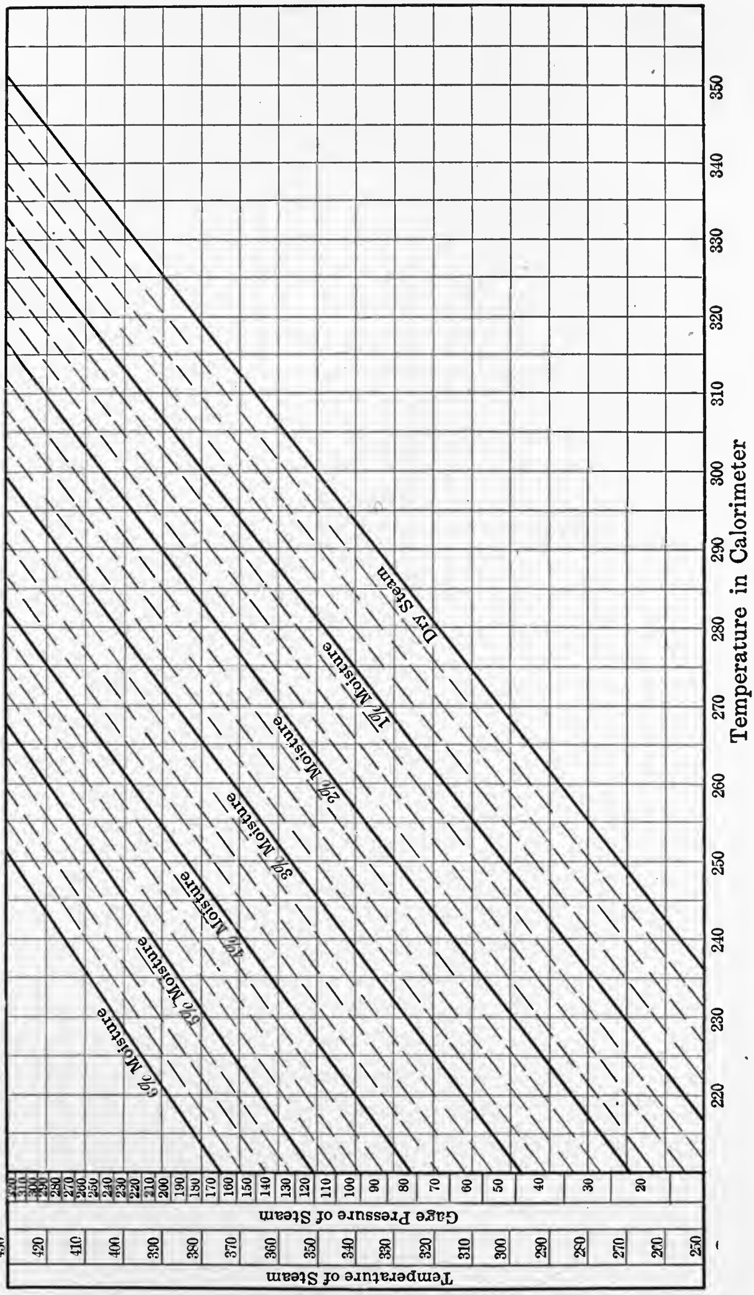

Dry Steam
1% Moisture
2% Moisture
3% Moisture
4% Moisture
5% Moisture
6% Moisture
Temperature in Calorimeter
220 230 240 250 260 270 280 290 300 310 320 330 340 350
Gage Pressure of Steam
Temperature of Steam

FIG. 70.

per cent and 3.50 per cent and is about 3.35 per cent, therefore, the quality is $100-3.35=96.65$ per cent.

The form of throttling calorimeter shown in Fig. 71 may be made from ordinary pipe fittings and, if properly made, will give quite accurate results. This calorimeter is made from four short nipples, one long nipple, two tees, two flanges, one elbow, and one union, put together as shown in Fig. 71. These fittings should not be of a less size than $1\frac{1}{2}$ in. in order to prevent "wire-drawing" (throttling) when the steam is passing through.

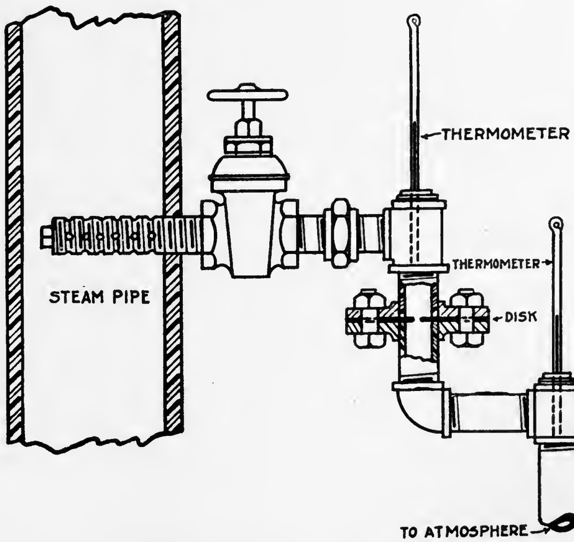



Fig. 71.—Throttling calorimeter made from pipe fittings.

A thin disc of sheet iron having a small hole bored through its center is placed between the two flanges. This hole is for the purpose of throttling the steam and thus superheating it, as is done by the nozzle in the throttling calorimeter previously described. Each of the tees is provided with a thermometer well, as shown. The upper thermometer is intended to take the place of a steam gage on the main pipe and need not be used where a steam gage is already on the pipe. By reading the temperature on this thermometer, the corresponding pressure can be found from a steam table. The lower thermometer shows the temperature inside the calorimeter, the same as the thermometer in the other form of throttling calorimeter.

Results are calculated by the same method for both calorimeters, except that in the one shown in Fig. 71 no provision is made for measuring the pressure inside the calorimeter and it is necessary, therefore, to assume this pressure to be that of the atmosphere, 14.7 lb. per sq. in. Where the pressure in the calorimeter is not measured, the exit of steam from the calorimeter should be free. To accomplish this purpose no piping or hose of any kind should be attached to it as this will increase the pressure in the calorimeter.

The sampling tube used with calorimeters, which is inserted in the steam pipe where the sample is to be taken, should be of 1/2-in. or 3/4-in. pipe, threaded for a sufficient length to permit screwing into the steam pipe until the end of the sampling tube comes within 1/2 in. of the opposite side of the steam pipe. The tube should have 1/8-in. holes bored in it, the holes being spaced about 1/2 in. from center to center, and bored all around the tube. None of the holes should be placed nearer than 1/2 in. to the walls of the steam pipe, in order to prevent water which may be flowing along the walls from entering the sampling tube and giving a wrong value to the quality.

**99. Superheated Steam.**—If saturated steam is removed from the presence of water and heat applied to it, its temperature may be raised above that at which it was formed, and this may be done without increasing its pressure. When steam is heated above the boiling temperature corresponding to its pressure it is said to be *superheated.*

The number of degrees by which its actual temperature exceeds that of the boiling-point corresponding to the pressure, is called the *degrees of superheat* and this term is used to designate the amount of superheat. Thus, if the gage pressure of the steam is 150 lb. per sq. in. and a thermometer inserted in it shows that its temperature is 465°, then, since the temperature of saturated steam at 150 lbs. per sq. in. pressure is about 365° its degree of superheat is $465-365=100°$. The temperature of saturated steam for any pressure may be found from the steam table while the actual temperature of superheated steam must be measured with a thermometer.

**100. Total Heat of Superheated Steam.**—Superheated steam contains more heat per pound than saturated steam at the same pressure. The total heat above 32° F. contained in a pound of superheated steam may be found by adding to the total heat of saturated steam for the same pressure, as found in the steam tables, the number of heat units required to superheat the steam. The method formerly used for calculating the number of heat units required to superheat a pound of steam was to multiply the specific heat of superheated steam by the degrees of superheat. Recent investigation shows that the specific heat of superheated steam is different at different temperatures, therefore this method of determining the number of heat units required to superheat steam is liable to cause serious error unless the average specific heat can be determined.

Within recent years many experiments have been made to determine the number of heat units required to superheat steam. The results of these experiments are shown in the following table. The total heat contained in a pound of superheated steam may be found by adding the values given in this table to the total heat of dry saturated steam as found in a steam table.

HEAT UNITS REQUIRED TO SUPERHEAT STEAM

| Absolute pressure | Degrees of superheat | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 40 | 60 | 80 | 100 | 130 | 160 | 200 | 250 | 300 |
| 1 | 4.9 | 9.6 | 18.8 | 27.9 | 36.9 | 46.0 | 59.6 | 73.2 | 91.3 | 114.0 | 136.8 |
| 10 | 5.4 | 10.4 | 20.1 | 29.6 | 39.0 | 48.4 | 62.4 | 76.3 | 94.9 | 118.0 | 141.2 |
| 15 | 5.5 | 10.6 | 20.5 | 30.2 | 39.7 | 49.2 | 63.3 | 77.4 | 96.1 | 119.4 | 142.9 |
| 20 | 5.6 | 10.8 | 20.9 | 30.7 | 40.3 | 49.9 | 64.1 | 78.3 | 97.1 | 120.6 | 144.2 |
| 30 | 5.7 | 11.1 | 21.4 | 31.4 | 41.3 | 51.0 | 65.5 | 79.8 | 98.8 | 122.6 | 146.5 |
| 40 | 5.9 | 11.3 | 21.8 | 32.0 | 42.0 | 51.9 | 66.6 | 81.1 | 100.3 | 124.2 | 148.3 |
| 50 | 6.0 | 11.5 | 22.2 | 32.5 | 42.4 | 52.6 | 67.4 | 82.1 | 101.4 | 125.6 | 149.8 |
| 60 | 6.0 | 11.7 | 22.5 | 32.9 | 43.2 | 53.3 | 68.2 | 82.9 | 102.4 | 126.7 | 151.0 |
| 80 | 6.2 | 11.9 | 22.9 | 33.6 | 44.0 | 54.2 | 69.3 | 84.2 | 103.9 | 128.4 | 152.9 |
| 100 | 6.3 | 12.2 | 23.3 | 34.1 | 44.6 | 55.0 | 70.2 | 85.2 | 105.1 | 129.7 | 154.4 |
| 130 | 6.4 | 12.4 | 23.8 | 34.7 | 45.4 | 55.8 | 71.3 | 86.4 | 106.4 | 131.2 | 156.1 |
| 160 | 6.5 | 12.6 | 24.2 | 35.3 | 46.0 | 56.6 | 72.1 | 87.4 | 107.5 | 132.5 | 157.5 |
| 200 | 6.7 | 12.9 | 24.7 | 35.9 | 46.8 | 57.4 | 73.1 | 88.6 | 108.9 | 134.1 | 159.3 |
| 250 | 6.9 | 13.2 | 25.1 | 36.5 | 47.6 | 58.4 | 74.3 | 89.9 | 110.4 | 135.9 | 161.3 |
| 300 | 7.0 | 13.5 | 25.6 | 37.1 | 48.3 | 59.2 | 75.3 | 91.0 | 111.7 | 137.4 | 163.0 |

The use of this table may be illustrated by the following example.

**Example:** Determine the number of heat units contained in a pound of superheated steam having a pressure of 130 lb. per sq. in. absolute and having a temperature of 447.1° F.

By referring to the steam table, we see that the temperature of saturated steam at 130 lb. pressure is 347.1° and that its total heat is 1187.8 B.t.u. The degrees of superheat are, therefore, $447.1 - 347.1 = 100°$ and the above table shows that for this degree of superheat and for a pressure of 130 lb. the number of heat units required to superheat the steam is 55.8. The pound of superheated steam will, therefore, contain

$$1187.8+55.8=1243.6 \text{ B.t.u.}$$

The average specific heat of the superheated steam may be found from the table by dividing the value given in the table by the degrees of superheat. Thus, for the above example the average specific heat would be

$$\frac{55.8}{100}=.558$$

Since superheated steam contains more heat than dry saturated steam it is evident that the superheated steam is also dry. If superheated steam is passed through a throttling calorimeter, it will show a quality greater than 100 per cent, which indicates simply that the steam was already superheated when it entered the calorimeter.

**101. Density of Superheated Steam.**—The weight per cubic foot of superheated steam, or its density, may be calculated from the following equation:

$$D=\frac{1.684p}{t_s+461}$$

in which $D$ is the weight per cubic foot,

$p$ is the absolute pressure in pounds per square inch,

and $t_s$ is the temperature of the steam in degrees Fahrenheit.

The temperature $t_s$ in the above formula may be found by adding the number of degrees of superheat to the temperature of saturated steam corresponding to the pressure $p$ as found from the steam table.

**Example:** What is the weight per cubic foot of superheated steam having a pressure of 120 lb. per sq. in. absolute and 59 degrees of superheat?

Since the temperature of saturated steam at 120 lb. per sq. in. is 341° F.,

$$t_s=341+59=400$$

$$D=\frac{1.684\times 120}{400+461}=.2347$$

**102. Superheaters.**—Steam may be superheated by taking it away from the presence of water and applying heat to it. If the steam is wet to begin with, the heat will first dry the steam and then superheat it. There are three methods in use for superheating steam. The first and most economical of these methods is to pass the saturated steam through coils of pipe placed in the path of the hot flue gases on their way from the boiler to the chimney. Unless the steam has a very high pressure, about 100° of superheat may be obtained in this way from heat which would otherwise pass out the chimney and be wasted. This method can be used only where the draft will not be seriously impaired by lowering the temperature of the flue gases.

The second method consists in placing the superheater inside the boiler setting, allowing the hot gases to pass through it before they leave the boiler and in some cases even before they strike the boiler. This method has the disadvantage that the temperature is rather hard to regulate, but it is quite economical.

The third method of superheating steam is to have the superheater entirely independent of the boiler and separately fired. With this method the temperature may be easily regulated and the superheater readily cut out when required, but it is more wasteful of fuel than either of the other two methods.

**103. The Future of Superheated Steam.**—It appears that superheating will continue to grow in favor, but the degree of superheat will be moderate and the devices used for securing the superheat will be those which are placed in the combustion chamber of the boiler or those made to utilize the waste heat in the chimney gases. One of the principal wastes in a steam plant comes from the heat lost up the chimney and any of this heat that is saved is a direct gain. The temperature in chimneys is from 150° to 300° above the temperature of the steam in the boiler and is often much higher than is necessary to produce sufficient draft, so that a part of this heat may be used for superheating the steam without any evil effects in the running of the plant, and without any extra cost for fuel. The saving thus effected may amount to from 5 to 15 per cent according to the design and size of the boilers. Often boilers that will barely furnish enough steam for the engines may be made to meet the requirements easily by the addition of a superheater in the chimney flue.

**104. Equivalent Evaporation.**—If we wish to compare the amounts of steam generated by boilers which are working under different conditions it is necessary to have some standard with which to compare them. Thus, one boiler may be receiving feed water at 60° F. and generating steam at a pressure of 120 lb. per sq. in. gage, having a quality of 96 per cent; under these conditions this boiler generates 8 lb. of steam per pound of coal. Another boiler taking feed water at 170° F. and generating steam at a pressure of 150 lb. per sq. in. gage, having a quality of 98 per cent, produces $7\frac{1}{2}$ lb. of steam per pound of coal under these conditions. By simply comparing the number of pounds of steam generated per pound of coal in each case, no idea can be gained of which boiler is doing more work. It is necessary to have some standard by which to compare the performance of each boiler.

If we wish to compare two different lengths, we first compare each of them to some standard length, such as the foot or the yard. Thus one length, when compared to the standard, may be three times as long, while another length, compared to the same standard, may be six times as long as the standard, showing that the second distance is twice as great as the first.

In comparing the performance of boilers we take as the standard the number of heat units transferred when one pound of feed water having a temperature of 212° F. is turned into steam having a temperature of 212° F. or a pressure of 14.7 lb. per sq. in. absolute. This requires only the latent heat of steam at 14.7 lb. per sq. in. absolute to be transferred, which, from the steam table, is 965.8 B.t.u.

As an example of the way in which we may compare the performance of a boiler with this standard, suppose that 6 lb. of feed water are pumped into a boiler for every pound of coal burned, the feed water having a temperature of 32° F. and the steam being formed under a pressure of 125 lb. per sq. in. absolute and having a quality of 100 per cent. Referring to the steam table we see that each pound of steam formed under these conditions receives 1186.9 B.t.u. and the 6 lb. receives $6\times1186.9 = 7121.4$ B.t.u. This is equivalent to $7121.4 \div 965.8 = 7.37$ lb. of steam formed from feed water at 212° into steam at 212°. Suppose the feed water in this example had a temperature of 150° instead of 32°, the heat it would receive would then be $H-(t-32)$ per pound or the 6 lb. would receive

$$\begin{aligned} 6[H-(t-32)] &= 6[1186.9-(150-32)] \\ &= 6(1186.9-118) \\ &= 6\times1068.9 = 6413.4 \text{ B.t.u.} \end{aligned}$$

The term $(t-32)$ represents the heat in the feed water above 32°. The 6 lb. of water evaporated under the above conditions would be equivalent to $6413.4 \div 965.8 = 6.64$ lb. evaporated from a feed water temperature of 212° into steam at 212°. As a further condition, suppose the steam formed in the last example had a quality of 98 per cent, the feed water being at 150°. In this case the heat given to each pound of steam would be

$$\begin{aligned} & h+qL-(t-32) \\ & =315+.98\times 871.9-(150-32) \\ & =315+854.5-118 \\ & =1051.5 \text{ B.t.u.} \end{aligned}$$

and for the 6 lb., $6\times 1051.5=6309$ B.t.u. and this would be equivalent to $6309 \div 965.8 = 6.53$ lb. evaporated from feed water at 212° into steam having a temperature of 212°.

In the three cases given above the 7.37, 6.64 or 6.53 lb. is called the *equivalent evaporation.* This quantity is sometimes called, also, the *equivalent evaporation from and at* 212° or the evaporation *from and at.* We may define the equivalent evaporation as the total number of heat units supplied to a quantity of steam divided by the latent heat of steam at a pressure of 14.7 lb. per sq. in. absolute.

**105. Factor of Evaporation.**—The equivalent evaporation of 1 lb. of steam is called the *Factor of Evaporation.* In the last example given above, the factor of evaporation would be $\frac{1051.5}{965.8} =$ 1.088+. If we multiply the actual evaporation by the factor of evaporation the result will be the equivalent evaporation. Thus, 6 lb. of water evaporated under the conditions given in the last example above would be equivalent to $6\times 1.088=6.53$ lb. evaporated from and at 212°, which is the same result as obtained by the other method of calculation. The factor of evaporation may be calculated with the following formula:

$$f=\frac{h+qL-(t-32)}{965.8}$$

in which, $f$ = the factor of evaporation
$h$ = the heat of the liquid for the boiler pressure
$L$ = the latent heat of the steam at the boiler pressure
$q$ = the quality of the steam
and $t$ = the temperature of the feed water.

The following table gives the factors of evaporation for various

FACTORS OF EQUIVALENT EVAPORATION

| Steam pressure by gage | Temperature of feed water in degrees F. | | | | | | | | | Steam pressure by gage |
|---|---|---|---|---|---|---|---|---|---|---|
| | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | |
| 10 | 1.188 | 1.177 | 1.167 | 1.157 | 1.146 | 1.136 | 1.125 | 1.115 | 1.105 | 10 |
| 20 | 1.194 | 1.183 | 1.173 | 1.163 | 1.152 | 1.142 | 1.132 | 1.121 | 1.111 | 20 |
| 30 | 1.199 | 1.188 | 1.178 | 1.168 | 1.157 | 1.147 | 1.136 | 1.126 | 1.116 | 30 |
| 40 | 1.203 | 1.192 | 1.182 | 1.172 | 1.161 | 1.151 | 1.140 | 1.130 | 1.120 | 40 |
| 50 | 1.206 | 1.196 | 1.185 | 1.175 | 1.165 | 1.154 | 1.144 | 1.133 | 1.123 | 50 |
| 60 | 1.209 | 1.199 | 1.188 | 1.178 | 1.168 | 1.157 | 1.147 | 1.136 | 1.126 | 60 |
| 70 | 1.212 | 1.201 | 1.191 | 1.181 | 1.170 | 1.160 | 1.150 | 1.139 | 1.129 | 70 |
| 80 | 1.214 | 1.204 | 1.194 | 1.183 | 1.173 | 1.162 | 1.152 | 1.142 | 1.131 | 80 |
| 90 | 1.217 | 1.206 | 1.196 | 1.186 | 1.175 | 1.165 | 1.154 | 1.144 | 1.134 | 90 |
| 100 | 1.219 | 1.208 | 1.198 | 1.188 | 1.177 | 1.167 | 1.157 | 1.146 | 1.136 | 100 |
| 110 | 1.221 | 1.210 | 1.200 | 1.190 | 1.179 | 1.169 | 1.158 | 1.148 | 1.138 | 110 |
| 120 | 1.223 | 1.212 | 1.202 | 1.191 | 1.181 | 1.171 | 1.160 | 1.150 | 1.140 | 120 |
| 130 | 1.224 | 1.214 | 1.204 | 1.193 | 1.183 | 1.173 | 1.162 | 1.152 | 1.141 | 130 |
| 140 | 1.226 | 1.216 | 1.205 | 1.195 | 1.185 | 1.174 | 1.164 | 1.153 | 1.143 | 140 |
| 150 | 1.228 | 1.217 | 1.207 | 1.196 | 1.186 | 1.176 | 1.165 | 1.155 | 1.145 | 150 |
| 160 | 1.229 | 1.219 | 1.208 | 1.198 | 1.188 | 1.177 | 1.167 | 1.156 | 1.146 | 160 |
| 170 | 1.231 | 1.220 | 1.210 | 1.199 | 1.189 | 1.179 | 1.168 | 1.158 | 1.148 | 170 |
| 200 | 1.235 | 1.224 | 1.214 | 1.203 | 1.193 | 1.183 | 1.172 | 1.162 | 1.152 | 200 |
| 225 | 1.238 | 1.227 | 1.217 | 1.206 | 1.196 | 1.186 | 1.175 | 1.165 | 1.155 | 225 |
| 250 | 1.240 | 1.230 | 1.220 | 1.209 | 1.199 | 1.188 | 1.178 | 1.168 | 1.157 | 250 |
| 275 | 1.243 | 1.233 | 1.222 | 1.212 | 1.201 | 1.191 | 1.181 | 1.170 | 1.160 | 275 |
| 300 | 1.245 | 1.235 | 1.225 | 1.214 | 1.204 | 1.193 | 1.183 | 1.173 | 1.162 | 300 |

FACTORS OF EQUIVALENT EVAPORATION—*Continued*

| Steam pressure by gage | Temperature of feed water in degrees F. | | | | | | | | | Steam pressure by gage |
|---|---|---|---|---|---|---|---|---|---|---|
| | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 | 210 | 212 | |
| 10 | 1.094 | 1.084 | 1.073 | 1.063 | 1.053 | 1.042 | 1.032 | 1.021 | 1.011 | 1.009 | 10 |
| 20 | 1.100 | 1.090 | 1.080 | 1.069 | 1.059 | 1.048 | 1.038 | 1.027 | 1.017 | 1.015 | 20 |
| 30 | 1.105 | 1.095 | 1.084 | 1.074 | 1.064 | 1.053 | 1.043 | 1.032 | 1.022 | 1.020 | 30 |
| 40 | 1.109 | 1.099 | 1.088 | 1.078 | 1.068 | 1.057 | 1.047 | 1.036 | 1.026 | 1.024 | 40 |
| 50 | 1.113 | 1.102 | 1.092 | 1.081 | 1.071 | 1.061 | 1.050 | 1.040 | 1.029 | 1.027 | 50 |
| 60 | 1.116 | 1.105 | 1.095 | 1.084 | 1.074 | 1.064 | 1.053 | 1.043 | 1.032 | 1.030 | 60 |
| 70 | 1.118 | 1.108 | 1.098 | 1.087 | 1.077 | 1.066 | 1.056 | 1.045 | 1.035 | 1.033 | 70 |
| 80 | 1.121 | 1.111 | 1.100 | 1.090 | 1.079 | 1.069 | 1.058 | 1.048 | 1.037 | 1.035 | 80 |
| 90 | 1.123 | 1.113 | 1.102 | 1.092 | 1.082 | 1.071 | 1.061 | 1.050 | 1.040 | 1.038 | 90 |
| 100 | 1.125 | 1.115 | 1.105 | 1.094 | 1.084 | 1.073 | 1.063 | 1.052 | 1.042 | 1.040 | 100 |
| 110 | 1.127 | 1.117 | 1.106 | 1.096 | 1.086 | 1.075 | 1.065 | 1.054 | 1.044 | 1.042 | 110 |
| 120 | 1.129 | 1.119 | 1.108 | 1.098 | 1.087 | 1.077 | 1.067 | 1.056 | 1.046 | 1.044 | 120 |
| 130 | 1.131 | 1.121 | 1.110 | 1.100 | 1.089 | 1.079 | 1.068 | 1.058 | 1.047 | 1.045 | 130 |
| 140 | 1.133 | 1.122 | 1.112 | 1.101 | 1.091 | 1.080 | 1.070 | 1.060 | 1.049 | 1.047 | 140 |
| 150 | 1.134 | 1.124 | 1.113 | 1.103 | 1.092 | 1.082 | 1.072 | 1.061 | 1.051 | 1.049 | 150 |
| 160 | 1.136 | 1.125 | 1.115 | 1.104 | 1.094 | 1.083 | 1.073 | 1.063 | 1.052 | 1.050 | 160 |
| 170 | 1.137 | 1.127 | 1.116 | 1.106 | 1.095 | 1.085 | 1.075 | 1.064 | 1.054 | 1.051 | 170 |
| 200 | 1.141 | 1.131 | 1.120 | 1.110 | 1.099 | 1.089 | 1.079 | 1.068 | 1.058 | 1.055 | 200 |
| 225 | 1.144 | 1.134 | 1.123 | 1.113 | 1.102 | 1.092 | 1.082 | 1.071 | 1.061 | 1.058 | 225 |
| 250 | 1.147 | 1.136 | 1.126 | 1.116 | 1.105 | 1.095 | 1.084 | 1.074 | 1.063 | 1.061 | 250 |
| 275 | 1.149 | 1.139 | 1.129 | 1.118 | 1.108 | 1.097 | 1.087 | 1.076 | 1.066 | 1.064 | 275 |
| 300 | 1.152 | 1.141 | 1.131 | 1.121 | 1.110 | 1.100 | 1.089 | 1.078 | 1.068 | 1.066 | 300 |

pressures and feed-water temperatures. In calculating the quantities given in this table the quality of the steam has been neglected, it being assumed that the steam is perfectly dry. The pressures given in the table are gage pressures.

**106. Boiler Horse-power.**—In a previous assignment the boiler horse-power was defined in terms of the number of square feet of heating surface. This is a very unsatisfactory way of rating a boiler as all parts of the heating surface of a boiler are not equally effective in transmitting heat, that which is near the furnace transmitting more than the part near the smoke outlet.

Since the work of a boiler consists in evaporating water, the logical basis for rating it is on the number of pounds of water evaporated, but as the conditions under which the water is evaporated are different in different boilers, the evaporation should be reduced to some standard, such as the equivalent evaporation.

The best and most commonly used definition of a boiler h.p. is as follows: *One boiler h.p. is the evaporation of* $34\frac{1}{2}$ *lb. of water per hour from a temperature of* 212° *into steam at* 212°. This may be expressed in few words by saying that a boiler h.p. is the equivalent evaporation of $34\frac{1}{2}$ lb. of water. To illustrate this by an example, suppose we wish to find the horse-power of a boiler which evaporates 12,000 lb. of feed water per hour from a feed-water temperature of 170° into steam at 150 lb. gage pressure. Referring to the table of factors of evaporation we see that for feed water of 170° and steam at 150 lb. gage pressure the factor of evaporation is 1.092. Therefore, 12,000 lb. is equivalent to $12{,}000 \times 1.092 = 13{,}104$ lb. from and at 212°. The boiler h.p. would then be

$$\text{Boiler h. p.} = \frac{13{,}104}{34.5} = 379.8$$

# CHAPTER IX

## FUELS

**107. Classification of Fuels.**—Fuels may be defined as those substances which may be burned economically by means of air, to generate heat. The chief heat producing elements of all fuels are carbon and hydrogen. Fuels may be classed as artificial and natural.

Artificial fuels are those which are manufactured and which are not usually found in nature, at least in a form suitable for use in a furnace. They are generally manufactured from natural fuels, or they are the by-products of some process of manufacture.

Natural fuels are those forms of carbon and hydrogen which are found in nature in a condition to be used. These include wood, coal, mineral oil, and natural gas. The solid fuels may be classified as wood, peat, and coal; and coal is further divided into several classes as will be seen later.

**108. Wood.**—Wood as a fuel is rapidly dropping out of use, though it is still important in some of the more thinly settled sections of the country, and around wood-working establishments where the refuse is burned. When freshly cut, wood contains about 50 per cent of moisture but when air dried, contains only about 20 per cent moisture, and in this condition it has a heating value of about 5800 B.t.u. per pound.

The composition of woods of different kinds is practically the same, the average being about as follows: carbon, 49.70 per cent; hydrogen, 6.06 per cent; oxygen, 41.30 per cent; nitrogen, 1.05 per cent; ash, 1.89 per cent.

**109. Peat.**—Peat lies between wood and coal in its character, and, in fact, seems to be coal in the process of formation. It occurs in certain swampy regions in the temperate zone and is composed of semi-aquatic plants which, under special conditions of heat and moisture, are going through a transformation whereby the oxygen is being eliminated and the carbon left behind. It occurs in beds from 1 to 40 ft. thick; that near the surface, being in a less decomposed state, is light, spongy, and of a fibrous nature and of a yellow or reddish-brown color. Lower down it is of a darker color and is more compact, while in the still lower layers it is almost black and of a pitchy nature.

In its natural state, peat contains too much water to be used as a fuel, the water sometimes being as high as 85 or 90 per cent of its entire weight, and it must be dried out before it can be used. Owing to the abundance of other good fuels in this country, peat is not used very much, but in Ireland, Germany, and Sweden it is used extensively.

The average composition of perfectly dry Irish peat is about as follows: carbon, 59.00 per cent; hydrogen, 6.00 per cent; oxygen, 30.00 per cent; nitrogen, 1.25 per cent; ash, 4.00 per cent. In this condition its heating value per pound is 10,040 B.t.u.

**110. Coal.**—Coal is the most important and most commonly used fuel which we have. This is because it is found scattered over such widely distributed areas and in such large quantities; because it has a high heating value for a given weight; and because it is easily transported from place to place and stored. Coal represents the energy stored in the earth during past ages by the sun, whose heat aided the formation of the coal.

Coal is a fossilized product of plant growth which has accumulated during past ages. Its origin is explained as follows: In the early ages of the earth the atmosphere contained a very large proportion of carbon dioxide, much more than it does at present. This excess of carbon in the air, which is the food upon which plants live, caused the earth to be covered with a very dense and rank growth of vegetation. By the continual growth and death of this vegetation, parts of the earth became covered with vegetable matter, which, as time went by, was buried under a mass of soil and rocks. The pressure of this weight, together with the heat from the sun caused a gradual change in the structure of the vegetable matter whereby some of its oxygen was liberated and the remainder assumed the form of coal. As this process is a very gradual one, we would expect to find the vegetable matter in all stages of transformation, varying from the vegetable form to solid coal. These stages extend all through the various grades of peat, lignite, bituminous or soft coal, and anthracite or hard coal, the anthracite being the furthest along in the development of the coal, having less oxygen, more carbon, and being heavier and more homogeneous.

The following table shows very well the change in the principal constituents of the coal in the process of change from wood to anthracite coal, the values being only approximate. The ash and other elements besides those given here have been left out in giving the percentages.

| Description | Carbon | Hydrogen | Oxygen |
|---|---|---|---|
| Wood fiber | 52% | 5.5% | 42.5% |
| Peat | 60 | 5.9 | 34.1 |
| Lignite | 70 | 5.3 | 27.7 |
| Bituminous coal | 76 | 5.7 | 18.3 |
| Semi-bituminous coal | 88 | 5.1 | 6.9 |
| Anthracite coal | 92 | 3.9 | 4.1 |

The most noticeable change is in the carbon, which increases, and in the oxygen, which decreases, as the coal is developed from wood into the harder varieties of coal.

As the process of change from wood into coal is a very gradual one, no sharp line of distinction can be drawn between the different classes of coal, but they may be classified in a general way according to the amounts of fixed carbon and volatile matter which they contain. The following is suggested as such a classification:

| | Per cent of volatile matter in the combustible part of the coal |
|---|---|
| Anthracite | 0 to 7.5 |
| Semi-anthracite | 7.5 to 12.5 |
| Semi-bituminous | 12.5 to 25 |
| Bituminous | 25 to 40 |
| Lignite | over 40 |

Bituminous coal may be further classified into Caking, Non-caking, and Cannel coals.

While coal is widely scattered over the United States, the different varieties are confined more or less to certain localities as indicated in the following classification.

| | |
|---|---|
| Anthracite | Eastern portions of Allegheny Mountains and Rocky Mountains of Colorado. |
| Bituminous | Caking—Mississippi Valley.<br>Non-caking—Maryland, Virginia, and Pennsylvania.<br>Cannel—Pennsylvania, Indiana, and Missouri. |
| Lignites | Colorado, Kentucky, Southwest, and Northwest. |

The characteristics of each of the varieties of coal will next be considered, starting with the softer varieties.

**111. Lignite.**—This substance lies between peat and bituminous coal, and is supposed to be of later origin than bituminous coal. It varies in color from brown to almost black, that coming from a greater depth being darker than that obtained near the surface. Some lignites show the vegetable structure quite plainly while others are quite dense. As lignite is quite soft and brittle, it is not suitable for transportation and must, therefore, be used near the place where mined. This restricts its use considerably. If exposed to the weather for any length of time the softer varieties crumble and absorb moisture; they must, therefore, be used soon after being mined. It has but moderate heating value, but is used to some extent in parts of the West where it is plentiful, and where other varieties of coal are expensive. Its average composition when dry is about as follows: fixed carbon, 44.7 per cent; volatile matter, 54.92 per cent; ash, 6.41 per cent.

It will be noticed that the analysis just given is expressed in different terms than those previously given. This analysis is called a *proximate* analysis while those given previously are called *ultimate* analyses. In the ultimate analysis each constituent in the fuel is determined and its amount found. While these elements do exist in the fuel, most of them are combined with other substances; thus, part of the hydrogen is combined with different proportions of carbon, forming a whole series of substances, such as marsh gas, olefiant gas, etc., which are very volatile, that is, they are readily driven out of the fuel by heating it. The remainder of the hydrogen may be combined with oxygen in the form of water.

All of the carbon which is not combined with other substances is called *fixed carbon* because it exists as carbon and cannot be driven out of the fuel by a low degree of heat.

We see from the above that fuels contain volatile substances and nonvolatile or fixed substances, and the proximate analysis shows the relative amounts of these. When coal is heated away from air (so it will not burn) the volatile matter is driven off and a coke is left. This coke contains the fixed carbon and the ash.

It must be remembered that the fixed carbon shown by a proximate analysis does not represent *all* of the carbon in the fuel. A certain kind of coal may contain as much as 80 per cent carbon, yet have only 50 per cent of fixed carbon, the other 30 per cent being combined with hydrogen in the form of volatile matter.

**112. Bituminous Coal.**—The classification of bituminous coal is made difficult by the lack of sharp lines of distinction between the different varieties. In ultimate composition it consists of: carbon, 75 to 80 per cent; hydrogen, 5 to 6 per cent; nitrogen, 1 to 2 per cent; oxygen, 4 to 20 per cent; sulphur, 0.4 to 3 per cent; ash, 3 to 12 per cent.

The principal characteristic of this coal is that it emits yellow flame and smoke when burning. In color it varies from pitch black to brown, with a resinous luster in the denser varieties and a silky luster in the less compact specimens. All bituminous coals may be roughly divided into caking and non-caking.

**113. Caking Coal.**—This is the name given to those coals which, when thrown on the fire, seem to melt and run together. This fused mass of coal sometimes spreads entirely over the fire and seems to swell in size and form blisters in spots, these blisters bursting and emitting streams of gas which burn with a bright yellow or reddish flame terminating in smoke. These coals are usually very rich in volatile hydrocarbons and are, therefore, well adapted to gas making.

**114. Non-caking Coal.**—This name is applied to those varieties of bituminous coals which do not stick or melt together in the fire. For this reason they are sometimes called "free burning." Such coals are valuable for use under boilers because of the clean fires which they give. The structure of this variety of coal is in layers, which, when broken at right angles to the layers, show a bright shiny surface.

**115. Cannel Coal.**—This is a variety of bituminous coal which is very rich in carbon. It differs in appearance from other coals in being very compact and having a dull luster. When broken, the cleavage does not seem to follow any particular line. It kindles easily and burns freely with a bright flame resembling that of a candle, from which fact its name is derived. It varies in fixed carbon from about 40 to 55 per cent and in volatile matter from about 43 to 55 per cent, and from its richness in hydrocarbons it is very valuable in gas-making.

**116. Semi-bituminous Coals.**—These resemble the anthracite more closely than the bituminous, but they are lighter, and kindle and burn more readily. When they burn they give off an intense heat with very little smoke, and being free-burning it is easy to keep a clean, good fire which requires but little attention. For these reasons, semi-bituminous coal is very desirable as a steam-producing coal. In analysis it runs about as follows: fixed carbon, 70 per cent; volatile matter, 16 per cent; sulphur, 0.75 per cent; ash, 12 per cent.

**117. Semi-anthracite.**—Coal which contains from 7 to 12 per cent of volatile combustible matter is classed as semi-anthracite. It kindles and burns more readily than anthracite, is lighter, not so hard, and has not so much of a metallic luster as true anthracite.

A sample of this coal analyzes about as follows: fixed carbon, 88.90 per cent; volatile matter, 7.68 per cent; ash, 3.49 per cent.

**118. Anthracite.**—This coal ignites and burns with a short yellowish-blue flame and without giving off smoke. It contains only from 3 to 7 per cent of volatile combustible matter, which accounts for its short flame, but when ignited, gives off an intense heat due to the combustion of the almost pure carbon of which it is composed. This coal is distinguished by its hardness, density, and high specific gravity and by its metallic luster.

The standard commercial sizes are:

Egg coal, which must pass a 2¾-in. mesh but not through a 2-in. mesh.

Stove coal, which must pass a 2-in. mesh but not through a 1¼-in. mesh.

Chestnut coal, which must pass a 1¼-in. mesh but not through a 3/4-in. mesh.

Pea coal, which must pass a 3/4-in. mesh but not through a 1/2-in. mesh.

Buckwheat No. 1, which must pass a 1/2-in. mesh but not through a 1/4-in. mesh.

Buckwheat No. 2, which must pass a 1/4-in. mesh but not through a 1/8-in. mesh.

An average analysis of this coal shows it to contain fixed carbon 89.5 per cent; volatile matter, 4.5 per cent; ash, 6.0 per cent. The percentage of ash is lower in the larger sizes of coal and higher in the smaller sizes, increasing by about 1½ per cent from one size to the next smaller size.

**119. Petroleum.**—The only natural liquid fuel of any importance is crude petroleum. Petroleum has a high heating value, ranging from 18,000 to 20,000 B.t.u. per pound; therefore, it is possible to have a great amount of energy stored in a small space. Kerosene, benzine, and gasoline are all made by distilling petroleum, but, while these substances have a high heating value, they are not suitable as boiler fuels on account of their cost.

There are two kinds of petroleum found in the United States, that which yields a paraffin residue on being distilled, and that which yields asphalt. The former is found in the East and Middle West and yields such a variety of valuable light oils, that the crude product is too valuable to be used as fuel. Practically all of this oil is refined to obtain the more valuable and lighter oils. The asphaltic variety is found in Texas and California and is used mostly for fuel.

In general, petroleum is of a brownish color tinged with green, and it consists mostly of carbon and hydrogen. It also contains a certain percentage of water varying from 1 to 50 per cent, but, if the oil is handled properly when taken from the well, the water may be separated. As the water is a detriment, one should be careful in buying oil to see that the percentage of water is low. The amount of water and dirt in the oil may be determined by mixing a small quantity of it with an equal quantity of gasoline and allowing it to stand in a warm place for 24 hours, when the dirt and water will settle to the bottom.

A sample of Texas oil analyzed as follows: carbon, 85.66 per cent; hydrogen, 11.03 per cent; oxygen, 3.31 per cent. The heating value of this oil is 19,240 B.t.u. per pound.

**120. Heating Value of Fuels.**—The fuel elements which generate heat on being burned are carbon, hydrogen, and sulphur, though the latter is rarely ever present in sufficient quantities to be very important and is considered undesirable on account of the acid formed when it burns.

In the process of burning, these fuel elements unite with oxygen, and in doing so liberate a definite amount of heat for each pound of the fuel element which is so united. The carbon may form one of two substances. If there is sufficient oxygen present and the carbon is brought into contact with it, carbon dioxide will be formed. This is the product resulting from complete combustion of the carbon, since it has united with all the oxygen possible. If there is not sufficient oxygen present, the compound formed will be carbon monoxide.

The hydrogen unites with oxygen and forms water, and the sulphur unites with oxygen to form sulphurous acid, $SO_2$. These chemical combinations of the substances liberate heat to the extent shown by the following table:

| | |
|---|---|
| 1 lb. of carbon burned to $CO_2$ | 14,500 B.t.u. |
| 1 lb. of carbon burned to CO | 4400 B.t.u. |
| 1 lb. of hydrogen burned to $H_2O$ | 62,100 B.t.u. |
| 1 lb. of sulphur burned to $SO_2$ | 4000 B.t.u. |
| 1 lb. of CO burned to $CO_2$ | 4330 B.t.u. |

Whatever oxygen the fuel may contain is considered to be already combined with a part of the hydrogen in the form of water and, therefore, the amount of hydrogen available for combination with the oxygen of the air in the process of burning and hence for the production of heat, will be the total amount of hydrogen less that which is in combination with the oxygen in the coal. As 8 lb. of oxygen will combine with 1 lb. of hydrogen, the part of the hydrogen already combined with the oxygen in the coal will be $\frac{O}{8}$ where $O$ represents the weight of oxygen, and this quantity must be subtracted from the total weight of hydrogen in the coal. Thus the hydrogen left for heat production will be $\left(H-\frac{O}{8}\right)$, and, if the letters $H$ and $O$ represent the parts of a pound of the hydrogen and oxygen, then the heating value of the hydrogen will be $62{,}100\left(H-\frac{O}{8}\right)$. If the part of a pound of fuel which is carbon is represented by $C$, the heat obtained from the combustion of the carbon will be 14,500 $C$, and, in a like manner, the heat evolved by the burning of the sulphur will be 4000 $S$. Therefore, the entire heating value of the fuel will be

$$\textit{Heating value in B.t.u.} = 14{,}500C + 62{,}100\left(H-\frac{O}{8}\right) + 4000S.$$

If $C$, $H$, $O$, and $S$ represent the weight of each of these substances in a pound of fuel, the heating value will be expressed in B.t.u. per pound. As an illustration of the application of this formula, we will find the heating value per pound of coal which analyzes as follows: carbon, 80 per cent; hydrogen, 5 per cent; oxygen, 2.7 per cent; nitrogen 1.1 per cent; sulphur, 1.2 per cent; ash, 8.3 per cent.

$$\begin{aligned}\text{B.t.u. per lb.} &= 14{,}500C + 62{,}100\left(H-\frac{O}{8}\right) + 4000S \\ &= 14{,}500\times .80 + 62{,}100\left(.05-\frac{.027}{8}\right) + 4000\times .012 \\ &= 11{,}600 + 2894 + 48 \\ &= 14{,}542\end{aligned}$$

From the above it is seen that of the entire 14,542 B.t.u. in the pound of coal, the carbon furnishes 11,600, the hydrogen 2894, and the sulphur only 48. The small amount furnished by the sulphur might well be neglected and this is, in fact, often done. Owing to the many difficulties in the way of getting an accurate analysis of coal and to the length of time taken, it is better and quicker to find the heating value of coal by means of a coal calorimeter, which is an instrument in which the coal is actually burned and the heat which is evolved is measured. A detailed

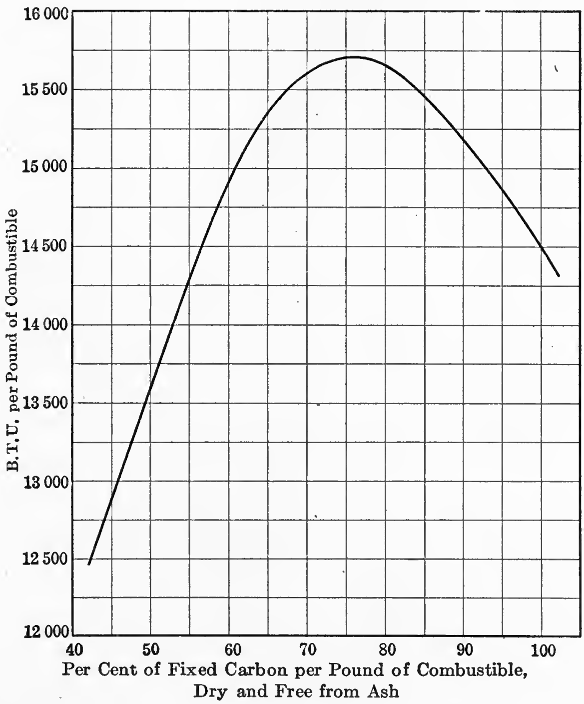



Fig. 72.

account of this apparatus and its operation may be found in books on Fuels.

Owing to the time required and the difficulty in making an ultimate analysis, it is not usually done in commercial work, but instead, the proximate analysis is made as this can be done in a much shorter time. For this reason we see the proximate analysis of a coal stated much oftener than the ultimate. It would be very desirable to have some short method of calculating the heating value of a fuel from its proximate analysis, as may be done from the ultimate analysis. Several equations for doing this have been proposed but none of them seem to give very satisfactory results when applied to American coals.

To accomplish the same results, the heating values of a great many American coals have been plotted on the curve shown in Fig. 72. If the proximate analysis of a coal is known, its heating value can be obtained from this curve with a fair degree of accuracy.

As the exact composition, and hence the heating value of that part of the coal known as the volatile matter, is quite variable, it is reasonable to suppose that where the analysis shows a small percentage of fixed carbon in the combustible matter, or in other words, a large portion of volatile matter, the curve will not be as accurate as when the fixed carbon is large. In general, the curve will give results which are within 5 per cent of the true heating value of the coal, and this is close enough for many purposes.

To illustrate the use of the curve, consider a sample of Illinois coal showing the following proximate analysis.

| | |
|---|---|
| Moisture | 5.96 per cent |
| Volatile matter | 30.29 per cent |
| Fixed carbon | 52.16 per cent |
| Ash | 11.59 per cent |
| | 100.00 per cent |

The ash and moisture are not combustible. Therefore, the combustible consists of

| | |
|---|---|
| Volatile matter | 30.29 per cent |
| Fixed carbon | 52.16 per cent |
| | 82.45 per cent |

and the per cent of fixed carbon per pound of *combustible* is

$$52.16 \div 82.45 = 63.3 \text{ per cent.}$$

Finding the percentage 63.3 on the base line of the curve and following this point upward until we reach the curve, then looking opposite this point to the left-hand margin, we find the heating value *per pound of combustible* to be 15,225 B.t.u. As the combustible forms only 82.45 per cent of the coal, the heating value *per pound of coal* is

$$15{,}225 \times .8245 = 12{,}553 \text{ B.t.u.}$$

## CHAPTER X

### CHEMISTRY OF COMBUSTION

**121. Combustion.**—Combustion may be defined as the chemical union of a substance with oxygen, accompanied by the giving off of light and heat. Some substances unite with oxygen so slowly as not to give off light, and this process would not be called combustion. Such is the case when iron rusts. The same amount of heat is given off, however, whether the process takes place slowly or rapidly. The substance that burns is called the *combustible* while the oxygen is the *supporter of combustion.*

**122. Oxygen.**—Oxygen is the universal supporter of combustion and our largest source of supply for it is the atmosphere. Although oxygen is one of the most common substances, yet it is never found alone in nature, but is always associated with some other substance, being either combined with it, or merely in the form of a mechanical mixture. By a combination of substances is meant the union of them into a single substance, as when hydrogen and oxygen unite to form water. In a mechanical mixture the substances are not united but are simply mixed and each retains all its original characteristics. Air is a mechanical mixture of oxygen and nitrogen in the following proportions.

COMPOSITION OF AIR

| | Parts by volume | Parts by weight |
|---|---|---|
| Oxygen................ | .207 | .23 |
| Nitrogen................ | .793 | .77 |

Nitrogen is an inert substance, that is, it does not combine readily with other substances and seems to be there merely for the purpose of diluting the oxygen. The above proportions of oxygen and nitrogen seem to be fairly constant in air taken from any part of the earth. Besides these substances, there are small amounts of other gases in air, but they are present in such small quantities that we need not consider them here.

Oxygen is a very active substance and under favorable conditions combines readily with almost any other element.

**123. Carbon.**—Of all combustible substances found in nature, the most common and easily obtained is carbon and it is by reason of the large amounts contained in coal, wood, and other fuels, that these substances are so valuable as fuels.

Carbon is an infusible, non-volatile substance which is found in nature in three forms: viz., (1) diamond, (2) plumbago or graphite, (3) charcoal or lampblack. Among natural fuels, anthracite coal approaches most nearly to pure carbon and is classed between graphite and charcoal, while of the artificial fuels, coke has a very large percentage of carbon.

**124. Chemical Definitions.**—All substances are either elements, compounds, or mixtures.

An Element is a substance which, so far as we know at present, cannot be broken up into any simpler form. Iron, carbon, silver, hydrogen, oxygen, and nitrogen are all elements and there are a great many more that need not be considered here.

A Compound is a substance which can be broken up into simpler forms by chemical process and is thus known to be a combination of certain elements. Water is a compound and we find by decomposing it that hydrogen and oxygen are the elements which compose it. Carbonic acid is a compound formed by the union of carbon and oxygen.

A compound is represented by a formula composed of the letters representing the elements of which the compound is composed. For example, $H_2O$ is the formula for water, and indicates that two atoms of hydrogen are combined with each atom of oxygen in forming the water. $CO_2$ is the formula which represents carbonic acid, and indicates that two atoms of oxygen have combined with one of carbon.

A Mixture consists of two or more substances that are merely mingled together without causing any chemical change in any of the ingredients. Coal is a mixture of moisture, ash, fixed carbon, and volatile matter. The air is a mixture of nitrogen and oxygen.

**125. Molecules and Atoms.**—If a substance were divided and redivided into particles, until we had the smallest particle of that substance which could exist by itself without losing the nature of the substance, we would have what is known as a *Molecule* of that substance, and, if this molecule were broken up into the chemical elements which make it up, these new divisions would be what are called *Atoms* and are, presumably, indivisible. The chemical symbols for compounds indicate to us the numbers and kinds of atoms which are contained in each molecule of the compound. For example, the symbol $H_2O$ for water indicates that two atoms of hydrogen and one atom of oxygen comprise one molecule of water. The symbol for ethyl, or grain, alcohol is $C_2H_6O$ and from this symbol we know that one molecule of alcohol contains two atoms of carbon, six of hydrogen, and one of oxygen. As a rule atoms seldom exist uncombined, as they have a tendency to combine with other atoms unless conditions are such as to prevent it. This tendency of atoms to combine, explains why a molecule of hydrogen gas has two atoms of hydrogen. Similarly, the molecules of oxygen and nitrogen also each contain two atoms. In other words, if an atom of a substance has nothing else to combine with, it will unite with one or more atoms like itself.

**126. Atomic Weights.**—The atoms of different substances have different weights and, as that of hydrogen is the lightest, its atomic weight is generally given as 1 and the weights of the other atoms are given in terms of that of hydrogen.

The following table gives the atomic weights of the elements which need to be dealt with in the study of fuels.

| Element | Symbol | Atomic weight |
|---|---|---|
| Hydrogen | H | 1 |
| Carbon | C | 12 |
| Sulphur | S | 32 |
| Oxygen | O | 16 |
| Nitrogen | N | 14 |

**127. Molecular Weights.**—When two or more elements combine to form a compound, the relative weight of the molecule of the compound will equal the sum of the weights of the atoms which comprise it. This is called the molecular weight of the compound. One atom of oxygen combines with two of hydrogen to form water, and from this we see that the molecular weight of water equals the weight of one atom of oxygen ($=16$) plus the weight of the two atoms of hydrogen ($=2$), so that the molecular weight of water is 18. From this we gather that 2/18 of the water by weight is hydrogen and 16/18 is oxygen. The molecular weight of $CO_2 = 12 + 32 = 44$. By weight, 12/44 is carbon and 32/44 is oxygen. Twelve pounds of carbon and 32 lb. of oxygen will form 44 lb. of $CO_2$.

**128. Compounds of Carbon and Oxygen.**—Some substances will unite with oxygen in more than one proportion. Such is the case with carbon. If there is an abundant supply of oxygen present and the conditions are favorable, each atom of carbon will take up two atoms of oxygen. This is the greatest number of atoms of oxygen which one atom of carbon ever takes up. If the atom of carbon unites with two atoms of oxygen *complete combustion* takes place, since there is an abundant supply of oxygen. The product of this union of the carbon and oxygen is $CO_2$, which is variously called carbonic acid, carbon dioxide, or most often by merely the chemical formula $CO_2$. When the carbon is burned completely to $CO_2$ there will be given off 14,500 B.t.u. for every pound of carbon burned. This quantity is called the heat of complete combustion of carbon.

If, on the other hand, there is not a sufficient supply of oxygen present, then each atom of carbon will unite with only one atom of oxygen and the product will be carbon monoxide, whose chemical symbol is CO. When carbon unites with oxygen to form carbon monoxide there are only 4400 B.t.u. given off for every pound of carbon burned. This shows the importance of securing complete combustion in the furnace since, for every pound of carbon burned, there is a loss of $14{,}500 - 4400 = 10{,}100$ B. t.u. if the combustion is incomplete.

Carbon dioxide is a colorless gas one and a half times heavier than air, and has a slightly acid taste and smell. It is incombustible since it is already the product of complete combustion. It is not a direct poison but it will not support animal life or combustion.

Carbon monoxide gas is slightly lighter than air, is colorless and ordorless. It is a direct poison and is dangerous because when it enters the system it takes up oxygen from the blood. Since it is the product of incomplete combustion it will burn, and in so doing take up one more atom of oxygen for every molecule of carbon monoxide, thus forming $CO_2$. The process may be represented by

$$CO + O = CO_2$$

When CO burns to $CO_2$ there will be given off 10,100 B.t.u. for every *pound* of *carbon* involved in the operation, but for every *pound* of *carbon monoxide* burned there will be given off only 4330 B.t.u., since 1 lb. of carbon monoxide contains only a fraction of a pound of carbon.

**129. Process of Combustion of Fuel.**—Besides carbon, coal contains other substances in smaller quantities, such as hydrogen, oxygen, sulphur, and also the incombustible matter which is called ash. The hydrogen is combined with a part of the carbon in a series of compounds called *hydrocarbons.* This series of hydrocarbons consists of about 50 compounds, the simplest of which is $CH_4$ and ranging from this to the most complex forms of carbon and hydrogen. These hydrocarbons are very inflammable and when burned they are split up into simpler and simpler forms until finally all the carbon is united with oxygen to form $CO_2$ if the combustion is complete, and the hydrogen unites with oxygen to form water, $H_2O$.

As there is a large percentage of carbon in coal, there is much more than is needed to make up the hydrocarbon compounds. All the carbon which is not thus combined is known as the fixed carbon.

It may thus be seen that the process of combustion is a very complicated one and it is impossible to tell exactly what does take place in the furnace of a boiler. Associations and dissociations of the elements in the fuel occur in rapid succession. Combinations which are formed at first are later split up by the intense heat and their parts again unite into the same or simpler combinations. But, whatever the process, it is certain that the products of complete combustion should be carbon dioxide ($CO_2$), water ($H_2O$), nitrogen ($N_2$), and perhaps a small quantity of sulphurous acid ($SO_2$), while if the combustion is incomplete there will be some carbon monoxide (CO) and less $CO_2$.

While we do not know exactly the order of events in the combustion of coal we may say in a general way that when the fresh coal, say of a bituminous character, is thrown on the fire, it absorbs some heat from the fire in being warmed and the fire is cooled thereby. When the coal is heated to 212°, the moisture contained in it begins to evaporate and this cools the fire more, since heat is abstracted from the fire in order to evaporate the moisture. At a temperature of about 220° the volatile hydrocarbons begin to be driven off and, mixing with air and passing over the hot bed of coal, burn into $CO_2$ and water. During this stage of the combustion it is very important that the hydrocarbons be mixed with a sufficient supply of air to insure their being burned completely, and for this purpose considerable air should be admitted through the fire doors above the fire so as to come into direct contact with the hydrocarbons. If the particles of carbon liberated by the splitting up of the hydrocarbon compounds do not immediately meet with sufficient oxygen, they will unite with only one atom of oxygen, forming CO, and, by the time they have come in contact with sufficient oxygen, they may be cooled to so low a temperature that the union is impossible, and the carbon will then pass out as the product of incomplete combustion, CO. Thus it is seen to be of extreme importance to insure that the carbon be burned completely to $CO_2$ before it is allowed to be cooled by coming in contact with any metal surfaces, such as the tubes or the shell of a boiler.

During the combustion of the fixed carbon left on the grate the following process is assumed to take place. The air passes through the grate and, encountering incandescent carbon, the plentiful supply of oxygen causes the formation of $CO_2$. Some of this gas will take up more carbon and form CO as it passes upward through the fuel bed. If there is sufficient oxygen left uncombined, this CO will immediately burn to $CO_2$. There is always, however, some CO in the gases rising from the top of the fuel bed and the uniting of this CO with the oxygen necessary to form $CO_2$ explains the short blue flames usually seen at the top of a coke fire. Unless this CO is brought in contact with an excess of oxygen above the fire it will pass out of the chimney in the form of CO, with its attendant loss of heat as pointed out before. This points again to the necessity for securing complete combustion of the carbon before it leaves the furnace, for once it has left the furnace in the form of CO there is small chance of its combining with more oxygen to form $CO_2$, as this operation requires a high temperature and the further away from the furnace the gas gets the cooler it becomes.

**130. Air Required for Combustion.**—From a knowledge of the atomic weights of substances and the composition of air we may readily calculate the air required for combustion of any fuel, if we know the composition of the fuel. The process is best illustrated by an example. Suppose we wish to calculate the amount of air required to burn a certain kind of Illinois coal having the following composition.

| | | Parts to 1 lb. |
|---|---|---|
| Carbon | 69.80 per cent | 0.6980 |
| Hydrogen | 5.26 per cent | 0.0526 |
| Oxygen | 8.35 per cent | 0.0835 |
| Nitrogen | 1.33 per cent | 0.0133 |
| Sulphur | 2.02 per cent | 0.0202 |
| Ash | 13.24 per cent | 0.1324 |
| | 100.00 | 1.0000 |

The nitrogen and the ash take no part in the combustion, so we have to consider only the carbon, hydrogen, oxygen, and sulphur.

We have already seen that in forming water, 1 lb. of hydrogen will unite with 8 lb. of oxygen. This is obtained from the atomic weights.

$$H_2:O=(2\times 1):(1\times 16)=2:16=1:8$$

If the carbon is burned completely the product will be $CO_2$ and, since the atomic weight of carbon is 12, the proportion of oxygen to carbon will be

$$O_2:C=(2\times 16):12=32:12=2\tfrac{2}{3}:1$$

In other words, $2\frac{2}{3}$ lb. of oxygen are required to burn 1 lb. of carbon to $CO_2$.

In the same way, the atomic weight of sulphur is 32, and in burning to sulphurous acid $SO_2$, the oxygen required may be found from the proportion of oxygen to sulphur.

$O_2:S=(2\times 16):32=32:32=1:1$ Or 1 lb. of oxygen is required to burn 1 lb. of sulphur to $SO_2$.

We may consider that all the oxygen that is in the coal is already combined with a part of the hydrogen, rendering it inert as far as combustion is concerned. Thus the .0835 of a pound of oxygen will be already combined with $\frac{.0835}{8}=.0104$ lb. of hydrogen. Enough oxygen will have to be supplied in the air then to combine with

| | | |
|---|---|---|
| Carbon | = | .6980 lb. |
| Hydrogen .0526 − .0104 | = | .0422 lb. |
| Sulphur | = | .0202 lb. |

| | | |
|---|---|---|
| The carbon will require | $.698\times 2\frac{2}{3}=1.861$ | lb. of oxygen. |
| The hydrogen will require | $.0422\times 8=.3376$ | lb. of oxygen. |
| The sulphur will require | $.0202\times 1=.0202$ | lb. of oxygen. |
| Making the total oxygen required | 2.2188 lb. | |

As air contains .23 parts by weight of oxygen, the weight of air which will contain 2.2188 lb. of oxygen will be $2.2188 \div .23 = 9.64$ and this is the amount of air needed to supply sufficient oxygen to completely burn 1 lb. of the fuel mentioned above. As 1 lb. of air at 62°F., has a volume of 13.14 cu. ft., 9.64 lb. would occupy a volume of $9.64 \times 13.14 = 126.67$ cu. ft. and this quantity of air would have to be admitted to the furnace for every pound of coal burned.

For approximate determination of the air required for combustion the following formula may be used.

$$\text{Weight of air} = 12C + 35\left(H - \frac{O}{8}\right)$$

in which $C$, $H$, and $O$ represent the parts of a pound of carbon, hydrogen, and oxygen respectively in a pound of the coal. By this formula, the sample of coal we have just been considering would require

$$12 \times .698 + 35\left(.0526 - \frac{.0835}{8}\right)$$

$$= 8.38 + 35 \times .0422 = 8.38 + 1.47 = 9.85 \text{ lb.}$$

which is quite close to the result obtained before. As it is unnecessary for practical purposes to calculate accurately the amount of air required to burn coal, and as most fuels require between 11 and 12 lb. of air per pound of fuel, it is usual to consider that 12 lb. of air will be required to burn each pound of coal.

When it is considered how complicated the chemical actions are and how great the chances that the carbon will not meet its full complement of oxygen, it will readily be seen that it is necessary to admit more air into the furnace than is actually required to burn the coal, in order to be sure that each atom of carbon will meet an abundance of oxygen. This excess air is sometimes called *air of dilution* because it dilutes the gases rising from the fire and mingles with them, giving each atom of carbon an opportunity to combine with as much oxygen as it will. The amount of excess air necessary depends upon the draft of the chimney; the weaker the draft, the more air of dilution is required. It is usual to supply twice as much air as is actually required for combustion when natural draft is used and one and one-half times as much when forced draft is used. The air of dilution is then 100 per cent for chimney draft and 50 per cent for forced draft.

**131. Flue Gas.**—A sample of the products of combustion leaving a furnace may be collected and analyzed by a simple method, and this gives a check on the way in which the fires are being handled. It has been shown that an excess of air must be admitted to the furnace in order to complete the combustion. If the air supply is not sufficient, some of the carbon cannot

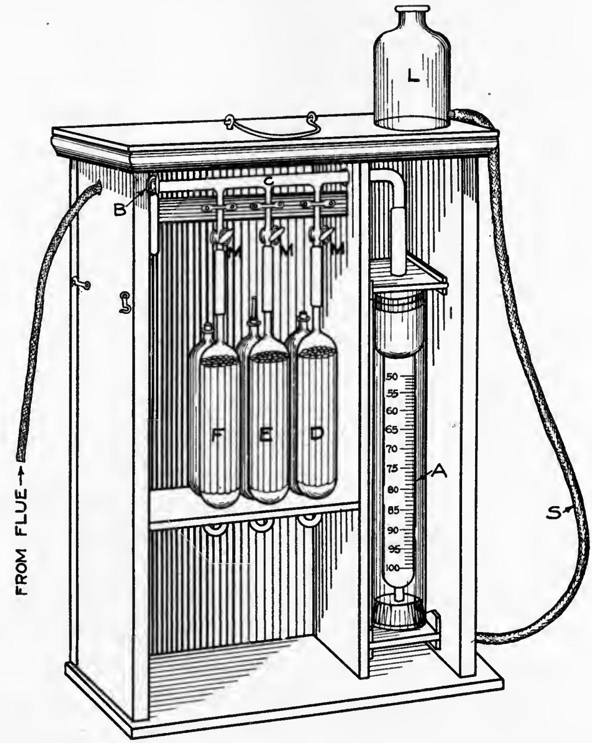



FIG. 73.—Orsat flue gas apparatus.

burn completely, and this will be indicated by CO showing in the flue gases, as the products of combustion are called.

The amount of oxygen present in the flue gases gives an indication of the amount of excess air admitted to the furnace, and the amounts of CO and $CO_2$ indicate the completeness of the combustion. From what has been said before, it will be seen that the flue gases will consist of $CO_2$ and CO, formed by the burning of the carbon; steam or water vapor formed by the burning of hydrogen; oxygen which is supplied in greater quantities than actually needed to carry on combustion and some of which therefore must pass out of the chimney in the form of oxygen; and nitrogen, which is inert and plays no part in the combustion.

The amount of these constituents present in the flue gas, except the steam, which condenses at the temperatures at which the analysis must be made and which therefore disappears from the gas, may be found by means of a simple device called an Orsat Apparatus (see Fig. 73). This consists of three pipettes, *D*, *E*, and *F*, filled respectively with caustic potash, a mixture of caustic potash and pyrogallic acid or pyrogallol, and cuprous chloride. A measuring burette, *A*, is also attached to the apparatus. A sample of the flue gas, say 100 c.c. (cubic centimeters), is taken into the measuring burette and then passed to the pipette *D* containing the caustic potash, which absorbs all the $CO_2$. If the volume of the gas is noted before and after the absorption, the difference will be the amount of $CO_2$ present in the flue gas. The gas is then passed through the second pipette *E* containing the mixture of caustic potash and pyrogallic acid, which absorbs the oxygen. The shrinkage in volume will be the amount of oxygen present in the flue gas. In the same way, the CO may be found by passing the remaining gas through the third pipette *F* containing the cuprous chloride, which absorbs CO. The remaining gas may be considered to be nitrogen.

If the combustion had been complete and there had been only enough air present to burn the fuel, then the flue gas would show by analysis only $CO_2$ and N, since all the oxygen would be combined with the carbon. Since air consists by volume of oxygen .207 parts and nitrogen .793 parts, the flue gas would then show by analysis $CO_2$, 20.7 per cent, and nitrogen 79.3 per cent, because $CO_2$ occupies the same volume as the oxygen from which it is formed. Now, as it is necessary to supply about 100 per cent excess air, the percentage of $CO_2$ will be much less than 20.7. Combustion will be complete when the percentage of $CO_2$ lies between 10 and 12 and when there is no CO, and the furnace should be so handled that these results will be obtained.

No more excess air should be admitted to the furnace than is required to secure complete combustion, as the air chills the fire and also causes a loss of heat by carrying off heat up the chimney. The heat lost in this way will depend on the weight of gases passing up the chimney, being equal to the weight of flue gases times their average specific heat times the difference in temperature through which they have to be heated. The average specific heat of the flue gases is about .25 and their temperature will usually be between 400° and 500°. If we consider the room temperature as 60° the difference in temperature will be about (450 − 60) = 390°. Now, if 24 lb. of air are admitted for every pound of coal burned and if nine-tenths of the coal is combustible and, therefore, passes up the chimney in the products of combustion, the total weight of the flue gas will be about 24.9 lb. per pound of coal burned. The loss per pound of coal from hot gases passing up the chimney would then be

$$24.9 \times .25 \times 390 = 2428 \text{ B.t.u.}$$

Now if the heating value of the coal was 13,000 B.t.u. per pound, this would represent a loss of $\frac{2428}{13000} = 18.7$ per cent of the total heating value of the coal. It will be readily seen that the greater the amount of air used the greater will be this loss of heat.

**132. Flue-gas Analysis.**—The sample of flue gas is usually taken from the breeching between the boiler proper and the stack, and preferably at a point where the flue gases are just leaving the boiler. A sampler may be constructed in the manner indicated in Fig. 74. The sampling tube may be made from a piece of 1/4-in. gas pipe having a length about 6 in. greater than the width of the breeching at the point where the sample is to be taken. A washer made of heavy rubber packing is placed on the sampling tube and held in place by a thin steel washer and collar on each side. The rubber washer should have a diameter about 6 in. greater than the hole in the breeching, so it may be held closely against the breeching while the sample of flue gas is being taken, thus excluding air from the sample. A number of 1/8-in. holes should be bored in the sampling tube in order that the sample collected may come from different portions of the breeching. The flexible rubber washer allows the sampling tube to be moved around over the cross-section of the flue, thus insuring that the sample collected will represent the average of the flue gas passing out of the stack.

The gas can be conveniently collected by means of the apparatus shown, consisting of two small tanks, each of about a gallon capacity. Each tank has a valve at $P$ and also at $Q$ as indicated.

Connect the valves *Q* by means of a small rubber hose, 2 to 3 ft. in length. Connect a sampling tube to one of the valves *P* by means of a rubber hose *N*. In preparation for collecting a sample, fill the tank *R* with water and have a small amount of water in the tank *S*, just barely sufficient to cover the entrance to the valve Q. Raise the tank *S* above the level of the discharge

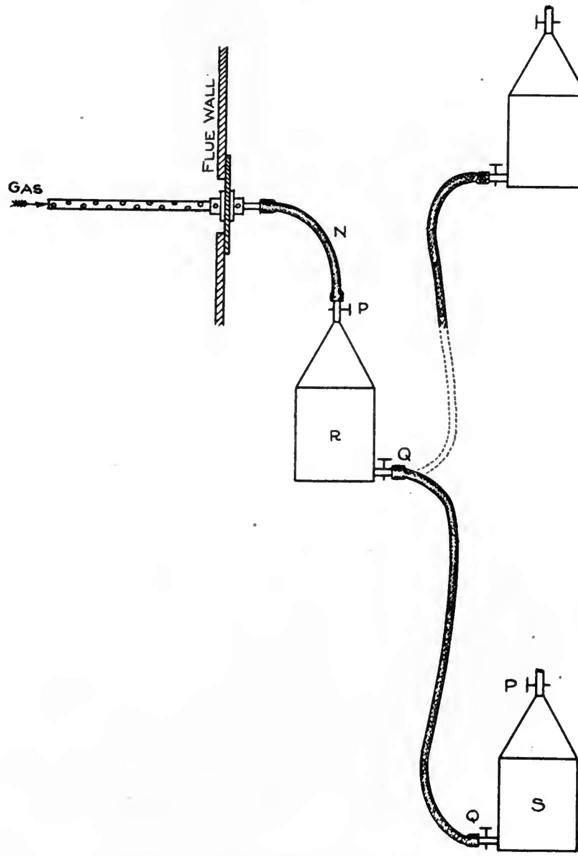



Fig. 74.—Sampling tube and tanks.

from the sampling tube and fill the hose *N* and also the sampling tube with water. Introduce the sampling tube into the stack and lower tank *S*, allowing the water to flow from tank *R* to tank *S*. The gases will thus be drawn into tank *R*. Again raise tank *S* above the level of the sampling tube and allow the water to return, again completely filling tank *R* and hose *N*.

Again lower tank *S* and take in a second sample, which sample will be used for the analysis. The first sample is taken into the tanks to saturate the water with $CO_2$, so that when the second sample is taken in, the water will not absorb any more of the $CO_2$, but will leave the sample just as it was in the flue. Disconnect hose *N* at *P* and connect tank *R* to the Orsat apparatus (see Fig. 73). To do this, attach a small hose to the capillary tube *C*. Open the valve *B* and completely fill this rubber tube with water in order to expel the air. Connect the rubber tube to the tank *R* at the valve *P*, lower the bottle *L*, and open the valve *P*. The water which was present in the hose connection will be drawn back to the measuring tube *A* and will then be followed by the gas. Allow the water from the measuring tube to flow into the bottle *L* until approximately 100 c.c. of the gas have been drawn into the measuring tube. Valve *B* is a three-way valve, one passage communicating with the atmosphere. Open the passage to the atmosphere, raise the bottle *L* and expel all of the gas which is present in the measuring tube. This gas is wasted so as to eliminate any error which might arise from the fact that air might have been trapped in the tube connections. This air would be drawn into the measuring tube when the first charge of gas is taken into the apparatus. Having discharged all of the gas, place valve *B* in such a position that a passage is again opened into the tank *R* containing the gas supply. Again lower bottle *L*, drawing in a little more than 100 c.c. of gas. Now close valve *P* and also valve *B*. At *S* there will usually be found a pinchcock which can be used for closing the connection between the bottle *L* and the measuring tube *A*. Bring the level of the liquid in the bottle *L* even with the level of the water in the measuring tube *A*, and open *S*. This will insure atmospheric pressure in the measuring tube *A*. If there are more than 100 c.c. of gas at atmospheric pressure, raise the bottle *L*, compress the gas to 100 c.c., close *S*, and open valve *B* for an instant to allow the surplus to pass to the atmosphere. Close valve *B*, again bring the level of the water in the bottle *L* even with the level of the water in the measuring tube *A*, open *S* to see if you have 100 c.c. of gas at atmospheric pressure. If there are still more than 100 c.c., repeat the operation. Having obtained 100 c.c. of gas at atmospheric pressure, open valve *M*, communicating with pipette *D*, raise the bottle *L*, and force the gas from the measuring tube into the pipette *D*. This pipette should absorb the carbonic acid which is present. Allow the gas to remain in pipette *D* for 4 or 5 minutes, during which time it may be taken back and forth two or three times. Now draw the gas back into the measuring tube *A* and in doing so bring the level of the liquid in pipette *D* to the mark which will be on the capillary tube just below *M*, then close the valve *M* of pipette *D*. Bring the level of the water in bottle *L* even with the level of the water in the measuring tube *A*, open *S*, thus insuring atmospheric pressure in the measuring tube. The reading will now indicate the number of c.c. of $CO_2$ which have been removed. Repeat the operation, returning the gas to pipette *D* and finally take the reading at atmospheric pressure as before. If the readings are the same, it is evidence of the fact that all of the $CO_2$ has been removed from the gas and, since we began with 100 c.c., the number of c.c. of $CO_2$ which have been removed will also be the per cent of $CO_2$ present in the flue gases.

Having removed the $CO_2$, open the valve *M* in pipette *E* and repeat the operation, using pipette *E* for the absorption of the oxygen.

After removing the oxygen, allow the gas to pass into pipette *F* in order to remove the CO.

**133. Preparation of Reagents.**—The reagents for filling the pipettes *D*, *E*, and *F* may be prepared as follows:

**Caustic Potash.**—Dissolve one part by weight of caustic potash made by the lime process in two to three parts of distilled water. The caustic potash must have been made by the lime process, as that made by the alcohol process is apt to give rise to errors when analyzing the flue gas.

**Pyrogallol.**—Take about 5 grams of pyrogallic acid (which is a snow-like powder) and wash it into the middle pipette, *E*, with the solution of caustic potash described above.

**Cuprous Chloride.**—Make up a stock bottle by taking 2 oz. of black copper oxide, 1 quart of commercial hydrochloric acid, and 1/2 lb. of copper wire, putting them in a bottle having an air-tight (rubber) stopper. Let this mixture stand until clear, which takes about 10 days, when it becomes ready for use. Fill the pipette from stock bottle and then add more acid to the stock bottle, and, if it seems to be needed, more copper wire or copper oxide. In this way a constant supply may be kept on hand. The cuprous chloride is the only reagent that must be prepared previous to the analysis.

## CHAPTER XI

### FIRING

**134. Methods of Firing.**—It is very hard to lay down any general rules for firing, as different kinds of coal require different treatments. Coals differ very much in their character and the way in which they should be handled. However, there are a few general principles which will apply to all kinds of coal and which should be observed. The best method of handling the fire with any particular kind of fuel is best found by experimenting with it, and this the fireman soon learns to do. There are three general methods of firing, known respectively as the *coking* method, the *alternate* method, and the *spreading* method.

**135. The Coking Method.**—The coking method should be used with those bituminous coals which cake, or seem to melt and run together, and it also serves well for coal which contains a large percentage of hydrocarbons, even if the coal is not a caking variety. In the coking method of firing, the fresh coal is placed just inside the furnace door and allowed to remain there until the heat from the fire drives the hydrocarbons out of the coal. As the hydrocarbons are driven off, a considerable quantity of air should be allowed to enter through the damper in the door. The air and hydrocarbons will become mixed and, as they have to pass over the hotter portions of the fire in order to reach the chimney, they should ignite and burn completely to carbon dioxide and water. After the hydrocarbons are driven out of the coal, the remainder is in the form of coke, which may be pushed back into the hotter portions of the fire where complete combustion is readily secured, and its place taken by a fresh charge of coal. Most of the mechanical stokers in use to-day make use of the coking method of firing.

The three requirements for securing complete combustion of the coal are: (1) to have a sufficient quantity of air; (2) to thoroughly mix the air with the hydrocarbon gases arising from the coal; (3) to have a sufficiently high temperature in the furnace to cause the oxygen in the air to unite with the hydrogen and carbon compounds in the gases.

These three requirements are very well met in the coking method of firing. The hottest portion of the fire is near the bridge wall where the coke is burning. Being in this position, the hydrocarbon gases must pass through a region of very high temperature on their way to the chimney. The hydrocarbons are driven off near the front of the fire where a sufficient quantity of air may be secured through the door, and the air will have sufficient opportunity to become thoroughly mixed with the hydrocarbons before they have reached the hottest part of the fire, and thus they will have no opportunity to pass out of the furnace without coming in contact with sufficient oxygen.

If it is attempted to fire a caking coal by spreading it over the fire, some of it will, of course, be placed back near the bridge wall and the hydrocarbons from this portion of the coal will have an opportunity to pass out of the furnace without becoming mixed with sufficient air, hence, will be unburned and the heat which they contain will be lost. The coal placed on other portions of the fire will soon melt and run together, forming a pasty mass which covers the entire fuel bed and serves to largely cut off the supply of air coming up through the grate. It will then require a much stronger draft to burn it than if the coking method of firing had been used. In this connection it may also be said that in the coking method, since the back part of the fire where the coke is being burned is much more open than the front part where the coal is being coked, the air will pass more readily through the back part of the fire, and for this reason it should be kept quite thick. A disadvantage of this method of firing is that the fire must necessarily be stirred up considerably when the coke is pushed back, and it is now recognized that the fire should be disturbed as little as possible.

**136. The Alternate Method.**—In this method, fresh coal is fired in a thin layer on first one side of the grate and then on the other. The volatile matter distilled from the fresh charge on one side is effectively burned by the air, which is heated when passing through the other side. Even in this case some of the hydrocarbons given off near the bridge wall are likely to pass out of the furnace without being burned. The two important stages of coal burning (combustion of the volatile matter and burning of the carbon) occur continuously with this method of firing. This makes it unnecessary to be continually altering the air supply to correspond with first one stage of the combustion and then with the other, as must be done when other methods of firing are used. The alternate method gives excellent results when properly carried out, but it is necessary to make provisions for thoroughly mixing the gases from the two sides of the fire if we expect to burn the volatile gases.

In this method, and in the spreading method to be described next, the coal should be thrown exactly where it is wanted and not be further disturbed by the poker or slice bar, except when absolutely necessary to clean fires or break up clinkers.

**137. Spreading Method.**—In this method very little coal is fired at a time, but it is fired often and each charge is spread evenly over the entire fire in a thin layer. The spreading method is perhaps used more extensively in hand firing than any other, probably on account of its being the easiest. This method has considerable merit when the boiler is set high above the grate so the gases may rise straight up from the coal, thus having an opportunity to burn before passing out of the combustion chamber. It is true that by the spreading method of firing some of the volatile matter rising from the coal near the back end of the grate will pass over the bridge wall without being burned, but the loss from this source will be small if the coal is spread in a thin layer and if a hot fire is maintained. This method, in common with the alternate method, has the advantage that the fire need be disturbed but little. Sometimes a modified spreading method is used whereby the coal is fired in patches, covering only a portion of the grate. It appears, however, that this modification has no advantage over the ordinary spreading method.

**138. Rules for Hand Firing.**—The following excellent rules have been formulated by the Coal Stoking and Anti-smoke Committee of the Illinois Coal Operators Association for the hand firing of Illinois and Indiana coals.

(1) Break all lumps, and do not throw any in the furnace which are larger than your fist. The reason for this is that large lumps do not ignite promptly and their presence also causes holes to form in the fire, which allow the passage of too much air.

(2) Keep the ash pits bright at all times. If they become dark this is evidence that the fire is getting dirty and needs cleaning, which, if not done, will cause imperfect combustion and smoke. If the furnace is equipped with a shaking grate, it should be

operated often enough to prevent any accumulation of ashes in the fire. Do not allow ashes to collect in the ash pits, as they not only shut off the air supply, but may cause the grate to be burned.

(3) In firing do not land the coal all in one heap but, as it leaves the shovel, spread it over as wide a space as possible. A little practice will enable one to catch the proper motion to give the shovel in order to make the coal spread properly.

(4) Place the fresh coal from the bridge wall forward to the dead plate and do not add more than three or four shovels at a charge. If this amount makes smoke it should be reduced till smoke ceases, which means, of course, that firing will be at more frequent intervals than formerly to keep up steam. This rule applies in cases where the boiler is worked at a large capacity. In such instances, however, where a small capacity only is required, firing by the coking method, wherein the fresh coal is placed at the front of the fire, and pushed back and leveled when it has become coked, is the best.

(5) Fire one side of the furnace at a time so that the other side containing a bright fire will ignite the volatile gases from the fresh charge.

(6) Do not allow the fire to burn down dull before charging. If this is done, it will not only result in a smoky chimney, but an irregular steam pressure.

(7) Do not allow holes to form in the fire. Should one form, fill it by leveling and not by a scoop full of coal. Keep the fire even and level at all times. As far as possible level the fire after the coal has become coked.

(8) Carry as thick a fire as the draft will allow, but in deciding on the proper thickness, judgment must be exercised. If the draft is weak, a thin fire will be in order, but if strong, a thicker fire should be carried.

(9) Regulate the draft by the bottom or ash pit doors and not by the stack dampers, because, when the stack damper is used, it tends to produce a smoky chimney as it reduces the draft, while the closing of the ash pit door diminishes the capacity to burn coal. If strict attention is given to firing according to demand for steam, there will be no occasion to have recourse to the dampers except when there is a sudden interruption in the amount of steam being used.

(10) A good general rule is to fire little and often, according

to steam demands, rather than heavy and seldom. The former means economy in fuel and a clean chimney, while the latter signifies extravagance in fuel and a smoky chimney.

**139. Smoke Prevention.**—The prevention of smoke means more economical operation of the furnace, provided the absence of smoke is secured by the complete combustion of the coal and without too great excess of air. However, the absence of smoke should not be taken as conclusive proof that the furnace is being operated in the most economical manner. If a very great excess of air is admitted to the furnace, the smoke may be so diluted as to become almost invisible, but the efficiency will be low. Under such conditions, not only is the furnace temperature lowered, but also a large amount of heat is wasted in raising the temperature of the excess air. If an analysis of the flue gas shows more than 100 per cent excess air, steps should be taken at once to prevent so much air entering the furnace.

Smoke is the product of volatile matter that has not been burned. To burn the volatile matter of a coal we must have three things: first, a supply of oxygen sufficient for the volatile matter; second, a thorough mixture of this air and volatile matter; third, a sufficient temperature after mixing to cause and maintain combustion.

Fresh coal requires more air than coal that has been coked. Therefore, either more air should be supplied just after firing, or the firing should be continuous so as to constantly use the same proportion of air.

The boiler should not be too close to the fire. The volatile gases are often chilled by the bottom and the tubes of a boiler so that they cease burning. For coals containing much volatile matter, a Dutch oven furnace is highly desirable as it permits of thorough mixing of air and volatile matter and maintains a high furnace temperature. Automatic stokers naturally offer the best method of smoke prevention as they supply the coal continuously and the air as well as the depth of fire carried can be regulated.

**140. Mechanical Stokers.**—These may be divided into two general classes: (1) overfeed and (2) underfeed. The first feeds the coal above the fire and the second feeds it below, then upward, until it overflows out over the grates.

There are three kinds of overfeed stokers in use. In one, the coal is carried on horizontal or slightly inclined grate bars, and the individual bars are given a motion by which the coal is gradually advanced along the grates toward the bridge wall. In another, the grates are steeply inclined, and the fuel is pushed onto the upper ends, whence is slides down slowly toward the ash pit, being burned on its way down. Still another kind includes chain grates, in which the entire grate is an endless chain of short bars. The motion is from the fuel hopper, in front of the boiler, back toward the bridge wall, at which point the grate passes over a sprocket and returns through the ash pit.

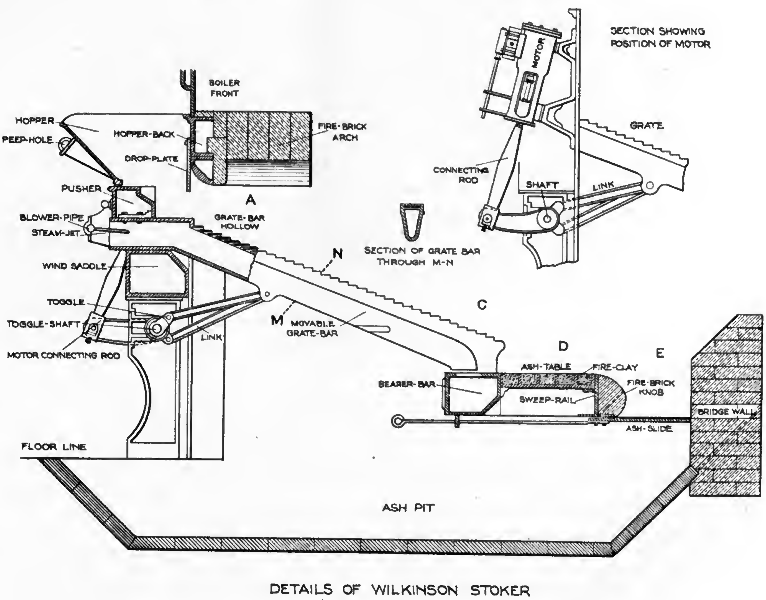



Fig. 75.

Underfeed stokers feed into a trough-shaped retort below the grates, and the fuel gradually overflows out and over the grates along each side of the retort. It undergoes a coking process in the retort and should be free from all volatile matter when the grates are reached. Air for combustion is supplied through openings along the edges of the retort. Some of these stokers operate intermittently by means of a plunger; others feed continuously through a screw motion. Forced draft is most often used.

**141. The Wilkinson Stoker.**—Fig. 75 shows the details of a Wilkinson mechanical stoker which is a representative of the front feed slightly inclined type. In this stoker the coal is fed from a hopper onto inclined grate bars. The grate bars are made in one piece with the upper edge corrugated in the form of steps. Each bar is fastened near its upper end to a link which connects it to a toggle shaft from which it takes its motion. The links have a reciprocating motion, and alternate bars are so connected to the toggle shaft as to be out of phase with the others, thus giving the bars a sawing motion which serves to feed the coal forward and downward. The toggle shaft is operated by a hydraulic motor which receives its supply of water from a small independent pump. The water is used over and over in the motor and pump. The grate bars are hollow and each one has a small steam jet in it by which a small amount of steam is blown through small openings in the upper edge of the grate bars and through the fires. This serves not only to prevent clinkering, but also draws air into the fire.

Part of the ash formed during combustion sifts through the grate bars. The remainder, together with the clinker, moves down the inclined grate bars to the ash table at the bottom. The motion of the lower ends of the grate bars pushes the ashes and clinkers onto a dumping plate which may be lowered, thus discharging them into the ash pit.

**142. The Roney Stoker.**—This stoker, illustrated in Fig. 76, is a good representative of the steeply inclined front feed stoker. Unlike the Wilkinson stoker, it has the grate bars placed across the furnace and each one forms a step just below the one above. The bars are T-shaped in section and are pivoted near their lower ends. The lower ends of the bars rest in slots cut in a rocker bar, from which they obtain their rocking motion. The rocker bar is given a reciprocating motion through a rod, which derives its motion from a shaft passing in front of the stoker and operated by a small steam engine. The coal is fed from a hopper to the dead plate just below, from which it is pushed onto the grate bars by a pusher plate sliding back and forth over the dead plate. The grate bars oscillate through an angle of about 30°, alternately assuming a horizontal and an inclined position, thus gradually feeding the coal down the incline. The stoker normally operates at about 10 strokes per minute and the rate of feeding the coal is regulated by adjusting a hand wheel which controls the amplitude of the motion of the pusher plate. By the time the coal reaches the bottom of the grates, it is completely burned, and the clinkers and ash may be dumped into the ash pit by means of a dumping grate provided for this purpose.

**143. The Murphy Stoker.**—The Murphy Stoker shown in Figs. 77 and 78, represents another style of steeply inclined stoker. This one differs from the other in that it has two sets of grates, one placed along each side of and extending the depth of the furnace. This apparatus is, in effect, a Dutch oven with an

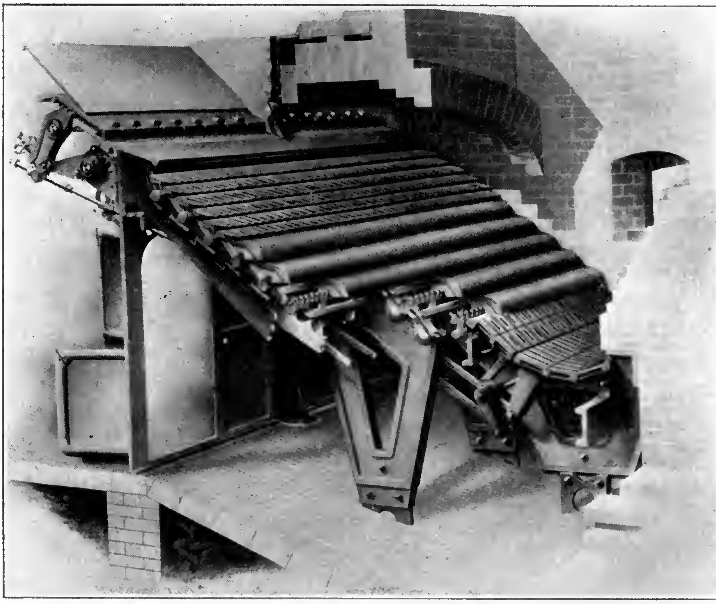


Fig. 76.—Roney stoker.

automatic feeding and stoking device. Coal is fed from hoppers placed along both sides of the furnace. From the hopper, the coal runs onto a coking plate from which it is pushed by a reciprocating stoker box. The grate bars are inclined toward the center of the furnace, and are pivoted near their upper ends. Only the alternate bars are movable, and these are connected to a shaft in the middle of the furnace and at the bottom in such manner as to give them a motion alternately above and below the surface of the stationary grates. This serves to feed the coal down the incline. A hollow shaft with strong teeth on the outside is placed in the bottom of the stoker for grinding

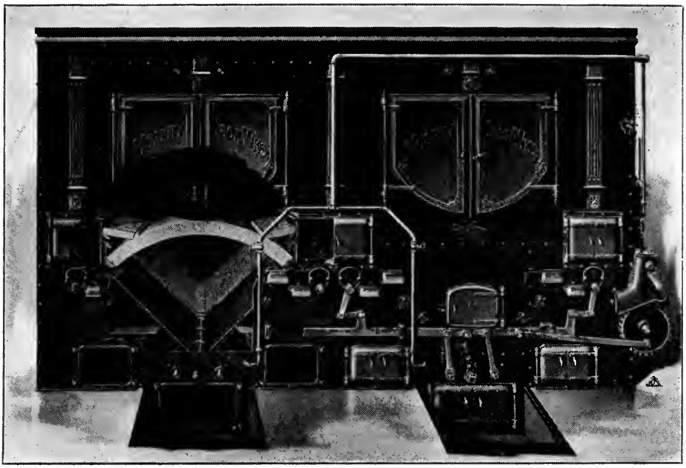


FIG. 77.—Murphy stoker.

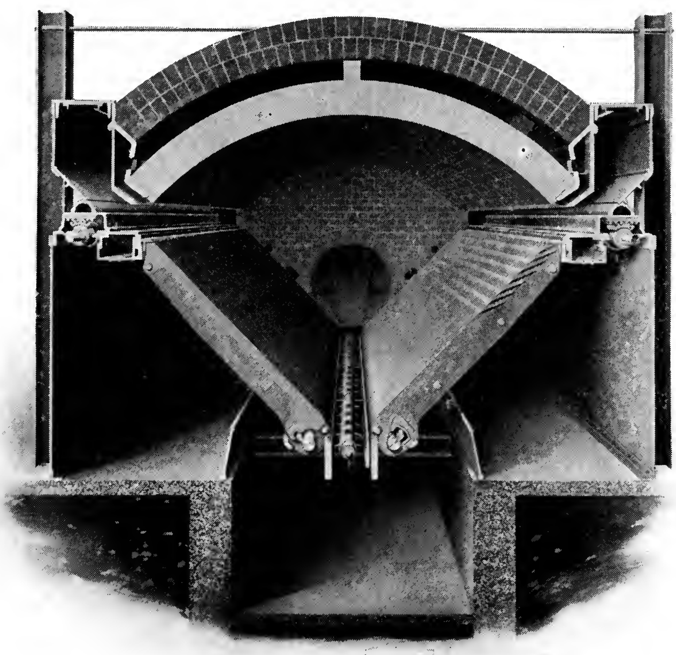


FIG. 78.—Rear view of Murphy stoker.

up the clinkers. Cold air passes through this shaft and prevents it from becoming overheated. Air for burning the volatile matter is fed through flues in the stoker box, where it is warmed before entering the furnace. The motion of the stoker box is adjustable to control the rate of feeding. A rear view of this stoker, showing a double arch construction, is illustrated in Fig. 78. This stoker can be operated without smoke at all loads, and is particularly well adapted for operation at small loads as the ashes may be allowed to collect and cover up a portion of the grates, thus reducing the effective grate area.

**144. The Jones Underfeed Stoker.**—The Jones Stoker shown in longitudinal section in Fig. 79 and in cross-section in Fig. 80 is

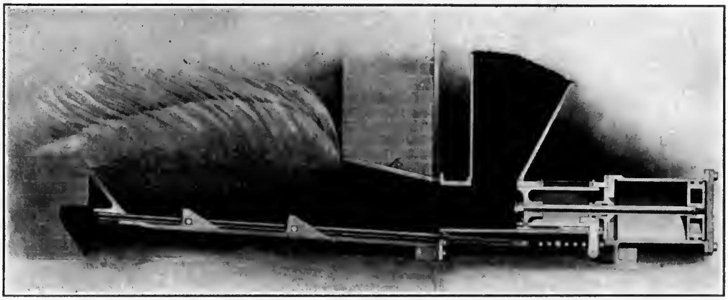


Fig. 79.—Longitudinal section of Jones underfeed stoker.

of the underfeed type. This stoker is very simple in construction and has but few moving parts. It consists of a retort, which is placed inside the furnace, and of a feeding mechanism placed outside. The retort is trough-shaped and along each side at the upper edge is placed the tuyères for admitting air under the bed of coal. The feeding mechanism consists of two cylinders fitted with pistons placed one in front of the other. The two pistons are placed on a single piston rod, and therefore move together. The outer or actuating piston is acted upon by live steam from the boiler and as this piston moves in, it pushes the other piston or ram which in turn pushes some coal from the hopper into the retort. As the ram forces more coal into the hopper, some of that which was already there is forced upward toward the top and in this way the bed of coals assumes the form of a ridge extending down the middle of the furnace, as seen in Fig. 80, being thick in the center and thin along the edges. In order to prevent the coal from heaping up too much in front of the furnace, a couple of pusher blocks connected to the piston rod are placed in the bottom of the retort, which, by their motion to and fro, serve to level the fire somewhat.

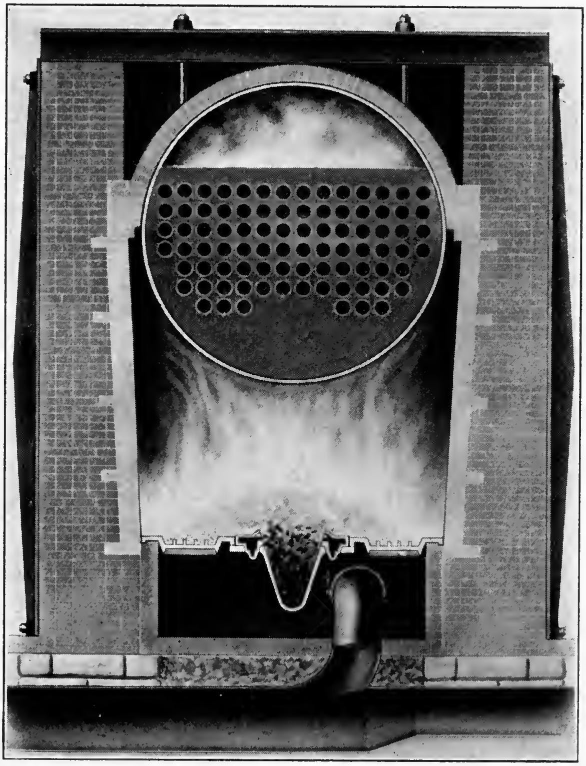


Fig. 80.—Cross-section of Jones underfeed stoker.

A fan is used to supply air beneath the stoker through a duct as shown in Fig. 80. From here the air passes through the tuyères on each side of the retort and up through the fire. The fan is run by a steam engine or electric motor whose speed is controlled automatically by the steam pressure. The frequency of strokes of the feeding ram is also controlled automatically by the steam pressure. By this method of control the amount of air supplied to the furnace is regulated to suit the required rate of combustion and there is no danger of excess air being supplied.

In the underfeed stoker just described, the ash and clinker are worked to the top of the fire by the upward motion of the coal. From here they gradually move down the sloping sides of the fuel bed to the sides of the retort, which are flat. Cleaning doors are provided at each side of the furnace through which the ashes and clinkers may be removed at intervals.

In the underfeed system of stoking, the hottest part of the fire is at the top of the fuel bed, while the fuel in the bottom of the retort is cool. As the fuel is fed upward, it becomes heated and the volatile matter is driven out. This must pass up through the hotter part of the fire above, where, the chances are, it will be completely burned before it passes out of the furnace. This principle of stoking permits very low grade coals being burned with a minimum of smoke, and also permits the metal parts of the boiler being set directly over the furnace without danger of the gases being cooled before they are burned.

**145. The Taylor Gravity Underfeed Stoker.**—The Taylor stoker, illustrated in Figs. 81 and 82, is a combination of the

Fig. 81.—Rear view of Taylor gravity underfeed stoker.

two types of stokers just described, having an inclined grate and at the same time being underfed. This stoker, like others of the underfeed type, requires a strong draft to force the air through the thick fuel bed, and this draft is best furnished by a fan. The inclined grate bars are all stationary and are hollow, having openings on their faces as shown in the back view of the stoker, Fig. 82. These hollow grate bars are connected to a common air chamber underneath the stoker, which chamber is supplied with air through a duct, as illustrated in Fig. 81.

The feeding mechanism consists of two sets of rams, one near the top of and between the grate bars, and the other immediately below, both sets being operated from a crank shaft on the out-

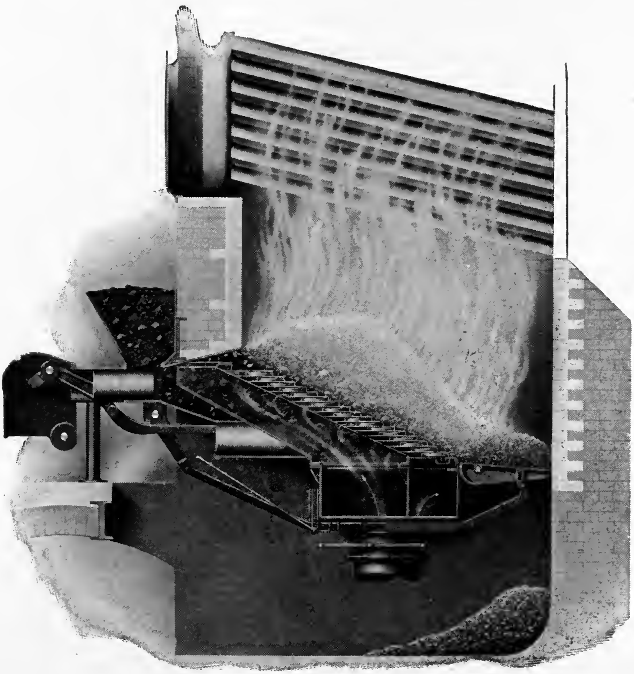


Fig. 82.—Longitudinal section of Taylor gravity underfeed stoker.

side of the stoker. The relative positions of the rams may be seen from Fig. 82. The top ram is located in the bottom of the coal hopper, and is the one which really does the feeding of fresh coal, while the other ram serves to keep the coal moving down the grate bars, thus securing a more uniform fire over the whole fuel bed.

The ashes and clinkers move toward the bottom of the grate bars as the coal is burned, and finally collect on the dumping plates at the bottom, from which they may be dumped into the ash pit by means of hand levers, which extend to the front of the stoker.

In the Taylor stoker, the air supply and rate of feeding coal are controlled automatically by the steam pressure, thus insuring at all times the proper amount of air to burn the coal. Besides the advantages common to all underfeed stokers, the Taylor has the further advantage that the fuel bed extends entirely across the furnace, thus utilizing all the space in the furnace and giving maximum capacity for minimum space.

**146. Chain Grates.**—Fig. 83 represents the Green chain grate as applied to a water tube boiler with fire-clay tiling on the lower course of tubes. It consists of an endless chain of grate

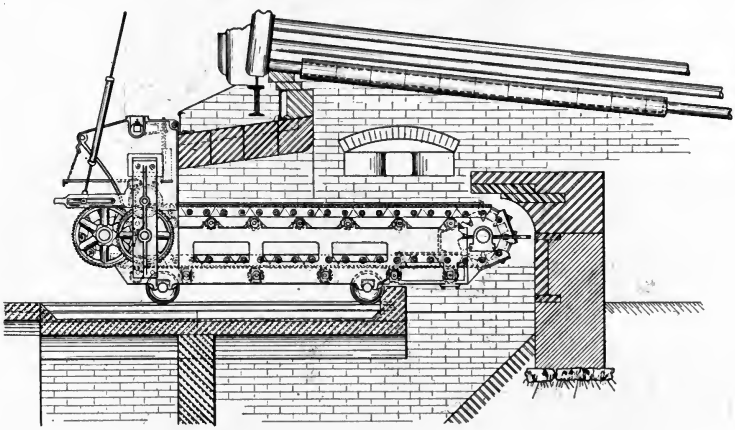


Fig. 83.—Green chain grate stoker.

bars mounted on a frame, with provision for the uniform feeding of the fuel. The driving mechanism consists of a train of gears operated from a line shaft, the gears being actuated by ratchet and pawls. Fuel is fed into the front end from a hopper provided with an adjustable feed gate for levelling and regulating the depth of the fuel bed. The entire stoker is mounted on wheels which run on a track, thus permitting the easy removal of the stoker for inspection or repairs. The thickness of the fuel bed and the speed of the grates are so regulated that the fuel is completely consumed by the time it reaches the rear of the furnace, and only the ashes and clinkers are dumped off into the ash pit. The combination of a chain grate with an inclined ignition arch, and with the lower course of tubes covered with fire tiles as shown in Fig. 83, makes an excellent smokeless furnace, though the depth of fuel and speed of the stoker must be closely regulated if it is to accomplish its purpose. With chain grate stokers there is apt to be considerable leakage of air past the sides of the grate, through the end, which is covered with ashes, and through the fuel in the hopper but, by careful construction, leakage from these sources may be largely overcome.

**147. Advantages and Disadvantages of Stokers.**—One of the most apparent advantages in the use of mechanical stokers is the saving in the fire-room labor. This is particularly true in large plants and where coal-handling machinery is used. Stokers may save as much as 30 to 40 per cent of the labor in large plants, that is, plants using over 200 tons of coal per week. In plants of medium size, those using from 50 to 150 tons of coal per week, the saving in labor may amount to from 20 to 30 per cent. In small plants there is not likely to be a saving in labor.

In a large plant, stokers will be advisable if they permit the use of a cheaper grade of fuel than could be used with hand firing, but it should be ascertained that the cheaper fuel could not be used without the stoker. Usually a stoker can be made to burn a lower grade of fuel than can be used with hand firing, since it carries a cleaner fire, the coal is fed more uniformly, and the amount of air required for combustion is supplied at a more constant rate.

Even if no saving can be effected by using a cheaper grade of fuel, it may still be advisable to use a stoker to lessen the smoke if a cheap grade of fuel is being used. It is difficult to prevent smoke when such fuels are hand fired. The amount of smoke given off by a furnace may be greatly reduced or even entirely eliminated by the use of a stoker of proper design, when operated according to the principles upon which it was intended to be operated. However, in practice, stokers are not always operated to the best advantage, and we sometimes see a stoker-fired furnace giving off quite as much smoke as a hand-fired one.

The grate area of a stoker is usually less than that of a hand-fired grate for the same furnace, but since the motion of the stoker maintains a cleaner fire by continuously disturbing the film of ash formed by the burning coal, the rate of combustion per square foot of grate is increased sufficiently to make up for the reduction in grate area.

It is often claimed that the use of stokers increases the evaporation per pound of coal. This will depend largely upon the design of the stoker and the way in which it is handled. In this connection it should be remembered that all fuel used to operate the stoker or steam jets, if there be any, should be charged against it.

Unless the fireman be expert, hand firing may occasion a loss as compared with a stoker, for the following reason. There is a certain supply of air per pound of coal which gives best results, too much or too little resulting in a loss. If the firing be continuous, as in a stoker, the supply of air may be adjusted to suit the rate of firing. If the firing be intermittent, as in hand firing, the air supply is first too small and then too large, and a loss results. The more intermittent the firing, the greater will be the variation from the proper air supply and the greater will be the loss. The proper air supply per pound of coal shows a greater tendency to vary with soft coals than with hard coals, hence, with soft coals, it is more difficult to obtain good results with hand firing than with the use of a stoker.

After the best type of stoker to handle a particular grade of coal has been chosen, then the best stoker will be that one which is least complicated and whose details are designed according to good mechanical principles.

**148. Oil Burning.**—The use of crude oil as a fuel under power boilers has attained considerable prominence within the last few years. Railroads have been the most prominent users of this fuel, and particularly those railroads which run near the oil fields.

In order to burn oil successfully, it is necessary to have a suitable spraying device for the oil and a furnace constructed especially for oil burning. The spraying devices used most commonly in this country are either of the inside or outside mixing types. While there are several good burners of each of these types on the market, only one of each type will be described, as this will be sufficient to illustrate the principles of their construction. In all of these burners the oil is mixed with either steam or compressed air, which serves to spray it and force it into the furnace.

Fig. 84 shows a Booth burner which is of the outside mixing type. This burner consists of two pipes, one above the other, the spraying ends of the pipes being flattened out until the mouth is a thin slit. The oil passing through the upper pipe flows through the slit and falls upon a jet of steam issuing from the lower pipe, which atomizes and forces it into the furnace. A feature of this apparatus is its simplicity and freedom from clogging.

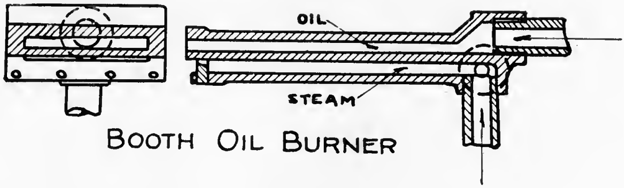
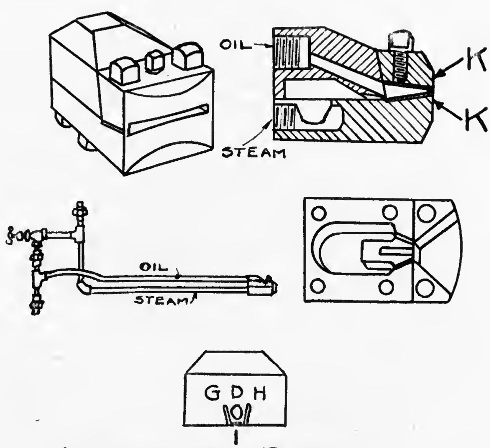



FIG. 84.

The Hammel burner, which is of the inside mixing type, is shown in Fig. 85. Oil enters the burner under pressure and flows through opening *D* to the mouth of the burner, where it is atomized by the steam jets issuing from the slots *G*, *H*, and *I* surrounding the oil opening *D*. The plate *K* serves to flatten




HAMMEL OIL BURNER

FIG. 85.

out and direct the spray. This plate is removable and is easily replaced when worn out or burned.

The construction of a furnace for the use of oil under a water-tube boiler is illustrated in Fig. 86. The bottom of the furnace consists of a double air passage which allows the air to be heated before it enters the furnace. The jet of oil and steam, or of oil and compressed air, impinges against the stack of loosely piled fire brick placed just in front of the bridge wall. These brick serve the double purpose of storing heat and of projecting the lining of the bridge wall. Being piled loosely, they may be readily replaced when they become burned.

Some years ago the U. S. Naval Liquid Fuel Board conducted an elaborate series of experiments upon liquid fuel and among its conclusions were:

(1) That oil can be burned in a very uniform manner.

(2) That the evaporation efficiency of nearly every kind of oil per pound of combustible is probably the same.

(3) That a marine steam generator can be forced to as high degree with oil as with coal.

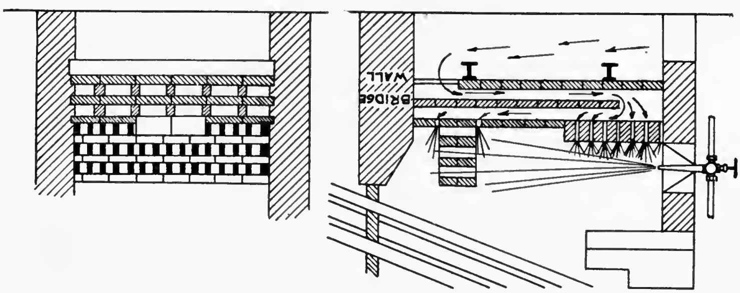



Fig. 86.—Furnace fitted for burning oil.

(4) That no ill effects were shown upon the boiler.

(5) That the firemen were disposed to favor oil.

(6) That the air requisite for combustion should be heated, if possible, before entering the furnace.

(7) That the oil should be heated so that it can be atomized more readily.

(8) That when using steam, higher pressures are more advantageous than lower pressures for atomizing the oil.

(9) That under heavy forced draft, and particularly when steam was used, it was not possible to prevent smoke.

(10) That the efficiency of the oil fuel plant will be greatly dependent upon the general character of the installation of auxiliaries and fittings.

# CHAPTER XII

## THE SMOKELESS COMBUSTION OF COAL

**149. The Smoke Problem.**—There are two phases or sides to the smoke question; that of the proprietor who is responsible for the smoke and that of the community which is interested in the prevention of the smoke. For many years these two interests seemed to be antagonistic but more recently they have come to recognize a community of interests. It is not intended to deal in this course with the civic problem of smoke except to give a few interesting figures. According to the smoke inspector of Chicago, the annual loss in ruined merchandise, increased laundry bills, and in other ways, due to smoke, amounts to $50,000,000 for Chicago alone. Since one-third of our population lives in cities, the U. S. Geological Survey has reasoned from this that the annual loss to the country is about $600,000,000 or about $6 per individual. Whether these figures are correct or not there is doubtless a considerable loss due to the smoke produced by our factories and power stations. At first glance it might appear that the factory proprietor is not interested in smoke prevention to any greater extent than that of his own $6 share in the annual loss. But this $600,000,000 expenditure decreases the purchasing power of the people by that same amount yearly and thus what we call the prosperity of the country is correspondingly diminished. It is true that most of the money so expended stays in our country but the expenditure of this money whether within or without the country, since it is not in exchange for something else of permanent value, has as evil an effect on our prosperity as if the nation were carrying on a continual war at an expense of $600,000,000 yearly. The business of each factory or power station is, therefore, diminished in the proportion which this $600,000,000 bears to the total business of the country.

But since these facts do not seem sufficient to influence the industrial interests of the nation, it becomes necessary to demonstrate the economy of smoke prevention in another way.

The issuing of black smoke from a chimney is invariably a sign that the best results are not being obtained from the coal burned. When it is considered that the coal bill of the average factory, if saved, would pay a 6 per cent dividend on the capital stock, it is seen that what the factory manager can save by proper attention to the generation of his power will go a considerable way toward making up the dividends which he is expected to earn.

Geologists figure that, at the present rate of increase in our coal consumption, our visible coal supply will last only about 200 years longer. This fact may also have little effect on the factory manager until he is made to realize that this approaching shortage in coal is already having its effect on the price of coal. This can be readily appreciated when we see shallow veins of coal being mined that a few years ago could not have been worked at a profit.

It is not the unburned carbon in smoke that is the great loss, since this carbon or soot in the blackest smoke is less than 1 per cent of the total carbon in the coal, but in general the presence of soot indicates also the presence of other combustible matter that is not visible but is being wasted in amounts of from 3 to 10 per cent of the available combustible. Furthermore, the heat which is liberated in the furnace may not be so liberated as to give its greatest possible percentage to the water in the boiler. Understanding and observing the principles of combustion may save to the owner of the smoky chimney, in some cases, from 20 to 30 per cent of his coal bill. This means 2 per cent additional dividends to the stockholder from this saving alone. Thus, we see that the question of smokeless combustion is so intimately connected with that of furnace and boiler efficiency that the prevention of smoke is a sound economic proposition.

**150. Principles of Smokeless Combustion.**—To obtain perfect combustion in a boiler furnace, the furnace itself must be *properly designed* and *properly operated.* Neither of these features is of itself sufficient but they must go hand in hand. The following general statements by the U. S. Geological Survey indicate the lines that must be followed:

1. The flame and the distilled gases should not be allowed to come in contact with the boiler surfaces until combustion is complete.

2. Fire-brick furnaces of sufficient length and a continuous or nearly continuous supply of coal and air to the fire make it possible to burn most coals efficiently and without smoke.

3. Coals containing a large percentage of tar and heavy hydrocarbons are difficult to burn without smoke, and require special furnaces and more than ordinary care in firing.

4. In ordinary boiler furnaces (hand fired) only coals high in fixed carbon can be burned without smoke, except by expert firemen using more than ordinary care in firing.

5. Combinations of boiler-room equipment suitable for nearly all power plant conditions can be selected, and can be operated without objectionable smoke when reasonable care is exercised.

6. Of the existing plants, some can be remodeled to advantage. Others cannot, but must continue to burn coals high in fixed carbon or to burn other coals with inefficient results, accompanied by more or less annoyance from smoke. In these cases, a new and well designed plant is the only solution of the difficulty.

The problem of smoke prevention is very intimately connected with that of securing better combustion of the fuel, for where there is perfect combustion there will be no smoke. The matter of the actual money value of the fuel which passes off as smoke is not of very much importance, since this loss is probably never more than 2 per cent of the total value, but the importance of smoke prevention lies largely in the suppression of a public nuisance, and in the fact that the presence of smoke usually indicates incomplete combustion which in itself is a great loss, as has been pointed out in previous chapters. The whole problem, therefore, resolves itself into one of securing perfect combustion of the coal, and it may be stated as a general truth that "any fuel may be burned economically and without smoke if it is mixed with the proper amount of air at a proper temperature."

This condition may be secured, according to Mr. Wm. Kent, by fulfilling the four following conditions:

(*a*) Having the gases distilled from the coal slowly.

(*b*) Bringing the gases, when distilled, into intimate contact with very hot air.

(*c*) Burning the gases in a hot fire-brick chamber.

(*d*) Not allowing the gases to come into contact with comparatively cool surfaces, such as the shell or tubes of a steam boiler, until complete combustion has taken place; this means that the gases shall have sufficient space and time in which to burn before they are allowed to come into contact with the boiler surfaces.

Smoke consists of carbon or soot in a light flaky form which is light enough to float in air. It is mixed with the products of combustion, such as carbon dioxide, carbon monoxide, sulphurous and sulphuric acid, water, nitrogen, ammonia, carburetted hydrogen, and other vapors of lesser note.

**151. Causes of Smoke.**—Before taking up the problem of smoke prevention it is necessary to understand fully all the conditions which contribute to smoke making, and, therefore, to the proper and economical combustion of the fuel. In this connection Professor Olin A. Sandreth of Vanderbilt University in a report to the State Board of Health of Tennessee on "Smoke Prevention," says:

"When fresh coal is thrown on a bed of incandescent coal, or is otherwise highly heated, there immediately begins the distillation of the more volatile portions of the hydrocarbons in the coal, which distilled matter is burned if the temperature is high enough and a sufficient supply of oxygen is present; but which passes up the chimney as yellowish fumes if either of these two essential conditions of combustion is wanting. As the fresh coal becomes more highly heated the less volatile hydrocarbons are distilled, and these being, chemically speaking unstable compounds, are decomposed or dissociated by the heat at a temperature much below that at which the carbon thus liberated combines with oxygen in combustion. The temperature necessary for combustion of this free carbon is very high, approximately 2000° F., and, hence, there is a wide margin of opportunity for this portion of the, carbon to escape unburned, as this temperature is somewhat difficult to maintain in the mass of gaseous matter above the coal."

It is free carbon, unburned and in a finely divided state, which produces the bright luminous flame, and which, when cooled, produces the black clouds of smoke that issue from the chimney and which afterward settles as soot. After the volatile matter is all driven off, there still remains the fixed carbon, which now is in the form of coke. In burning, this gives but little flame and no smoke, as the particles are not detached from the solid mass until combustion takes place.

In the ordinary boiler furnace, as generally constructed and fired, the conditions are very unfavorable for perfect combustion during the period in which the volatile matter is driven off from each charge of coal. When the fixed carbon stage is reached, there is but little difficulty in maintaining perfect combustion, but, when a fresh charge of coal is added, the difficulties reappear; the air supply, if not in excess during the burning of the previous incandescent coal, will now be insufficient since the distillation of the volatile matter calls for an increased amount of air, while, in fact, the greater depth of coal now on the grate actually reduces the supply.

If an additional supply of air is admitted through the furnace doors, it will be cold and cannot be thoroughly mixed with the combustible gases. Likewise, the furnace temperature, if high enough before charging, is now much lower owing to the cooling effects: first, of the cold air rushing in when the doors are opened; second, of the mass of coal; third, of the evaporation of the moisture in the coal and of the distillation of the volatile matter. Thus, we see that at the time a high temperature is needed to burn the free carbon, the furnace is coldest.

In fulfilling the requirements of sufficiency of supply and thoroughness of mixing the air with the combustible gases, it must be noted that these conditions should not be secured by a reckless surplus of air, as this carries away useful heat which is not only a loss in itself, but may, and often does, result in lowering the temperature of the combustible gases below their temperature of ignition, thus causing the escape of unburned fuel. Owing to the difficulty of effecting such a thorough mixture as to bring to each combustible particle just the proper amount of air, it is necessary to provide a surplus of air, but this should be considered as an evil to be kept at a minimum by the most thorough mixing possible.

**152. Means of Prevention.**—Passing to the means of accomplishing combustion without smoke production, it is safe to say that, so far as it pertains to steam boilers, the object must be attained by one or more of the following agencies:

(1) By the proper design and setting of the boiler plant. This implies proper grate area, sufficient draft, the necessary air admission space between grate bars and through the furnace, and ample combustion room under boilers.

(2) By that system of firing which is best adapted to each particular furnace to secure the perfect combustion of bituminous coal. This may be either (a) "coke firing," or charging all coal into the front of the furnace until partially coked, and

then pushing back or (b) "alternate firing" or (c) "spreading" by which the coal is spread over the whole grate area in a thin uniform layer at each charging.

(3) The admission of air through the furnace door, bridge wall, or side walls.

(4) Steam jets or other artificial means of thoroughly mixing the air and combustible gases.

(5) Prevention of the cooling of the furnace and boilers by the inrush of cool air when the furnace doors are opened for charging the coal and handling the fire.

(6) Establishing a gradation of the several steps of combustion, so that the coal may be charged, dried, and warmed at the coolest part of the furnace, and then moved by successive steps to the hottest place, where the final combustion of the coked coal is completed, and compelling the distilled combustible gases to pass through the hottest part of the fire.

(7) Preventing the cooling by radiation of the unburned combustible gases until perfect mixing and combustion has been accomplished.

(8) Varying the supply of air to suit the periodic variation in demand.

(9) The substitution of a continuous uniform feeding of coal instead of the intermittent charges.

(10) Down draft burning, or causing the air to enter above the grates and pass down through the coal, carrying the distilled products down to the high temperature plane at the bottom of the fire.

(11) Underfeeding, or causing the volatile matter and air to mix and pass upward through the incandescent bed of coke, thus causing complete combustion of the volatile matter.

The number of smoke prevention devices are legion. Only a brief classification of the principles of working will be attempted here. These are:

(*a*) Mechanical stokers, which automatically deliver the fuel in a finely divided state into the furnace at a uniform rate, and which also keep the fire clean by a slow but constant motion of the individual sections of the grate. They accomplish their object by means of agencies 5, 6, and 9, and sometimes 11, of the foregoing list. They sometimes effect a very material saving in the labor of firing, and are efficient smoke preventers when not pushed above their capacity, and when the coal does not cake badly. They are rarely susceptible to the sudden changes in the rate of firing frequently demanded in service.

(*b*) Air flues in side walls, bridge walls, and grate bars, through which air when passing is heated (agency 3). The results are always beneficial, but the flues are difficult to keep clean and in order.

(*c*) Coking arches, or arched over spaces in front of the furnace in which the fresh coal is coked, both to prevent cooling of the distilled gases and to force them to pass through the hottest part of the furnace just beyond the arch (agencies 6 and 7). The results are good for normal conditions, but ineffective when the fires are forced. The arches are also easily burned out and injured by working the fire, and are expensive to replace.

(*d*) Dead plates, or a portion of the grate next to the furnace doors reserved for warming and coking the coal before it is spread over the grate (agency 6). These give good results when the furnace is not forced above its normal capacity. This embodies the coking method of firing mentioned previously.

(*e*) Down draft furnaces, or furnaces in which the air is supplied above the coal and the products of combustion are carried away beneath the grate, thus causing a downward draft through the coal, carrying the distilled gases down through the highly heated incandescent layer of coal on the grate (agency 10). In this furnace the grate bars must be kept cool by the circulation of water through them, as they have to bear the hottest portion of the flame.

(*f*) Steam jets to draw or inject air into the furnace above the grate, and also to mix the air and combustible gases (agency 4). A very efficient smoke preventer, but one liable to be wasteful of fuel by inducing too rapid a draft.

(*g*) Baffle plates placed in the furnace above the fire, to aid in mixing the combustible gases with the air (agency 4).

(*h*) Double furnaces, of which there are two entirely different styles. The first of these places the second grate below the first. The coal is coked on the first grate, during which process the distilled gases are made to pass over the second grate, where they are ignited and burned; the coke from the first grate is dropped on to the second grate and burned (agencies 6 and 7). This is a very efficient and economical smoke preventer, but rather complicated to construct and maintain. In the second form the products of combustion from the first furnace pass through the grate and fire of the second, each furnace being charged with fresh fuel when needed, the latter generally with a smokeless coal or coke—an irrational and unpromising method.

It is no longer a problem whether smoke can be prevented or not. This has been settled conclusively in the affirmative in

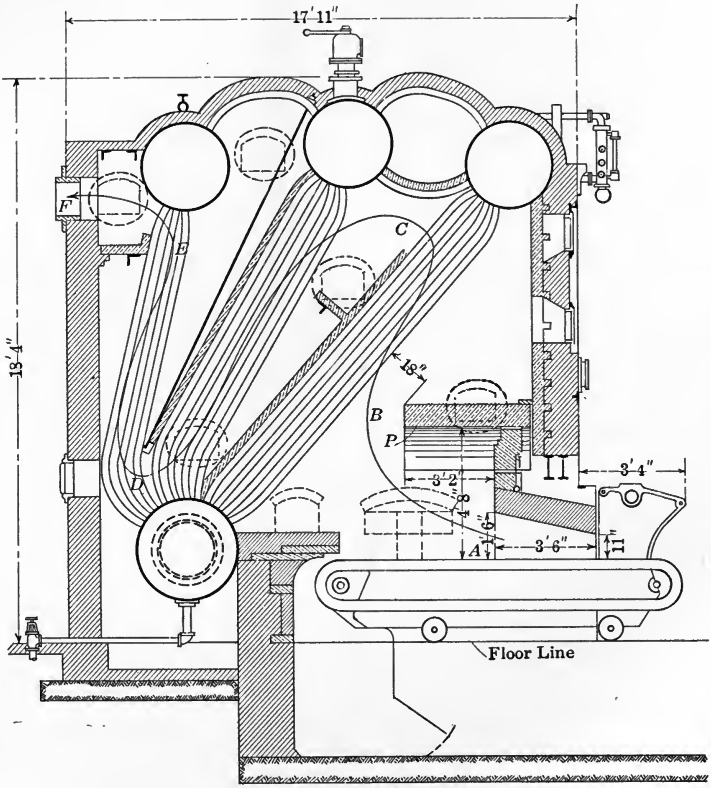



FIG. 87.

a number of localities where proper laws for the abatement of smoke have been passed and enforced. It must be borne in mind that the method which is successful in preventing smoke with one kind of coal may not be successful with another kind, and each particular kind of coal will have to receive its own consideration in the design of a furnace for smokeless combustion. The principles laid down above are, however, of a general nature and apply to all ordinary grades of smoke-producing coals.

An extensive series of experiments have recently been conducted by the Engineering Experiment Station of Illinois with a view to devising methods of burning Illinois coals without smoke. From these experiments it has been determined that the method of setting the boiler and furnace exerts considerable influence upon smoke production. A number of different kinds of settings were built and tried. Some of those which proved

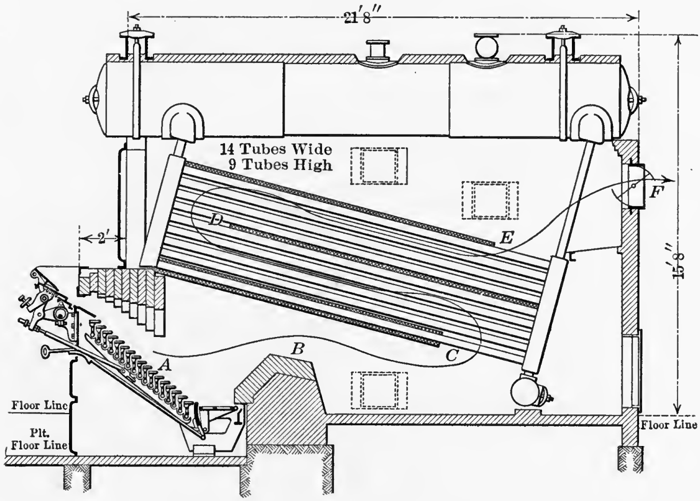



Fig. 88.

successful in preventing smoke are shown in Figs. 87, 88, and 89. The dimensions shown on all these drawings are general dimensions which will serve as a guide in proportioning the setting for other sizes of boilers.

In all of these settings, it will be noticed that one feature is common—the gases travel for a considerable distance before coming in contact with any surfaces by which they would be cooled to any considerable degree. This gives the volatile gases a chance to be burned completely before they come in contact with the cold metal surfaces and to be cooled to such a temperature that chemical combination with oxygen would be impossible. It will be remembered that a high temperature is required for each atom of carbon to unite with two atoms of oxygen to form carbon dioxide. Therefore it is of extreme importance that the hot gases should not come in contact with any surface which will cool them before combustion is completed. In the settings of horizontal water-tube boilers, just shown, it will be noticed that the tubes have been covered with tile to prevent the hot gases from coming in contact with them and being cooled before combustion has been completed. For this purpose, the hot gases should be made to travel from 6 to 8 ft. before coming in contact with any cooling surfaces.

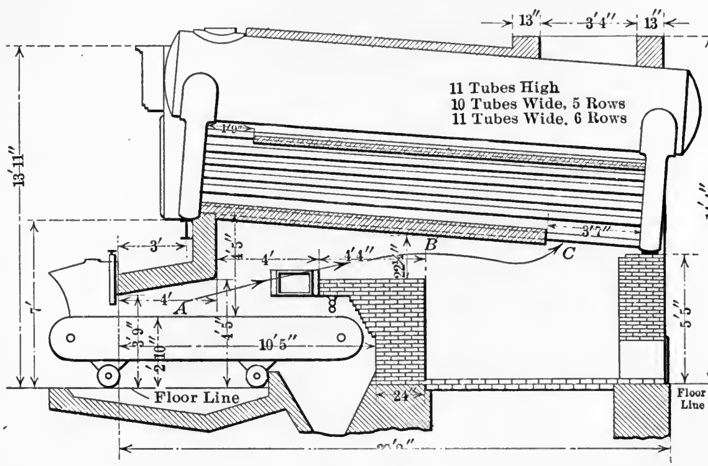



Fig. 89.

**153. Types of Furnaces.**—Mechanical stokers, when properly set and operated, produce better results than hand firing, but any stoker is effective only when set so that the principles of combustion are properly observed. Although hand-fired furnaces may be operated without objectionable smoke, the fireman is so variable a factor that the best solution depends on the mechanical stoker. It is not possible to say that any one type of stoker is the best, since no type is equally valuable for burning all kinds of coal. If the furnace is in every case properly designed for the stoker that is used, there will be found little difference in the efficiencies of the different types. The primary requisite is to set the stoker so that combustion may be completed before the gases strike the heating surface of the boiler. When partly burned gases strike the comparatively cold surfaces of a boiler, combustion is necessarily hindered or completely prevented, and smoke, together with a reduced efficiency, results.

The length of time required for gases to travel from the grates to the heating surface probably averages less than one second, which shows that the gases and air must be intimately mixed as soon as the gases are distilled, otherwise the gases may pass out of the furnace and become cooled before having come in contact with sufficient oxygen to burn them. This shows the desirability of some device for mixing the green gases with the necessary air for combustion as they are distilled.

The remaining articles in this chapter give the conclusions of the Geological Survey as to the use of different types of stokers and the proper settings for them.

**154. Chain Grates.**—The majority of stokers of this type are particularly adapted to free burning coals, high in volatile matter, such as are mined in the central and western fields. As they burn the cheapest grades of non-caking coals with complete combustion they offer a valuable means of producing power cheaply. Small sizes of coal seem to be preferred. The chief difference in different makes is in the length of the fire-brick arch which extends over the whole width of the grate and extends from the hopper backward. The tendency is to lengthen this arch and to proportion its length and slope to the coals used. This arch is a highly desirable feature as it prevents the gases from being cooled and aids considerably in mixing the gases and air while maintaining the high temperature necessary for combustion. With many water-tube boilers the arch is made short, this construetion being especially common in the Middle West. This short arch, and the consequent brief travel to the heating surface from the grates, are features which are unfavorable to smokeless combustion. These grates are liable to form dense smoke under variable loads unless properly handled. A sudden release of load requires a reduction of draft which is often carried too far. The draft should never be closed beyond a certain position which can be determined by experiment. For changes of load it is far better to change the depth of the fire than the rate of travel of the grate.

**155. Inclined Grate with Front Feed.**—Smokeless operation can be obtained with these grates by careful operation and the use of steam jets or the generous admission of air, but as a rule they are set too close to the heating surface and the coking arch is made too short. These stokers can force a fire quickly but tests show that, as usually set, more than average attention is required to prevent smoke. The coking arch should be extended beyond that generally used and if, with water-tube boilers, the bottom row of tubes is tiled so as to give a long passage to the gases before reaching the heating surface, much better results may be expected.

**156. Side-feed Stokers.**—These stokers, or furnaces, are characterized by large coking spaces and ample combustion chambers. As constructed at present, they all have a fire-brick arch extending over the entire grate area and have openings for admitting hot air just above the coal at the point where the volatile matters are distilled. These features help to ensure smokeless combustion. The Survey report states that no other type of stoker was found doing so well under so great a variety of conditions. The chief trouble was found in the device for discharging the ash. It was found that these stokers smoked in some of the earlier installations which did not have the arch extending over the whole grate area.

**157. Underfeed Stokers.**—These stokers maintain the fire in a long heap in the middle of the furnace and feed the fresh coal underneath the burning mass so that the volatile gases must pass upward through it. The clinker formed from the ash collects at the sides and is removed through the front of the furnace. These stokers are nearly always used with mechanical draft, and the latest models are installed with automatic control for both air and fuel, so that the relative amounts of air and coal may be adjusted, and these will then continue automatically. This stoker requires no fire-brick arch and the combustion space required is less than for any other type, although even here the gases should not be allowed to strike the heating surface too soon. From these facts we see that this type is well suited to replace hand firing in an old plant where the space is limited and where the old settings cannot be altered materially. It is also notable for the ease and economy of carrying variable loads. This stoker has been successfully applied to internally fired boilers of the locomotive and marine types. The only variable element in operation is the cleaning of the fires and, if the fireman is careful to burn the fires well down before cleaning or breaking up, there will be no difficulty about smoke.

**158. Hand-fired Furnaces.**—With hand firing the best results are obtained when the firing is done frequently and in small charges. The greatest trouble from smoking is during and just after charging, but, if air is admitted freely during these times so as to oxidize the volatile matter, the smoke will be reduced.

Tests seem to show a higher economy and less smoke with rocking grates than with stationary grates where coals that do not clinker excessively are used. All hand-fired furnaces which will burn coal without objectionable smoke, approach the theory of the mechanical stoker, but owing to the variable personal element they cannot, under average conditions, give as good results. In most successful hand-fired furnaces the travel of the gases from the grates to the heating surface is lengthened, and many types use the fire-brick arch or the Dutch oven. The design of some furnaces shows recognition of the value of thoroughly mixing the air and gases; and arches, retorts, piers, or steam jets are used for this purpose.

When steam jets are used, they should be arranged to be automatically thrown into use when the door is opened for firing and should remain in operation for a short time following the closing of the door. The steam jet is found usually in a furnace that is improperly designed or that has too small an air supply. It is an uneconomical device, but doubtless often aids in preventing smoke by compelling the air and gases to mix thoroughly. The claim sometimes made that the use of a steam jet will increase the thermal value of the fuel is erroneous as a steam jet which is operated continuously is a source of considerable loss.

Cracking the furnace door for a period following stoking aids considerably in efficiency and smokelessness, but introduces the personal element. Automatic air openings in the doors are also used. The coking furnace requires less care on the part of the fireman to secure smokeless combustion but unless care is taken excess air is liable to leak through and reduce the efficiency.

The down draft furnace as ordinarily used has an upper grate formed of water tubes through which water circulates. Coal is fed upon this grate and, after being partially burned, falls upon the lower grate, where combustion is completed by the excess of air drawn through the upper and lower grates. The distilled gases from the fresh fuel pass through the fuel bed on the upper grate, thus being thoroughly mixed with air and facilitating combustion between the grates. Fig. 90 illustrates the application of this form of furnace to a return fire-tube boiler, and shows the method of connecting the grates to the water space and the boiler.

There are many small hand-fired power plant units which smoke badly. The construction of many of these furnaces is such that it is almost impossible to operate the plant without smoke. Still, something might be done to reduce the smoke if the firemen exercised more care in firing. Whatever can be done by firemen in the way of properly introducing the fuel into the furnace is just so much gained, and it relieves the auxiliary mixing devices or baffles, if such exist, from just so much work later on.

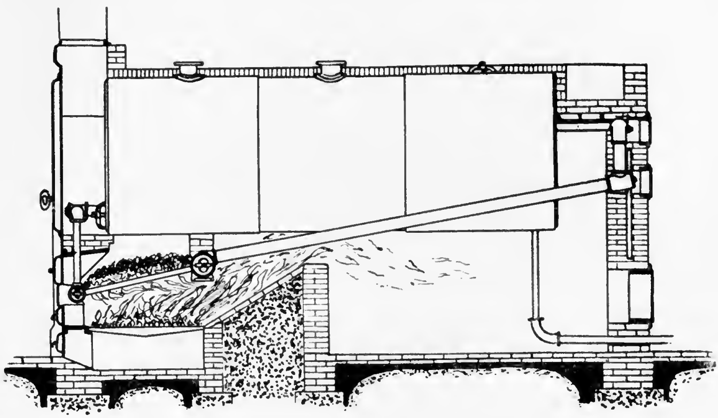


FIG. 90.—Hawley down-draft furnace.

The best method of hand firing for smokelessness is also the best method for economy. The spreading method is satisfactory, and generally used for anthracite; the coking method for caking coals and the alternate for non-caking coals. It is the alternate method which is best suited to most of the coals used in districts of Wisconsin, Michigan, and Illinois. This method allows much of the air supply to come through the bright fuel bed, and thus become heated and suitable for mixing with the highly volatile content which is being rapidly driven from the freshly fired coal on the other side. Just because fresh fuel has been spread over one part of the fuel bed, the air most needed at that moment cannot as easily flow through it, and another part of the fuel bed should be left free for its passage at that time.

When the fuel bed area is very large, some checker board system of firing in which the coal is fired in small thin patches may be adopted. When alternately fired and left free for air passage, this will result in a large reduction in the amount of smoke produced by the too common method of spreading the coal over the entire surface at each firing.

It must not be forgotten that a large supply of warm air is needed immediately after fresh fuel is spread over a part or all of the fuel bed; this is best supplied as just explained, but it may be advantageous to provide for still more air by leaving the fire doors open slightly just after each firing.

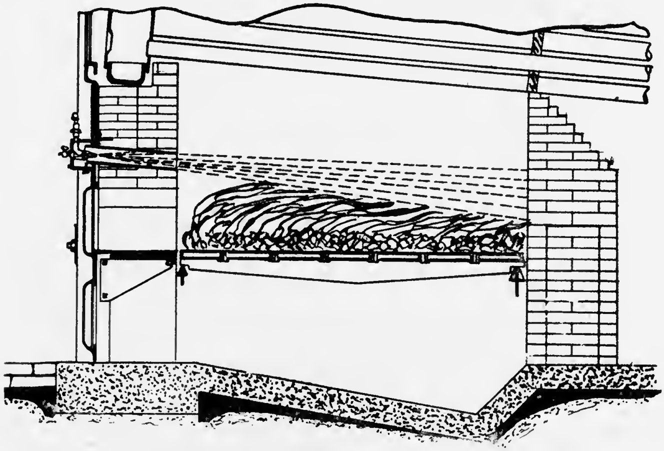


Fig. 91.—Climax smoke preventer.

There are several devices on the market which provide for an air supply over the fire, which are turned on with the opening or closing of the fire door and which can be arranged to close at the end of any desired time depending upon the rate of driving and frequency of firing found desirable. Fig. 91 illustrates the application of the Climax Smoke Preventer which is a device for accomplishing this purpose. This device blows steam into the furnace above the fire through a nozzle whose mouth is between 1/16 and 1/8 in. in diameter. The nozzle is surrounded by a piece of pipe of larger diameter through which air is drawn by the jet of steam. The jet of steam is directed toward the bridge wall for the purpose of thoroughly mixing the air with the volatile gases being distilled from the coal. The steam jet is started when the furnace door is opened and is closed at a definite time after the door is opened, by an electromagnet operated from a clock mechanism. The time at which closing occurs may be easily changed by the fireman to suit the frequency of firing and the quality of coal that is being used. If desirable, several of these steam jets may be attached to a single furnace.

The firing of small amounts of coal at frequent intervals produces less smoke than the firing of large amounts at long intervals. The latter method, however, usually proves less tiresome to the fireman and is for that reason more frequently adopted by him unless he is closely supervised.

While careful hand firing will reduce the smoke considerably, the chief difficulty is that nearly all hand-fired furnaces are improperly designed. The customary setting for a hand-fired fire-tube boiler is all wrong except for anthracite coal or coke. Placing the grate directly beneath the boiler shell is in direct violation of principles *c* and *d* given on page 185. The bridge wall further deflects the gases against the shell as they pass over it. No matter what care is taken in firing, the hydrocarbons cannot be completely burned under such conditions. To remedy this, the grate should be moved forward at least a distance equal to its own length, so it will be entirely out from under the boiler, and an arched fire-brick furnace built over it. This furnace should be high and roomy, so that the gases from the coal will not be drawn out too quickly. Another important point is to have the gases thoroughly mixed before they become cooled. In this way, the surplus oxygen that may be admitted at one point will be available for burning the excess of hydrocarbons that is driven off at another point of the fire. This may be done by steam jets or by baffle plates. In some cases, the shape of the furnace and bridge wall has been found to create eddy currents sufficient to mix the gases thoroughly in the furnace.

It will be seen that the chief difficulty of hand-fired furnaces is the irregular supply of coal and the consequent variation in the proportions of the air and fuel. Nearly all devices aiming to make hand-fired furnaces smokeless are merely devices intended to increase more or less automatically the air supply when more air is needed. The best solution of this part of the problem, however, is the use of a mechanical stoker which will deliver a continuous supply of fuel. Then if the stoker is properly set and operated, even the peats and lignites can be burned with little or no smoke.

# CHAPTER XIII

## SETTINGS

**159. Foundations.**—In selecting the location of boilers, attention should be given to the nature of the soil upon which they are to rest. It is always better to construct a foundation for the walls of the setting to rest upon, as this will insure their permanent alignment. If the soil is firm, the foundation may be light, but if the soil is not firm, the foundation should be heavier and more extensive. The foundation is usually constructed of concrete, but stone or even brick may also be used where more convenient.

**160. Setting for Fire-tube Boilers.**—The setting for a boiler includes the general arrangement of furnace, boiler, and chimney, in relation to one another and the manner in which the furnace and boiler are enclosed and built in. For the ordinary return fire-tube boiler, which is the most common type, there are two standard forms of setting, known as the *full-arch front* and the *half-arch front.* The full-arch front is also known as a *flush front* because the front of the setting is flush with the smoke box which is formed within the setting. The front of this setting is in the form of a large rectangular cast-iron plate with openings for the firing, ash pit doors, and flue doors. The front is of more or less ornamental design and, when boilers are set in a battery, gives a very neat appearance. A flush front setting is shown in Fig. 5. The smoke connection in this setting is cut off from the furnace by a sheet of steel bent into a half circle, as shown in Fig. 4. This half circle is bolted on one side to the shell of the boiler and the other side fits up close to the front.

The half-arch front is sometimes known as the *overhung front,* from the fact that the smoke box, or front connection, extends out in front of the setting instead of being formed inside. The cast-iron front, instead of being rectangular, extends up to the boiler and fits up underneath the curve of the shell. The boiler shown in Fig. 92 has an overhung front. From this illustration it can be seen that the front is in two parts; the lower one extends up to about the middle of the boiler while the upper part fits around the top, giving a neat appearance to the front. Fig. 92 also illustrates the method of fastening the cast-iron front to the brickwork by means of long bolts, which pass entirely through the setting from front to rear, the bolts being imbedded in the brickwork. The overhung front is somewhat less expensive than the flush front, but it has the disadvantage that the end of the boiler projects out past the front and makes the operation of throwing coal into the furnace a little more difficult.

The smoke connection to a boiler with an overhung front is made to the projecting end of the boiler, the bottom part of the smoke box being enclosed by a steel band as in the flush front. If the boiler is small and a light steel stack is used, the weight of the stack may rest directly on the boiler. Heavier stacks

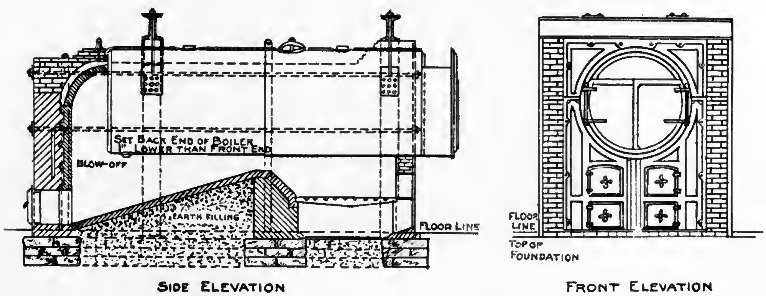



Fig. 92.—Setting of fire-tube boiler with overhung front.

should be built independent of the boiler, and connection made by a breeching passing from the smoke connection to an opening in the side of the stack.

When two or more boilers are set side by side with common front and rear walls, they form what is termed a *battery* of boilers. All the boilers of a battery may or may not be connected to the same chimney.

A standard setting for return fire-tube boilers, recommended by the Hartford Steam Boiler Inspection and Insurance Company, is shown in Fig. 93. In this setting the furnace is lined with fire brick and the walls are made very thick. In the cross-hatching on the illustration, the alternate full and dashed lines represent fire brick. The full lines represent common brick. In describing this setting the company has the following to say:

"The width of the furnace in the settings advocated by this company is 6 in. less than the diameter of the boiler. Beginning just above the

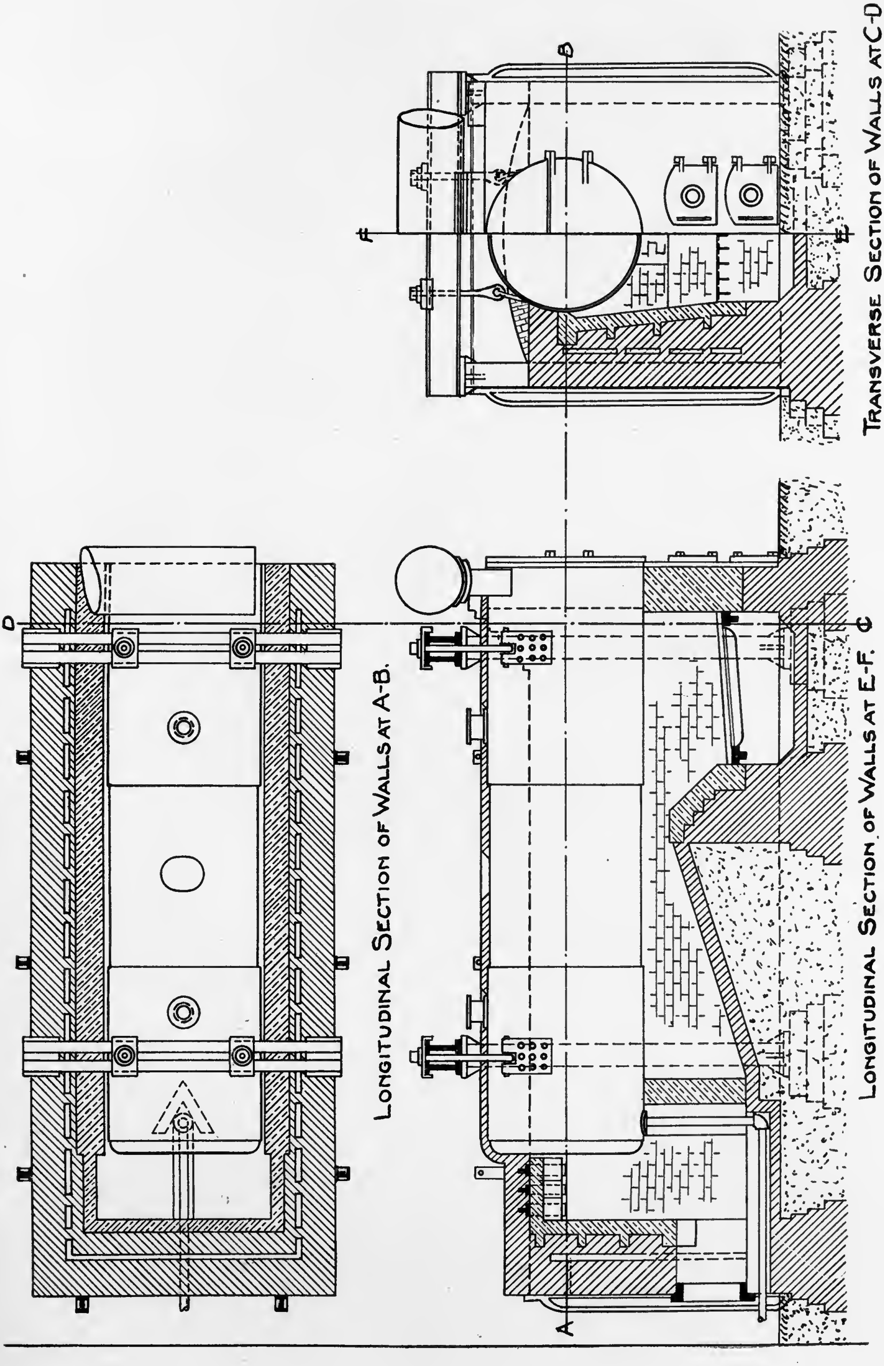

Transverse Section of Walls at C-D
Longitudinal Section of Walls at A-B.
Longitudinal Section of Walls at E-F.

Fig. 93.

grate, the side walls batter at such an angle as to make them 3 in. clear of the boiler at its center, where the walls project toward and close against the boiler. The batter gives greater stability to the walls, and another special feature of it is that it allows the heated gases to rise without impinging against the walls of the setting, and they flow away from the walls and distribute themselves evenly over the whole heating surface of the shell. The removal of ash and soot is also facilitated and, moreover, it is found that these deposits do not form so readily when the walls are battered as they do when the walls are straight and the space between them is correspondingly contracted. The batter also increases the volume of the combustion chamber and allows of a more thorough mixing of the oxygen and furnace gases, the result being that complete combustion of the fuel is greatly facilitated. The bridge walls slope back from about 4 in. above the grate at an angle of 40 degrees in order that the radiant heat from the fire may be diffused over a large portion of the boiler shell.

"The flame bed back of the bridge wall slopes down to the level of the boiler room floor. It is paved for easy cleaning, and the combustion chamber is large enough to make examination and repairs to the boiler comparatively easy. The cleaning door in the rear wall is placed on a level with the flame bed, in order that ashes may be readily removed, and, as it is below the currents of highly heated gases, loss by radiation through the door is largely prevented. The loss or waste of heat through this cause is often very great and it has not generally received the attention it deserves.

"Another point that demands more attention than it usually receives is the liability of leakage of cold air through the walls of the setting, with the resulting reduction of furnace temperature. To avoid loss of temperature from this cause, heavy double walls are constructed in this company's settings, the outside walls of a battery having a 2-in. air space between them. The division walls between two or more boilers should have a half-inch clear space between them, to allow free and independent expansion of the walls. With a solid wall and one or more boilers of the battery stopped, one side of the wall separating a boiler in use from one out of use would be hot and greatly expanded, while the other side of it would be cool; the result being that the bonded or solid wall must necessarily be strained or injured, and the joints in the masonry quite probably broken by the unequal expansion. Excessive leakage of air is likely to follow. These criticisms apply to all solidly built boiler settings. While the heavy double walls are somewhat more expensive in first cost, the increased economy and capacity of the boilers as well as the greater durability of the settings, fully warrant their construction. The results obtained in many large plants fully sustain this statement.

"The exposed portion of the boiler shells above the settings are covered with plastic non-conducting covering $2\frac{1}{2}$ in. thick. This is much lighter than brick, it is a better non-conductor, and does not exert a sensible thrust upon the setting walls as a brick arch does. If leaks occur along the joints of the covered part of the boiler, they are quickly noted by the discoloration of the covering, and may be stopped before injury from corrosion occurs.

"The illustrations give the general arrangement of the settings described above, in which it is desired to combine durability with simplicity in design and construction, and at the same time to obtain good results from the boilers, both in economy and capacity."

For estimating the number of bricks required to set return fire-tube boilers according to the plans just described, the table on the next page will be useful.

Good hard burned brick should be used, set in strong mortar of cement or lime and cement. The brickwork should not touch the boiler, as bricks absorb moisture and retain it a long time, thus rendering the boiler liable to corrosion at a place not easily seen. A better plan is to fill all spaces between the boiler and masonry with fire clay.

However set, all boilers must be allowed ample freedom for expansion and contraction, to prevent the setting from being damaged. The brickwork is often laid so close to the boiler that the rivet heads are imbedded in the masonry and, when expansion occurs, the walls are damaged at a place not easily seen. To prevent this, an iron angle is sometimes riveted along the sides of the shell and the brickwork brought up to it instead of up to the shell itself.

In building brick settings, if any trimming of bricks has to be done, red brick should be trimmed in preference to the fire brick as the broken section of a fire brick is quickly attacked by heat, causing it to crumble. For the same reason, no pieces of fire brick should be used unless the unbroken side can be turned toward the fire. The fire-brick lining should be independent of the balance of the setting, as it will require repairing from time to time and it is desirable that the lining may be taken down and replaced without disturbing the balance of the setting.

The tops of many externally fired boilers are covered with a brick arch resting on the side walls. This is not a good plan as leaks are liable to occur and not be noticed. A better plan is to build the side walls up a little higher than the top of the boiler,

## MATERIAL REQUIRED FOR BOILER SETTINGS

### Full Flush and Overhanging Front Settings

| Diameter of boiler inches | Length of boiler feet | Number of fire brick for one boiler | | Pounds of fire clay | | Number of common brick | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | For one boiler | | For two boilers | | For each additional boiler | |
| | | Full flush | Overhang | Full flush | Overhang | Full flush | Overhang | Full flush | Overhang | Full flush | Overhang |
| 30 | 8 | 686 | ...... | 275 | ...... | 4286 | ...... | 6493 | ...... | 2207 | ...... |
| | 10 | 779 | ...... | 315 | ...... | 4974 | ...... | 7473 | ...... | 2499 | ...... |
| 36 | 8 | 772 | ...... | 310 | ...... | 4863 | ...... | 7385 | ...... | 2522 | ...... |
| | 10 | 883 | ...... | 355 | ...... | 5551 | ...... | 8372 | ...... | 2821 | ...... |
| | 12 | 980 | ...... | 390 | ...... | 6197 | ...... | 9296 | ...... | 3099 | ...... |
| 42 | 10 | 1045 | ...... | 420 | ...... | 6212 | ...... | 9400 | ...... | 3189 | ...... |
| | 12 | 1173 | ...... | 470 | ...... | 6902 | ...... | 10383 | ...... | 3481 | ...... |
| | 14 | 1281 | ...... | 515 | ...... | 7666 | ...... | 11477 | ...... | 3811 | ...... |
| 44 | 10 | 1066 | ...... | 430 | ...... | 6258 | ...... | 9860 | ...... | 3602 | ...... |
| | 12 | 1183 | ...... | 475 | ...... | 6992 | ...... | 10960 | ...... | 3969 | ...... |
| | 14 | 1310 | ...... | 525 | ...... | 7756 | ...... | 12107 | ...... | 4351 | ...... |
| 48 | 12 | 1509 | 1318 | 605 | 530 | 12312 | 11475 | 18730 | 17505 | 6417 | 6030 |
| | 14 | 1662 | 1480 | 670 | 590 | 13618 | 12691 | 20620 | 19260 | 7002 | 6570 |
| | 16 | 1811 | 1627 | 725 | 650 | 14832 | 13995 | 22374 | 21150 | 7542 | 7155 |
| 54 | 14 | 1843 | 1627 | 740 | 650 | 14477 | 13478 | 21980 | 20520 | 7501 | 7043 |
| | 16 | 1990 | 1786 | 795 | 715 | 15781 | 14658 | 23867 | 22316 | 8086 | 7658 |
| 60 | 14 | 2109 | 1831 | 845 | 735 | 16208 | 15038 | 24720 | 23010 | 8513 | 7973 |
| | 16 | 2278 | 2002 | 915 | 800 | 17588 | 16418 | 26716 | 25006 | 9128 | 8588 |
| | 18 | 2458 | 2180 | 985 | 875 | 19058 | 17888 | 28786 | 27136 | 9728 | 9248 |
| 66 | 16 | 2495 | 2186 | 998 | 875 | 18838 | 17408 | 28765 | 26716 | 9927 | 9308 |
| | 18 | 2677 | 2364 | 1070 | 945 | 20308 | 19044 | 30745 | 29042 | 10437 | 9998 |
| 72 | 16 | 2770 | 2424 | 1110 | 970 | 20693 | 19185 | 31666 | 29460 | 10973 | 10275 |
| | 18 | 2971 | 2611 | 1190 | 1045 | 22513 | 20895 | 34306 | 32035 | 11793 | 11140 |
| | 20 | 3163 | 2816 | 1265 | 1130 | 24059 | 22641 | 36549 | 34470 | 12490 | 11830 |
| 78 | 18 | 3250 | 2861 | 1300 | 1145 | 23688 | 21988 | 36025 | 33530 | 12377 | 11543 |
| | 20 | 3499 | 3110 | 1400 | 1245 | 25769 | 24254 | 39242 | 37022 | 13473 | 12768 |
| 84 | 18 | 3603 | 3162 | 1445 | 1265 | 29811 | 27740 | 46160 | 43055 | 16350 | 15315 |
| | 20 | 3831 | 3372 | 1535 | 1350 | 32015 | 29960 | 49453 | 46363 | 17438 | 16403 |

*Notes.*—When boilers are set on brackets, the piers of foundation are omitted.

Fire brick figured to line the entire surface of furnace, including floor of combustion chamber, every fifth course to be a header course.

Fire clay, figured on basis of 400 lb. of fire clay per thousand of fire brick.

Common brick—one barrel of Portland cement, one barrel of lime and 5/8 cu. yd. of sand will lay 1000 common brick.

and fill in over the top with clean dry sand, which can easily be brushed aside. A still better plan is the use of a non-conducting covering as described before.

**161. Boiler Supports.**—Fire-tube boilers are usually supported either by brackets riveted to the shell and resting on the side walls, or suspended by straps riveted to the shell. A well designed support should allow free expansion of the boiler and distribute the weight equally among the different supports.

Boiler brackets are made of cast iron or stamped from sheets of boiler steel. Cast iron cannot resist bending strains as well as steel, and for this reason steel brackets are better than those made of cast iron. Brackets are usually riveted a little above the middle line of the boiler in such a position that about three-fifths of the circumference of the shell will be below them. The boiler shown in Fig. 5 is fitted with brackets of a shape commonly used. Small boilers are provided with two brackets on each side, but the larger sizes have three brackets on each side, the middle one being used to prevent the boiler sagging at this point.

To allow for free expansion of the boiler, the front brackets usually rest directly on cast-iron plates placed on the side walls, and the rear ones rest on iron rollers placed on cast-iron plates. This anchors the front end so it cannot move and leaves the rear end free to move and take up expansion. If there are three brackets on each side, both the middle and rear ones rest on rollers. The principal objection to supporting boilers by means of brackets is that sometimes the side walls will settle slightly after being built or will be damaged by the heat to which they are subjected, thus causing twisting strains to be thrown on the boiler.

A method of supporting fire-tube boilers which has come into extensive use in recent years is illustrated in Fig. 94. In this method, the weight of the boiler is not carried by the walls of the setting but by steel columns which are placed in the outer edge of the walls and which rest directly on the foundation. Steel channels are placed back to back across the boiler, two in front and two at the rear, and rest on top of the side columns. Slings are placed between the channels and fastened above by means of heavy cast-iron washers and nuts, and the boiler is hung by these slings, which are fastened to the lugs with pins. Boilers hung in this manner have perfect freedom for expansion without damage to the brick setting and, being made of steel, the supports are not liable to break as easily as the cast-iron brackets, nor will the boiler be disturbed if the walls of the setting should settle. A modification of the above method, which is sometimes used, is to support the rear of the boiler by means of slings, as described above, and to have the front end supported by brackets resting on cast-iron plates placed on the wall of the setting. This method, however, has few of the advantages of supporting entirely by slings and has the disadvantages of bracket supports.

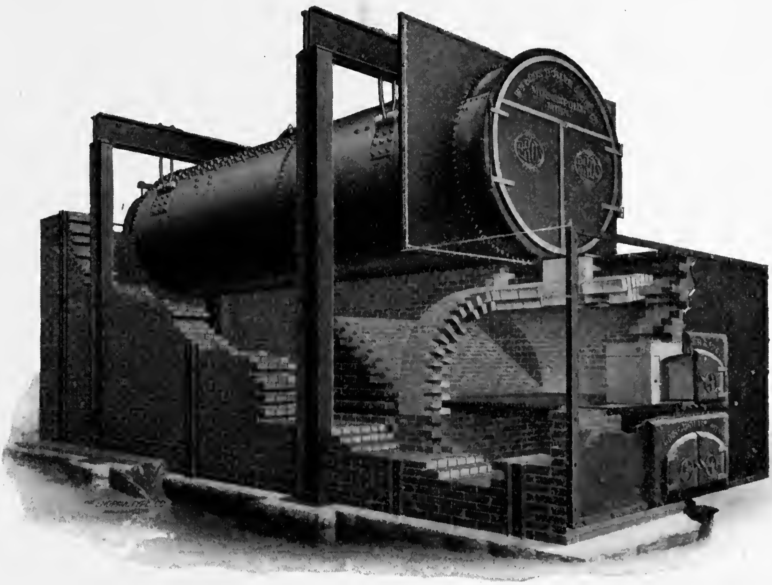


FIG. 94.—Fire-tube boiler with Dutch oven setting.

**162. Bridge Wall.**—The bridge wall is for the purpose of preventing the coal from falling off the grates and of forcing the air to pass up through the fuel bed. The shape of the wall, whether flat on top or curved to correspond with round shells, or whether with vertical or with sloping sides, appears to make little difference according to tests made by Mr. George H. Barrus. The area over the wall must be large enough not to check the draft but, beyond that, the effects of shape appear to be slight. A flat wall is easier to build, but most engineers prefer a curved top with a vertical front face, and with the upper edge cut away at an angle of 45 degrees.

With soft coals it is best to admit some air above the grate and for that purpose the bridge wall is often made "split," that is, hollow, with air passages in its back face or on top. These passages or holes may be made in a cast-iron plate set in the bridge wall, or be made between the bricks by spacing them a short distance apart. The hollow center of the wall can be connected to the air space in the side walls of the setting so as to draw heated air only. Fig. 95 illustrates a common method of constructing a split bridge wall. The air supply should be easily controlled by a damper. In internally fired flues, air may be passed from the ash pit through an opening in the plate beneath the bridge wall, which opening can be controlled by a

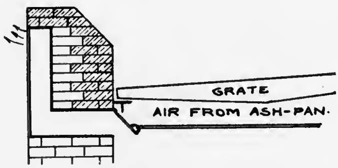



Fig. 95.—Split bridge wall.

slide or damper door easily moved from the front by the slice bar or poker. The split bridge often materially assists in preventing the generation of an excess of smoke, but like every other such device, must be handled with intelligence.

**163. Dutch Ovens.**—It has long been recognized that the setting previously described for return fire-tube boilers, while substantial and giving good results with anthracite coal, is not well suited for burning the poorer grades of bituminous coal. Various modifications of the ordinary setting have been used in an effort to secure better combustion of the cheaper grades of coal.

One of the most common of these is the Dutch oven setting shown in Fig. 94. This consists of an extension of the ordinary setting built out in front of the boiler and containing the grates. The extension is arched over and lined with good fire brick to resist the very high temperatures which exist in the furnace. The bridge wall, which is also lined with fire brick, is built just back of the furnace and has a sloping face for directing the hot gases against the boiler.

The principal advantage of the Dutch oven furnace is derived from its large combustion chamber and the longer path which the hot gases take before reaching the comparatively cool surfaces of the boiler, thus allowing a better opportunity for the combustible gases to become mixed with air and burned at a high temperature. These results are not always obtained, however, as the furnace is often built too short. Sometimes, also, the draft used is so strong that the gases are taken out of the furnace before they have mixed and burned.

The very high temperature maintained in a Dutch oven furnace causes the fire-brick lining to burn out quickly, making it expensive to maintain. The high temperatures require that the front wall be thick, which makes firing rather difficult. Even with the objections noted above, the Dutch oven gives much better results with bituminous coals than do the more common forms of settings.

**164. The Chicago Setting.**—The general details of settings for return fire-tube boilers, recommended by the Chicago Department of Smoke Prevention, are shown in Figs. 96 and 97. The

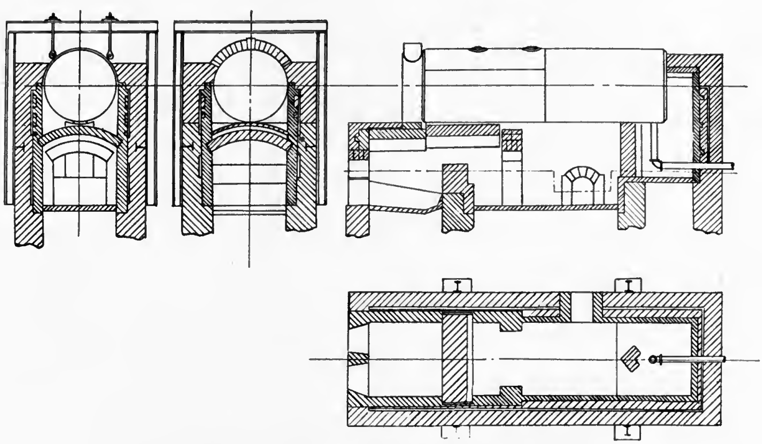


Fig. 96.—Chicago setting with single door.

setting shown in Fig. 97 differs from that shown in Fig. 96 in having two fire doors instead of one, thus allowing one side of the furnace to be fired at a time, in order that the gases being distilled from the freshly fired charge may have an opportunity to mix with the hotter gases given off from the other side of the furnace.

These settings differ from the ordinary setting in having an arched combustion chamber which extends from the front of the boiler to a point about 30 in. beyond the bridge wall. The arch prevents the combustible gases from coming in contact with the shell of the boiler before they have had an opportunity to be burned.

After passing the bridge wall, the hot gases are deflected downward and inward by another arch, thus making their path longer and causing them to remain in the combustion chamber a greater length of time.

Regarding the construction of this setting, the Department of Smoke Prevention makes several recommendations, among which are the following:

The doors should be provided with grids for admitting air above the fire. The grids should have an area of at least 4 sq. in. for each square foot of grate surface.

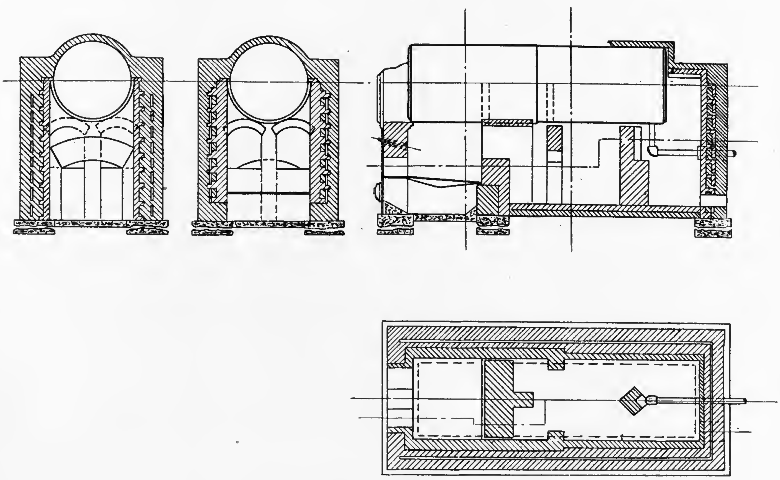


Fig. 97.—Chicago setting with double doors.

The arches should be made of wedge brick and not of two courses laid flat.

The bridge wall should be made of the best grade of fire brick above the grate line and faced with fire brick to a thickness of 9 in. on the combustion chamber side. The bridge wall should not extend entirely across the furnace, in order to allow a little space for expansion.

The combustion chamber floor should be paved with fire brick laid on edge.

The fire-brick lining below the spring of the arches should be not less than 9 in. thick, while the lining above the arches may be $4\frac{1}{2}$ in. thick with headers every fifth row.

The fire brick over fire and clean-out doors should be arched.

The thrust of the arches should be taken up by a piece of metal imbedded in the outer wall of the setting, directly opposite the point where the arch springs.

Broad flat top grates, such as the herringbone, should not be used with bituminous coal.

Chimneys less than 75 ft. above the grate line should not be used, and this height should be used only where the chimney is connected directly to the boiler uptake. In case a breeching and detached chimney is used, add to the height of the chimney 10 ft. for every turn in the breeching and 1 ft. for each foot length of the breeching.

Although the Chicago setting is more complicated than the ordinary setting, it has the advantage of requiring no more space and of giving good results when handled intelligently.

**165. The Burke Furnace.**—The Burke furnace shown in Figs. 98 and 99, is another modification in the ordinary setting designed to burn bituminous coal without producing smoke. This furnace

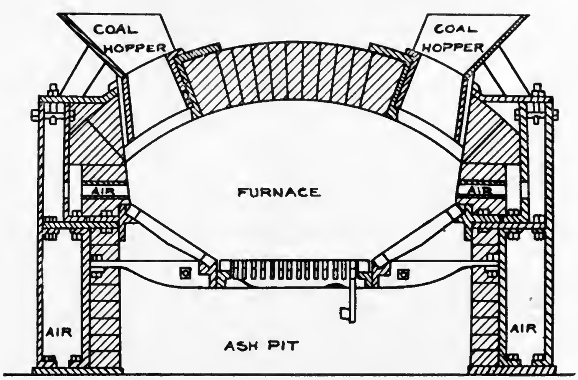



Fig. 98.—Cross-section of Burke furnace.

is built in the form of a Dutch oven extending in front of the boiler, but it differs from the ordinary Dutch oven in having three sets of grate bars. The grates on each side of the furnace are of the ordinary flat type and are inclined toward the center of the furnace, while the center is a horizontal shaking grate.

Coal is fed to the sloping grates through hoppers in the top of the furnace, thus making it necessary to open the furnace doors frequently. The furnace lining is cooled and prevented from burning by circulating air around it through spaces built in the side walls. Air enters the furnace both above and below the grates, that entering above being admitted through the side walls. This furnace resembles some forms of automatic stokers but differs from them in being manipulated by hand.

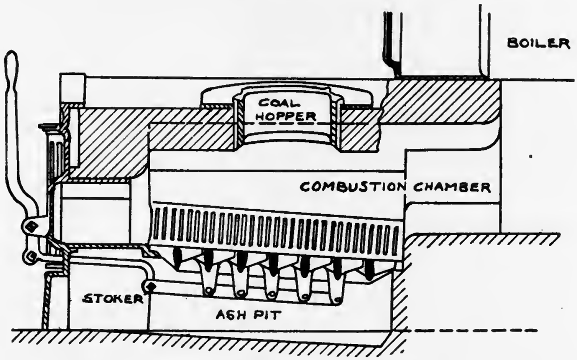



FIG. 99.—Longitudinal section of Burke furnace.

**166. Back Connections.**—The back connection of a boiler, which extends from the rear head to the rear wall of the setting, is for the purpose of guiding the hot gases from the combustion

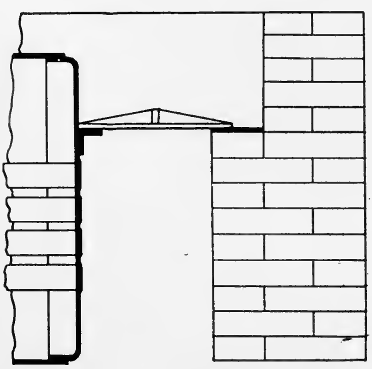


FIG. 100.

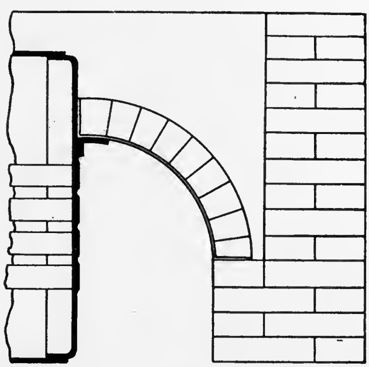


FIG. 101.

chamber into the tubes. It is usually constructed in one of the forms shown in Figs. 100 and 101. That shown in Fig. 100 consists of a flat cast-iron plate with a rib on the back to strengthen it, one end of the plate resting in a niche in the rear wall of the setting and the other end resting on a 2 in.×2 in. angle riveted to the rear head of the boiler. The plate is covered with 6 or 8 in. of dry dirt or sand to prevent air leaking in at this point and also to prevent the escape of heat. The filling should be done carefully, as air leaking into the setting at this point reduces the draft very much. The plate should be a little shorter than the distance from the boiler to the back edge of the niche in the setting in order to allow free expansion of the boiler without injuring the setting.

The form of back connection shown in Fig. 101 consists of a half arch sprung from the back wall of the setting to the rear head of the boiler, and resting on an angle iron riveted to the head. The arch consists of cast-iron skeleton forms filled with

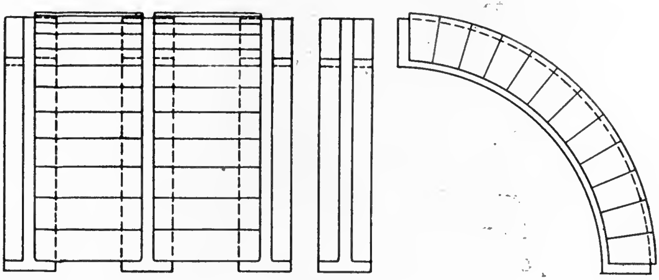


Fig. 102.

brick, as shown in Fig. 102, laid side by side and then covered with dry dirt or sand. As in the plate connection, there should be a little space between the head of the boiler and the arch to allow for expansion.

**167. Blow-Off Connection.**—Each boiler should be provided with a blow-off connection at its lowest point, for draining the boiler and blowing out the mud and sediment which collects from time to time. Horizontal boilers are set with the rear end 1 or 2 in. lower than the front end and with the blow-off connected to the bottom of the shell at the rear end as in Fig. 93. It is not good practice to connect the blow-off into the head, as it has to be placed above the curvature at the edge, leaving a depth of 1 or 2 in. from which the water cannot be drained. Mud and sediment will eventually collect at this point and become baked on the plates, leaving them in condition to be burned by the hot gases passing underneath. Water-tube boilers usually have a mud drum placed at the lowest point of the boiler, and the blow-off is connected to this.

The bottom blow-off should be of extra heavy pipe, 1½ in. in diameter for boilers up to 42 in. in diameter, 2 in. for 44 to 60-in. boilers and 2½ in. for boilers of larger size. When using the bottom blow-off, the velocity of the water flowing through the pipe should be sufficient to keep the mud and

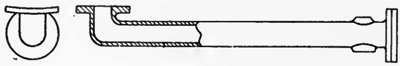


Fig. 103.—Cast-iron blow-off pipe.

scale moving, otherwise these are apt to collect at the bend and clog the pipe. For this reason the valve in the blow-off pipe should be opened wide when blowing.

When the blow-off pipe is 2 in. or larger in size, the shell should be reinforced with a plate at the point where the pipe enters the boiler, and the tapping should be done through both the plate and shell. Another way of reinforcing the shell is to rivet a tapped pipe flange to the shell.

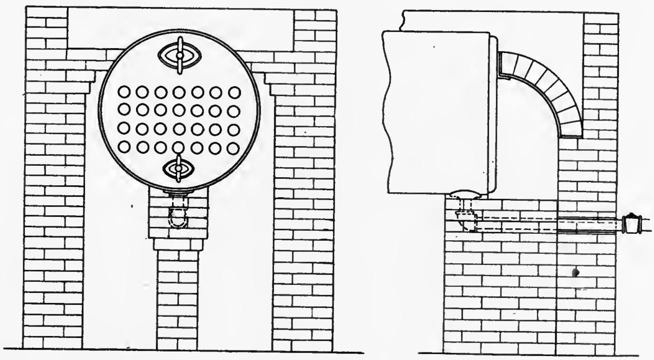


Fig. 104.

In some cases it is desirable to carry the blow-off pipe out of the setting above the level of the floor of the combustion chamber. Where this is done, the connection should be made with a heavy cast-iron pipe of the form shown in Fig. 103. Some boiler manufacturers furnish such pipe for this purpose. A horizontal blow-off should not be used if it can be avoided. It is better to run the blow-off pipe vertically to a point below the floor of the combustion chamber and then carry it outside the setting with an easy bend.

Whether the blow-off pipe is horizontal or vertical, it should be well protected from the action of the hot gases. Since the blow-off valve is placed outside the setting, the pipe is full of still water. Sediment will settle out of still water much quicker than when the water is in circulation, and as heat hastens the deposit of certain kinds of sediment, the blow-off pipe is apt to have sediment baked to it if it is left unprotected in the path of the hot gases leaving the furnace.

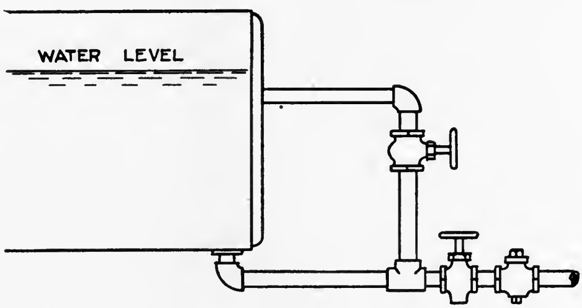



Fig. 105.

A good form of protection for a horizontal blow-off pipe is shown in Fig. 104, which consists of a narrow brick pier resting on the floor of the combustion chamber and having its top enclosing the blow-off pipe. As the pier is only 8 in. wide, it does not interfere materially with the passage of the flue gases. Wherever brick protection of the blow-off is used, the brickwork should not be brought right up to the shell, as this promotes external corrosion of the shell, nor should the brickwork be joined to the shell by means of mortar for the same reason, since the lime in the mortar absorbs moisture. Fire clay or red lead are better materials for this purpose.

A good protection for a vertical blow-off pipe may be made by placing around the part of the blow-off pipe which passes through the combustion chamber, a sleeve, made of glazed tile or cast-iron pipe 2 or 3 in. larger in diameter than the blow-off pipe itself, and packing the space between these pipes with some heat-resisting substance, such as asbestos. A fairly good protection may be constructed by building a V-shaped brick pier immediately in front of the blow-off pipe, as shown in Figs. 96 and 97.

In some cases the hot gases passing through the combustion chamber have a very high temperature, as where forced draft is used. If such is the case, and the boiler is not blown off frequently, it is desirable to run a circulating pipe from a point in the blow-off pipe outside the end wall to a point in the rear head of the boiler just below the water line, as shown in Fig. 105, each

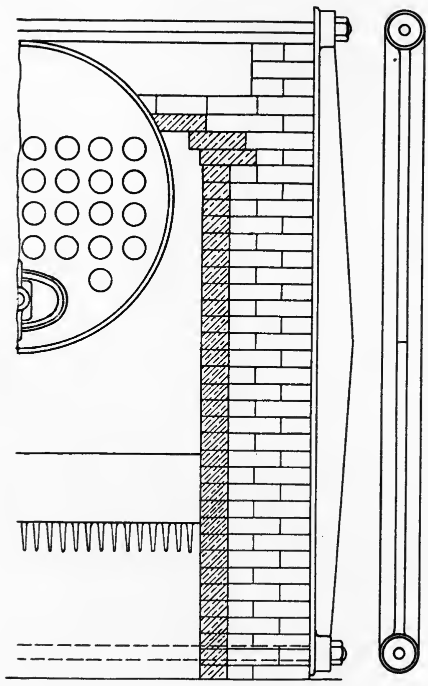


Fig. 106.—Buck-stay.

pipe being provided with a valve. A continuous circulation will then take place through the blow-off and the circulating pipes and there will be no danger of overheating. If this arrangement is used, it will not be necessary to place a protecting covering around the blow-off pipe. In blowing off the boiler, the valve in the circulating pipe should be closed; at all other times it should be left open.

When boilers are placed in batteries, the blow-off from each boiler in a battery may be connected outside the setting to a common blow-off pipe passing in the rear of all the boilers, each branch being provided with its own valve.

**168. Buck-stays.**—Buck-stays are used to brace the side walls of a setting to prevent their spreading. They are usually made of cast iron with a heavy web on the back, as shown in Fig. 106. The web is made about 4 or 5 in. wide and about 1 in. thick, like the other part of the buck-stay. These buck-stays are placed every 5 or 6 ft. along the side walls, and those on opposite sides of the setting are connected by long bolts passing entirely through the setting at the top and bottom.

**169. Water-tube Boiler Settings.**—Nearly every type of water-tube boiler has a different form of setting, so that very little information of a general nature concerning them can be given. The different forms of settings for these boilers may be seen in the illustrations given in Chapter II.

In general, those water-tube boilers, which have small, horizontal steam drums and sectional headers, are supported by bands which pass under the steam drums and are fastened to slings, which are in turn suspended from beams passing across the top of the boiler and resting on columns imbedded in the side walls. This relieves the setting from carrying the weight of the boiler and at the same time allows freedom for expansion. Those boilers which have horizontal steam drums and have the headers made from steel plates are usually supported by the bottoms of the headers, resting directly on the front and rear walls, although they are sometimes suspended by slings and bands. For vertical boilers, the setting is generally cylindrical in shape with the furnace at the bottom, the boilers being supported directly on foundation walls beneath them. All water-tube boiler settings are lined with fire brick wherever the hot gases come in contact with the setting.

The principal objection to the ordinary forms of settings for water-tube boilers is that it is practically impossible to burn bituminous coal in them without producing smoke. Various modifications have been made in the settings to secure more complete and smokeless combustion of these cheaper grades of coal. These modifications may be divided into three classes, namely, the addition of a Dutch oven to the furnace, the rearrangement of the passes and the covering of the lower tubes with tile, and a rearrangement of the setting to secure better mixing of the volatile gases and air.

The Dutch oven furnace has been described in connection with fire-tube boiler settings and needs no further attention here, as the furnace is the same whether applied to a fire- or water-tube boiler. As applied to water-tube boilers, it is usually equipped with a mechanical stoker which may be of any of the types previously described. The more common arrangements of the passes and the uses of tile covering for the tubes have also been described in Chapter XII on smokeless combustion.

**170. The Kent Wing Wall Setting.**—One of the settings very commonly used for water-tube boilers and designed to produce

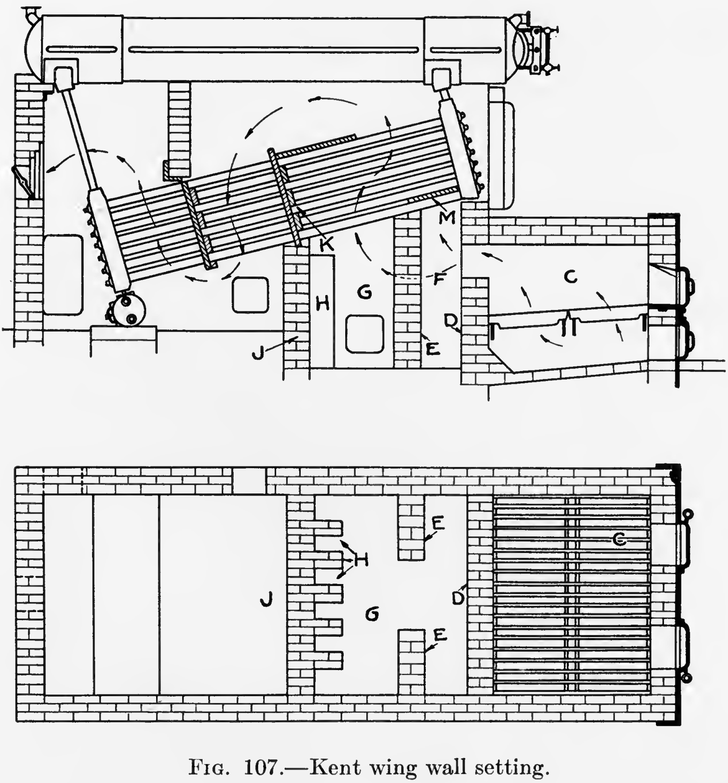



Fig. 107.—Kent wing wall setting.

smokeless combustion is known as the Kent Wing Wall Furnace, illustrated in plan and section in Fig. 107. This setting consists of a Dutch oven lined with fire brick and provided with two doors for alternate firing. Just back of the bridge wall are two wing walls, *E*, one on each side, projecting toward the center of the setting, and immediately back of these are a series of baffles *H*, built of fire brick. In operation, coal is spread evenly over only one-half of the furnace at each firing, and a large excess of air is admitted over the bed of fuel on the other half of the grate. The volatile gases distilled from the freshly fired fuel, and the air passing over the other half of the fire, are both forced to pass through the narrow opening between the wing walls,

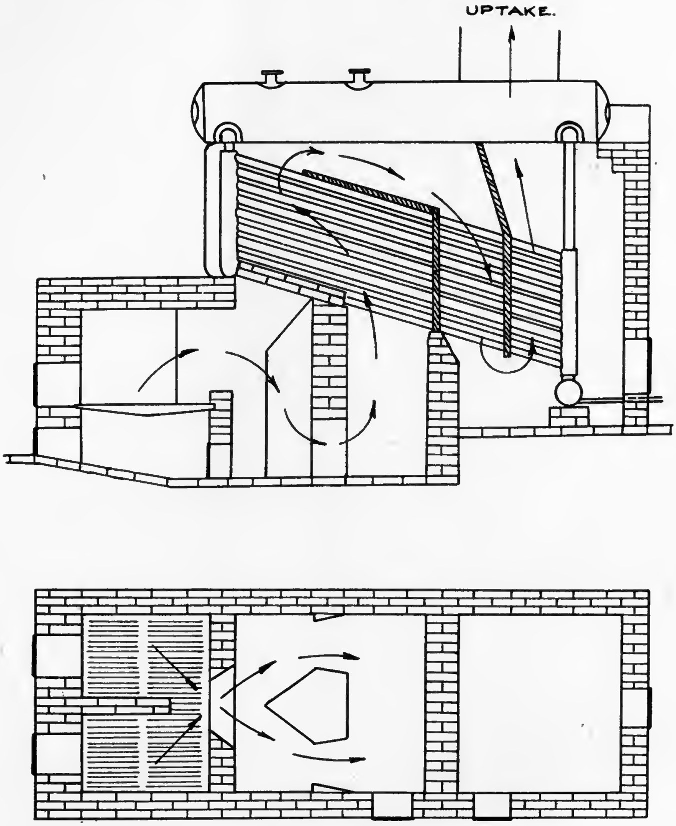



Fig. 108.—Wooley smokeless setting.

where they are thoroughly mixed. The baffles *H*, serve to further mix the gases and air, although their principal office is to store up heat when the furnace is hottest and give it out again when the temperature is lower. The good results obtained by the use of the Kent Wing Wall Setting are due largely to the roomy combustion chamber, the thorough mixing of combustible gases and air, and the length of time before the gases come in contact with the cooler boiler tubes.

**171. The Wooley Smokeless Setting.**—The Wooley Smokeless setting shown in Fig. 108 is another form commonly used with water-tube boilers. This setting consists of a Dutch oven with a dividing wall down the center, wing walls built on top of the bridge walls, and a deflecting wall inside the combustion chamber. This furnace is intended to be fired alternately, and the combustible gases and air are both forced to pass though the narrow opening between the wing walls. This opening, though narrow, has sufficient area to avoid reducing the draft. The deflecting wall causes the paths of the gases from each side of the furnace to cross as they pass between the wing walls, thus insuring a thorough mixing. The lower row of water tubes is covered with fire tile between the Dutch oven and the deflecting wall, and the hot gases pass beneath the deflecting wall in leaving the furnace, thus giving them a longer path before they reach the tubes.

**172. Steel Settings.**—Steel boiler settings have been used in some cases instead of the ordinary brick setting. Steel settings consist of an outer casing of sheet steel, riveted together and stiffened with angle irons or tee bars. The sheet steel is lined with, first, a thickness of asbestos over which is placed a layer of red clay and then a layer of fire clay. The principal advantages of these settings is that they are practically air tight, and that they are not injured by the continual expansion and contraction of the boiler, nor from settling of walls as is sometimes the case with brick settings. Their cost is about the same as for brick settings.

**173. Shaking Grates.**—Shaking or rocking grates are for the purpose of cleaning the fires and removing ashes without the necessity for opening the furnace doors. In order to accomplish this purpose, the grate bars consist of a number of small movable sections as shown in Fig. 109. The grate bars are connected to rods which extend to the front of the furnace and are there joined to levers by which they may be given the desired motion. By moving the levers slightly, the grate bars are given a gentle up-and-down motion which is sufficient to remove the ashes without disturbing the fire very much. Should clinkers collect, or the coal cake, the fire may be thoroughly stirred and the clinkers broken by giving a larger motion to the grate bars, as illustrated by the front section of the grate shown in Fig. 109.

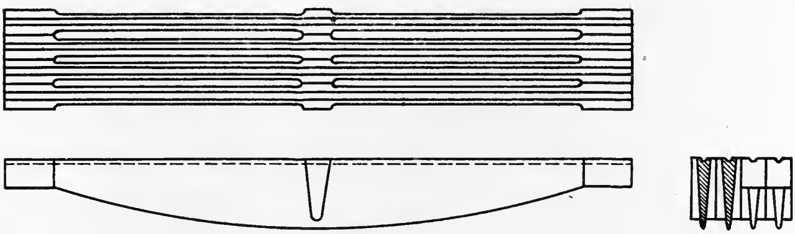
Since shaking grates render unnecessary the continual opening of furnace doors to trim the fires, they promote efficiency and smokeless combustion by preventing too much cold air from entering the furnace. They also lighten the labor of the fireman, as one of the hardest tasks he has to perform is that of standing in the hot glow from the furnace and slicing the fire.

FIG. 109.—Shaking grates.

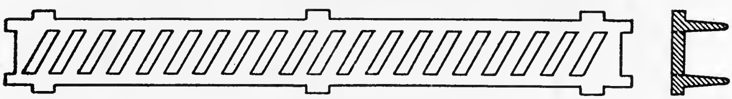
**174. Grate Bars.**—Grates are usually made of cast iron in the form of bars or sections which fit together to make up the entire grate, the bars being made up of alternate "lands" for the support of the fuel and openings for the admission of air. The most common forms of grate bars are the Plain, the Tupper, the Herringbone, and the Pinhole, shown in Fig. 110. The Tupper and Herringbone grates are suitable for burning anthracite and the free burning varieties of bituminous coals, but are not adapted to caking coals or those which clinker, as the clinker adheres to them and it is hard to run a slice-bar under the fire for breaking the clinker. The plain grate is best adapted for these coals, as there is a small groove along the top of each bar which soon fills with ash and prevents clinkers from adhering. A pointed bar may be easily run under the fire along this groove, making it easy to slice the fire. Pinhole grates are particularly adapted to burning sawdust and other refuse matter.

The openings in grates vary from 1/4 in. to 5/8 in. in width, depending on the size of coal to be used. The openings should be narrowest at the top of the grate and widen toward the bottom in order to prevent their being stopped up by small pieces of coal or coke. The open spaces should constitute one-half of the total area of the grate in order to admit sufficient air for combustion, but if they constitute a greater proportion of the area than this, too much air will be admitted and the efficiency of the furnace lowered.

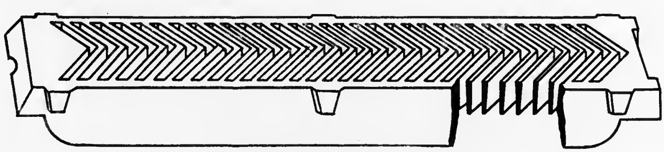
A web should be cast on the under side of each grate bar, to give it greater strength to support the fuel and also to give it



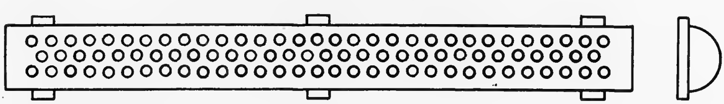
Plain grate bar.



Tupper grate bar.



Herringbone grate bar.



Pinhole grate bar.

Fig. 110.

enough stiffness to prevent its being warped by the heat to which it is exposed. If the web has a depth of about 4 in. there will be little danger of its breaking, even if the top becomes red hot.

Grate bars are usually made in lengths of 3 ft., and the total length of the grate will then be some multiple of 3. The most common length of grate for bituminous coal is 6 ft. A greater length than this cannot be sliced very easily, and ashes are apt to accumulate near the bridge wall. If a dead plate is used for caking the coal, it will add about 1 ft. to the furnace, making its entire length 7 ft. Grates for burning anthracite coal may have a length of 9 ft., as this kind of coal does not require slicing. Grates for this kind of coal are sometimes made 12 ft. long, but this is not advisable as it is very difficult for a fireman to throw coal so far and place it just where it should be. The grates should be given a slope of 1 in. in 20 toward the bridge wall in order to make it easier to throw coal to the back of the furnace.

The principal cause of the destruction of grates is the continuous heat to which they are subjected. The lack of a proper flow of air through the grates will quickly cause overheating and burning. The flow of air may be retarded or stopped by the openings becoming clogged with ashes or by the openings being too small. Another fruitful source of burned grate bars is an accumulation of ashes in the ash pit. These ashes, being hot, will heat the air passing over them and will restrict its amount until the grates are not cooled sufficiently and they will be burned. The remedy for this is, of course, to keep the ash pit cleaned.

# CHAPTER XIV

## PIPING AND BOILER FITTINGS

**175. Kinds of Pipe.**—Pipes used for conveying steam are made either of steel or wrought iron, except in a few special cases where copper pipe is used. By far the larger part of the piping erected to-day is of steel, as this is cheaper than wrought iron. Wrought-iron pipe wears better than steel as it is not so subject to corrosion, and, as it is softer, it may be threaded more perfectly and with greater ease than the steel pipe. Very few companies are now manufacturing wrought-iron pipe, though a number of them sell steam pipe which is branded as wrought iron. Steel pipe is not so easily welded as wrought iron, hence, it is often poorly welded and is apt to split, though great improvement in this respect has been made by the manufacturers in recent years.

Each length of pipe as sold is threaded on both ends and is provided with a coupling or collar screwed on one end. There is no standard length for pipe, the range of length usually being from 16 to 24 ft., with occasional short pieces. It can be ordered in lengths cut as desired for a slight increase in price, but it can be readily cut to any length and threaded by a pipe fitter. The pipe now made by manufacturers is of standard size so that pipe obtained from one manufacturer is reasonably certain to fit that made by another firm.

Both wrought iron and steel pipe are quite malleable and, when heated, may be readily bent to almost any shape by a skillful workman without materially changing the form of the cross-section. It is not a good plan to bend pipe while cold, on account of the liability of splitting the joint or seam and also the danger of changing the cross-section, though the latter may be prevented by inserting a coil spring of the same size as the pipe or by filling the pipe with sand before attempting to bend it.

Merchant pipe is a term used to designate regular pipe of the market, and orders are filled with this kind unless otherwise specified in the order. Merchant pipe will weigh from 5 to 10 per cent less than the weights given in the following table of dimensions of standard pipe. When full weight pipe is required the order should state this fact. Full weight pipe will weigh as much or a little more than the weights given in the table below.

Pipe is manufactured in three regular thicknesses or weights, called respectively *Standard, Extra Strong,* and *Double Extra Strong.* Standard pipe has the dimensions and weights given in the following table and is suitable for pressure up to 125 lb. per sq. in.

TABLE OF DIMENSIONS OF STANDARD STEAM PIPE

1 ¼ and Smaller Proved to 300 lb. per sq. in. by Hydraulic Pressure.
1 ½ and Larger Proved to 500 lb. per sq. in. by Hydraulic Pressure.

| Nominal inside diameter | Actual outside diameter | Thickness | Actual inside diameter | Inside circumference | Outside circumference | Inside area | Length of pipe containing 1 cu. ft. | Weight per foot | No. of threads per inch of screw |
|---|---|---|---|---|---|---|---|---|---|
| Inches | Inches | Inch | Inches | Inches | Inches | Square Inches | Feet | Lb. | |
| 1/8 | 0.405 | 0.068 | 0.270 | 0.848 | 1.272 | 0.0572 | 2500 | 0.243 | 27 |
| 1/4 | 0.54 | 0.088 | 0.364 | 1.144 | 1.696 | 0.1041 | 1385 | 0.422 | 18 |
| 3/8 | 0.675 | 0.091 | 0.494 | 1.552 | 2.121 | 0.1916 | 751.5 | 0.561 | 18 |
| 1/2 | 0.84 | 0.109 | 0.623 | 1.957 | 2.652 | 0.3048 | 472.4 | 0.845 | 14 |
| 3/4 | 1.05 | 0.113 | 0.824 | 2.589 | 3.299 | 0.5333 | 270 | 1.126 | 14 |
| 1 | 1.315 | 0.134 | 1.048 | 3.292 | 4.134 | 0.8627 | 166.9 | 1.670 | 11 1/2 |
| 1 1/4 | 1.66 | 0.140 | 1.380 | 4.335 | 5.215 | 1.496 | 96.25 | 2.258 | 11 1/2 |
| 1 1/2 | 1.90 | 0.145 | 1.611 | 5.061 | 5.969 | 2.038 | 70.65 | 2.694 | 11 1/2 |
| 2 | 2.375 | 0.154 | 2.067 | 6.494 | 7.461 | 3.355 | 42.36 | 3.600 | 11 1/2 |
| 2 1/2 | 2.875 | 0.204 | 2.468 | 7.754 | 9.032 | 4.783 | 30.11 | 5.773 | 8 |
| 3 | 3.50 | 0.217 | 3.067 | 9.636 | 10.996 | 7.388 | 19.49 | 7.547 | 8 |
| 3 1/2 | 4.00 | 0.226 | 3.548 | 11.146 | 12.566 | 9.887 | 14.56 | 9.055 | 8 |
| 4 | 4.50 | 0.237 | 4.026 | 12.648 | 14.137 | 12.730 | 11.31 | 10.66 | 8 |
| 4 1/2 | 5.00 | 0.246 | 4.508 | 14.153 | 15.708 | 15.939 | 9.03 | 12.34 | 8 |
| 5 | 5.563 | 0.259 | 5.045 | 15.849 | 17.475 | 19.990 | 7.20 | 14.50 | 8 |
| 6 | 6.625 | 0.280 | 6.065 | 19.054 | 20.813 | 28.889 | 4.98 | 18.767 | 8 |
| 7 | 7.625 | 0.301 | 7.023 | 22.063 | 23.954 | 38.737 | 3.72 | 23.27 | 8 |
| 8 | 8.625 | 0.322 | 7.982 | 25.076 | 27.096 | 50.039 | 2.88 | 28.177 | 8 |
| 9 | 9.625 | 0.344 | 9.001 | 28.277 | 30.233 | 62.722 | 2.26 | 33.70 | 8 |
| 10 | 10.75 | 0.366 | 10.019 | 31.475 | 33.772 | 78.838 | 1.80 | 40.06 | 8 |
| 11 | 11.75 | 0.375 | 11.00 | 35.343 | 36.91 | 95.03 | 1.455 | 45.95 | 8 |
| 12 | 12.75 | 0.375 | 12.000 | 38.264 | 40.840 | 113.09 | 1.235 | 48.98 | 8 |

Extra Strong pipe is made in sizes from 1/8 in. to 8 in. The ends are not threaded and supplied with couplings, as with Standard pipe unless specified when ordered. Extra strong pipe differs from Standard in having a greater thickness of walls. The ouside diameter is the same as that of Standard pipe, therefore, it can be joined to the Standard pipe, but its inside diameter is smaller. It is suitable for steam pressures up to 250 lb. per sq. in.

Double Extra Strong pipe has the same outside diameter as Standard pipe but its walls are even thicker than the Extra Strong, thus requiring that its inside diameter be less than that of the Extra Strong. It is suitable for pressures up to 800 lb. per square inch. To illustrate the difference in sizes of the three grades of pipe, the above table shows that a 1-in. pipe has an outside diameter of 1.315 in. and an inside diameter of 1.048 in. Extra Strong pipe of the same number has an outside diameter of 1.315 in. and an inside diameter of 0.951 in. Double Extra Strong pipe of the same number has an outside diameter of 1.315 in. and an inside diameter of 0.587 in. The outside diameters of different grades of pipe are made the same in order that the different grades may be joined together. It will be seen from the above table that the size of a pipe refers to its inside diameter, even though its inside diameter is not exactly the size number.

Pipes larger than 12 in. diameter are referred to as O. D. pipe, meaning that the size number refers to the outside diameter. O. D. pipe is made in thicknesses from 1/4 in. to 3/4 in. and in ordering it is necessary to specify the thickness wanted. If it is desired to have this pipe threaded it should be so stated on the order. In this connection it should be remembered that 5/16 in. thickness is the lightest that can be threaded. Thinner O. D. pipe than this should be provided with flanges.

**176. Determining the Sizes of Pipes.**—In the design of a steam plant no detail deserves more careful attention than the steam piping. Not only is this fact often overlooked, but the evils resulting from poor design are usually attributed to other parts of the equipment.

The nature of the substance to be conveyed by the pipe must be considered, as the requirements for steam are entirely different from those for water, oil, air, or gas. The principles governing steam-pipe design are: (1) The moment steam leaves the boiler it loses heat and some of it will condense. (2) Water of condensation is an evil and, since its formation cannot be prevented, a perfect pipe system must provide means for its removal as fast as it is formed. (3) There can be no flow of steam without a corresponding drop of pressure. (4) Drop of pressure of steam does not cause corresponding loss of energy. (5) The mechanical design must provide ample strength, provision for expansion, and properly located valves of suitable design.

The proper size of steam pipe to use in any case may be calculated from the following formulas. While these formulas are somewhat complicated they are given because they have been tested by comparison with measurements made on many actual piping systems.

$$p = .0003167 \frac{W^2L}{dD^5} \tag{1}$$

$$W = 55.45\sqrt{\frac{pdD^5}{L}} \tag{2}$$

$$D = .2\sqrt[5]{\frac{W^2L}{pd}} \tag{3}$$

$$V = 10163\sqrt{\frac{pD}{dL}} \tag{4}$$

in which $p$ is the loss of pressure in pounds per square inch
$W$ is the weight of steam flowing in pounds per minute
$L$ is length of pipe in feet
$D$ is diameter of pipe in inches
$d$ is density of steam in pounds per cubic foot
$V$ is velocity of steam in feet per minute.

To illustrate the use of some of these formulas, suppose we wish to find the drop in pressure in a 3-in. steam line 150 ft. long which carries 3600 lb. of steam per hour at a pressure of 106 lb. per sq. in. absolute. The density of this steam is found from the steam table to be 0.2425 and the weight flowing per minute is $\frac{3600}{60} = 60$ lb. therefore,

$$p = .0003167 \times \frac{60^2 \times 150}{.2425 \times 3^5} = 2.9 \text{ lb. nearly.}$$

If we wish to find the diameter of pipe that would carry the above steam with a drop of pressure of only 1 lb. per square inch we would substitute in the third formula above

$$D = .2\sqrt[5]{\frac{60^2 \times 150}{1 \times .2425}}$$

$$= .2\sqrt[5]{\frac{540000}{.2425}} = 3.72 \text{ in.}$$

The most useful of the above formulas are the second and third. The second is used when we wish to find the amount of steam that will flow through a pipe of a given size and the third is used when we want to find the size of pipe needed for a given amount of steam. The pressure drop $p$ allowed is usually about 1 lb. per 100 ft. of pipe, though this may be altered by special conditions.

**177. Expansion.**—Most of the breaks that occur in steam pipes

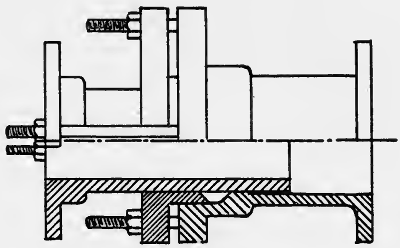


FIG. 111.—Slip expansion joint.

are breaks around the pipe near a joint. This indicates that these breaks are due to the expansion or contraction of the pipe. A break caused by excessive pressure within the pipe would run lengthwise of the pipe.

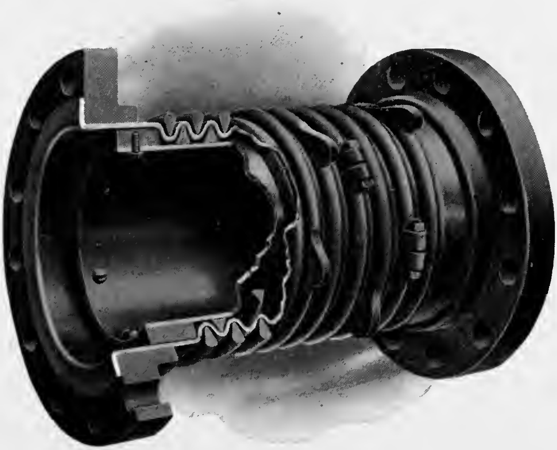


FIG. 112.—Wainwright expansion joint.

Ample provision should be made in all steam lines to allow for expansion and contraction in such manner as not to strain the pipe. About the simplest method of allowing for expansion is to provide elbows in the line with long legs on both sides of them.

The expansion in one leg will be taken up by the swing of the other leg which is at right angles to it. If high steam pressures are to be carried, a better method is to use long easy bends rather than elbows. In designing these bends it should be borne in mind that the thicker the pipe the longer should be the radius of the bend.

In the case of a long straight pipe where a bend or elbow cannot be used to take up the expansion, it is common to use some form of slip joint such as that shown in Fig. 111. These expansion joints are made to take up from 3 to 6 in. of expansion, and, as there is approximately 1 in. of expansion in 50 ft. of

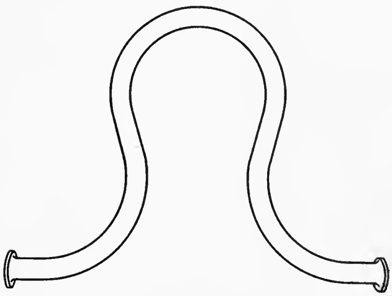


Fig. 113.

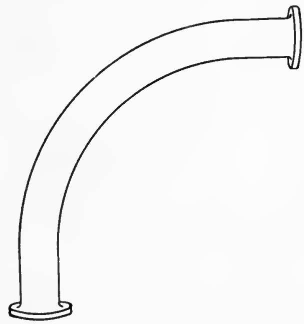


Fig. 114.

pipe, an expansion joint should be placed every 150 to 300 ft. In placing this type of joint in a line of pipe it should be remembered that there is nothing to prevent the joint pulling apart and for this reason great care should be used to firmly anchor the pipe at the proper distance from the joint. Some expansion joints of this type are provided with long bolts which pass through both end flanges with a nut on each end. This prevents the joint coming apart in case of excessive contraction. The packing in the type of expansion joint shown in Fig. 111 gives some trouble when used on high pressure lines but for ordinary work it is very satisfactory.

Another type of expansion joint suitable for line pipe where space is limited is shown in Fig. 112. This consists of an outer casing of corrugated metal provided with strengthening bands of steel passing around it and with flanges at the ends. An inner casing of polished steel is provided for reducing friction of the steam. Expansion is taken up by stretching the corrugated casing. In this type of expansion joint no trouble is experienced with packing or with the joint pulling apart.

In line piping carrying high pressures, an excellent method of providing for expansion is by inserting a bend, such as shown in Fig. 113 in the pipe line. Expansion will then be taken up by the spring of the bend. Such a bend should be made of heavy pipe and the flanges fastened securely, preferably by welding, as expansion brings very heavy strains on them. In order to prevent the bend stopping the drainage of condensation it should be turned down to a horizontal position or the pipe line should slope away from it on either side. A 90 degree bend of the

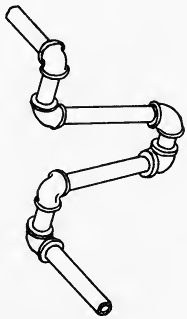


FIG. 115.

same kind is shown in Fig. 114. This kind is used very commonly in connecting each boiler of a battery to a steam main which passes across all the boilers in the battery.

In low-pressure piping systems, such as those used for heating, expansion can be taken up by constructing an off-set in the pipe line by means of elbows and short lengths of pipe, as shown in Fig. 115. This device takes up the expansion by a slight turning of the screwed joint, the turning being so small that the joint does not leak even after being used a number of years. When made as shown in Fig. 115 this expansion joint does not interfere with the flow of condensation.

**178. Erecting Pipe.**—The constructive details of steam piping have been so well worked out that only a few of the most important points need be touched upon. The defects usually noted are poor alignment of the piping, inadequate provision for expansion and drainage, and improper placing of valves.

If the piping is not in proper alignment, excessive strains are thrown on the flanges. As a rule, this is brought about by the flanges having been forced into contact with each other by tightening on the joining bolts instead of placing the pipe so the flanges will fit together. The flanges of modern steel pipe are amply strong if they are fitted together properly but if they are not lined up properly very heavy strain will be brought upon them. If the flanges do not come close enough together, a thin ring of metal should be put in to make up the length. When erecting heavy pipes, every length should be placed in position

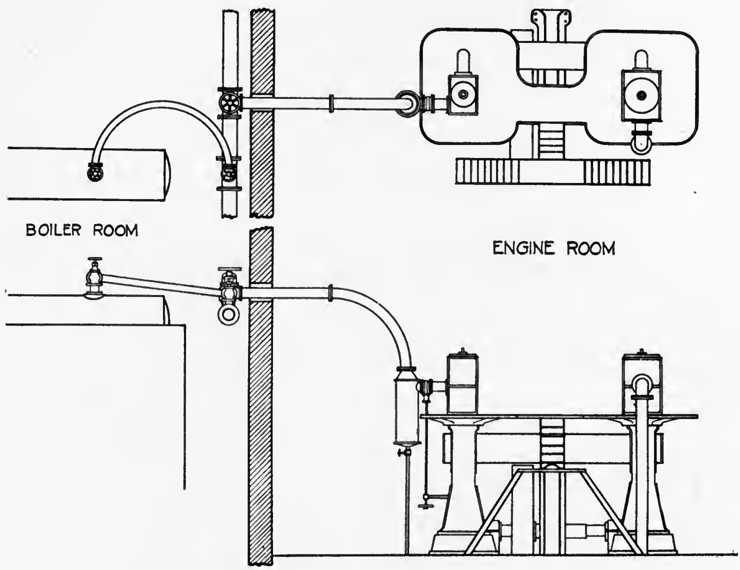



Fig. 116.

and properly supported and leveled by its own slings and brackets, and the flanges should not be bolted together permanently until this is done.

A good method of connecting engines to boilers, allowing ample provision for expansion and drainage, is shown in Fig. 116. By the use of bends of large radius, provision for expansion is made with but few fittings, and the piping has sufficient slope for drainage. A good rule to follow in determining which way the piping should slope is to arrange the stop valve of the boiler so that all condensation between it and the boiler will drain back into the boiler, and to slope the piping beyond the valve so that water will drain away from the boiler toward the engine. If several boilers are connected to a header, the condensation between the stop valve and the header may be drained into the header and the header drained by means of a bleeder pipe.

The position and method of placing valves is a very important matter and one which does not always receive the attention which it should. In placing stop valves the first and most important feature is to ascertain whether the valve will act as a water trap for condensed steam. Fig. 117 illustrates a common error in the placing of valves as this arrangement permits an

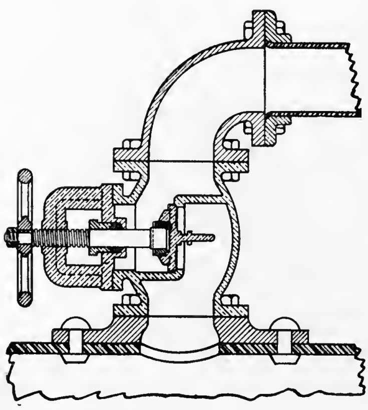


Fig. 117.—Wrong method.

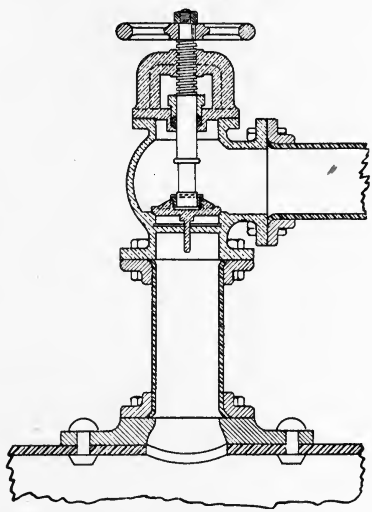


Fig. 118.—Right method.

accumulation of condensed steam above the valve when closed, and should the engineer open the valve suddenly, serious results would follow, owing to water-hammer. Fig. 118 illustrates the correct method of placing the valve. It sometimes happens, however, that it is not convenient to place the valve as shown in Fig. 118 and that the other position is the only place in which the valve can be inserted. In such cases the valve should have a drain and this drain should always be opened before the large valve is opened.

Lead or pipe grease used in erecting piping should be put on the pipe thread rather than on the valve thread. When the steam is turned on, this stuff is carried to the bearing parts of the valve, and, owing to its sticky nature, catches and holds grit and scale on the seats and discs of the valve, where it causes cutting.

In screwing a valve on a pipe, the mistake is often made of placing the wrench on the hexagon furthest from the end of the pipe. This brings a great twisting strain upon the body of the valve placing the seat out of line and causing the valve to leak.

Piping should be cleaned out before being placed in position and, if possible, the line should be blown out after the valves are in place. Unless this is done, loose scale and metal chips remaining in the pipe may injure the valve seats or discs, causing leaks. Should a valve leak slightly, considerable damage often results by applying additional leverage to the hand wheel to obtain a tight joint. The valve should be reground as soon as possible to secure a tight joint.

In putting together screwed joints, pipe fitters often make a mistake in putting the white lead, oil, or other cementing material on the inside thread or female fitting. This should not be done, as when the fitting is screwed up, the end of the pipe or threads will often carry the cementing material along in front of it and this will collect inside the female fitting and cause a stricture or reduction of area. The cementing paste should, therefore, always be put on the outside or male thread. This will accomplish the same purpose and give better results.

**179. Pipe Covering.**—When saturated steam is conveyed through pipes a portion of it will condense, the amount depending upon the temperature of the steam and the velocity and temperature of the air surrounding the pipe. This condensation causes a loss not only of volume of steam, but of efficiency in utilizing the remainder of the steam when it reaches the engine. Consequently, where fuel economy is an object, all steam pipe, boiler steam drums, receivers, etc., should be covered with some efficient heat insulating material, and the saving thus effected will pay large interest on the investment.

It has been experimentally determined that each square foot of bare iron pipe surface will radiate about 3 B.t.u. per hour for each degree Fahrenheit difference between the temperature of the steam in the pipe and the air surrounding it, the exact amount varying with the velocity of the air and the moisture in it. For practical purposes 3 B.t.u. per hour may be assumed. To determine the money value of the loss in any particular case, determine the square feet of exposed pipe surface, and the temperature of the steam by reference to a steam table; assume the temperature of the air surrounding the pipe and then compute the temperature difference. Conditions of operation of the plant will approximately determine the number of hours each year during which steam will be in the pipe line, hence, the total B.t.u.'s lost per year can be roughly determined. This, divided by 965.8 will give the number of pounds of steam from and at 212° equivalent to this loss; the evaporation per pound of coal and the cost of coal per ton (including cost of handling it and the ashes) being known, the money value of the loss is at once determined.

This may be put into a formula as follows:

$$\text{Cost per year of steam condensed} = \frac{3 \times A \times (t - t_1) \times N \times C}{965.8 \times E \times 2000}$$

in which $A$ = area of exposed pipe surface in square feet
$t$ = temperature of steam
$t_1$ = average temperature of surrounding air
$N$ = hours per year steam is in pipe
$E$ = evaporation from and at 212° per pound of coal
$C$ = cost of coal and handling per ton.

The application of this formula may be illustrated by the following example. In a certain power plant there is a line of bare pipe made up of 150 ft. of 3-in. and 50 ft. of 2-in. pipe carrying a pressure of 135 lb. per sq. in. absolute and with air at 90° temperature surrounding the pipe. The cost of coal, including handling is $3.20 per ton and 7 lb. of water are evaporated from and at 212° per pound of coal. What will be the loss from the steam pipe when the plant runs 24 hours a day for 360 days in the year?

Referring to the table of pipe sizes we see that it takes 1.091 lineal feet of 3-in. pipe and 1.611 lineal feet of 2-in. pipe to have 1 sq. ft. of external surface. The external area of the 3-in. pipe will therefore be $\frac{150}{1.091} = 137.3$ sq. ft. and of the 2-in. pipe $\frac{50}{1.611} = 31$ sq. ft. The total external area of bare pipe is therefore $137.3 + 31 = 168.3$ sq. ft. The temperature of the steam is, from the steam table, 350° and the number of hours per year which the plant runs is $360 \times 24 = 8640$, therefore, the cost of the steam condensed in the bare pipe is

$$\frac{3\times A\times(t-t_1)\times N\times C}{965.8\times E\times 2000}$$

$$=\frac{3\times 168.3\times(350-90)\times 8640\times 3.20}{965.8\times 7\times 2000}$$

$$=\$268.43 \text{ per year.}$$

By properly applying a covering of good grade, as much as 90 per cent of the loss from condensation may be saved. There are many brands of coverings on the market and the only practical way to be sure of what each will do is either to purchase of a firm of established integrity or else make comparative tests.

There is a dearth of accurate data on the life of pipe covering of different kinds. It is well known, however, that as a result of constant vibration some of them, when on horizontal pipe lines, lose their shape, hang loose on the pipe and allow the material to shift so that the covering becomes thicker on the bottom than on the top. Only previous experience or careful inquiry as to the experience of others can indicate what defects of this nature may develop in a covering after it has long been in use.

Pipe covering may be either *sectional,* that is, molded to shape and attached to pipes by bands, etc., so it can be removed at any time; or *plastic,* which is mixed in the shape of a mortar, and built up on the pipe in layers, so that it cannot be removed and replaced without working it over. The former has more joints, and often, under vibration, changes shape, but it is more convenient for work subject to future alterations. The plastic covering obviates joints, adheres closely to the pipe if of proper quality and workmanship, needs few repairs and the thickness can be varied to suit. It is more difficult to apply than sectional covering, but more permanent when applied.

Pipe coverings should receive the same care and frequent inspection as other parts of the plant. Their efficiency quickly falls off if air is allowed to circulate between them and the pipe and, if allowed to become wet, they only increase the evil they are expected to remedy.

The following table gives some idea of the insulating qualities of a few of the more common kinds of pipe coverings. In the last column will be found the number of heat units lost per square foot of pipe surface per hour for each degree difference in temperature between the steam and the air surrounding the pipe.

BARRUS' TESTS OF PIPE COVERINGS

| Name of covering | Cost (applied) per running foot, cents | Diff. of temp. between steam and air, deg. F. | Net surface of bare pipe, sq. ft. | Net condensation per hour, lb. | B.t.u lost per square foot per hour per degree diff. in temp. |
|---|---|---|---|---|---|
| 80-lb. Pressure, 2-in. Pipe | | | | | |
| Asbestocell | 13.60 | 263.0 | 63.68 | 13.47 | .728 |
| New York air cell | 16.32 | 256.6 | 63.24 | 13.43 | .750 |
| Carey's molded | 12.64 | 261.9 | 64.12 | 14.23 | .768 |
| Asbesto-sponge molded | 12.64 | 261.9 | 63.84 | 14.35 | .778 |
| Gast's air cell | 14.56 | 262.6 | 63.64 | 14.63 | .793 |
| 150-lb. Pressure, 2-in. Pipe | | | | | |
| A–S hair-felt, 3-ply plain | 23.89 | 303.5 | 64.41 | 10.22 | .462 |
| A–S hair-felt, 2-ply corrugated | 20.11 | 304.9 | 64.21 | 10.86 | .490 |
| A–S felt, 59 laminations | 23.20 | 304.1 | 63.78 | 10.76 | .490 |
| A–S felt, 48 laminations | 23.20 | 294.0 | 64.21 | 11.35 | .531 |
| Magnesia | 25.12 | 300.6 | 63.66 | 11.50 | .531 |
| Asbestos, navy brand | 22.24 | 300.6 | 63.82 | 13.16 | .606 |
| 150-lb. Pressure, 10-in. Pipe | | | | | |
| A–S felt, 76 laminations | 78.30 | 302.0 | 97.10 | 9.29 | .280 |
| A–S felt, 66 laminations | 59.00 | 315.0 | 97.10 | 10.60 | .306 |
| Magnesia | 71.00 | 299.2 | 97.10 | 11.64 | .354 |
| Asbestos, navy brand | 67.70 | 298.4 | 97.81 | 12.79 | .387 |
| Watson's imperial, 1 in | 41.00 | 303.0 | 97.81 | 14.37 | .428 |
| Bare Pipes | | | | | |
| 2-in. pipes, 80-lb. pressure | ........ | 273.2 | 63.70 | 59.16 | 3.081 |
| 2-in. pipes, 150-lb. pressure | ........ | 305.2 | 63.98 | 74.40 | 3.366 |
| 10-in. pipes, 150-lb. pressure | ........ | 295.4 | 100.45 | 107.84 | 3.220 |

The saving to be derived from covering pipes may be calculated from the preceding formula. For example, suppose the pipe mentioned in the example just given had been covered with asbesto-sponge, of which the factor of heat loss is 0.778, the cost of the steam condensed in the pipes would be

$$\frac{.778 \times 168\ 3 \times (350-90) \times 8640 \times 3.20}{968.5 \times 7 \times 2000} = \$69.42$$

Comparing this with the \$268.40 lost per year with the bare pipe, it will be seen that, by covering the pipe, a saving of \$268.40 – 69.41 = \$198.99 per year will be effected.

**180. Boiler Fittings.**—The fittings usually supplied with a new boiler are safety valves, steam gages, water gages, safety plugs and blow-off valve and connections, and sometimes also a water column and surface blow-off.

**181. Safety Valves.**—There are two general types of safety valves in common use, viz., the lever safety valve and the pop safety valve.

The lever safety valve is shown in Fig. 119. This valve consists of an iron or brass body shaped very much like an angle globe valve, and having on the inside an opening closed by a disc ground to fit tightly on a seat. From the disc, a spindle or stem extends out through the top of the valve body, the stem passing through a stuffing box which serves to prevent steam from leaking past and also to guide the disc so it will seat itself properly. The disc is held on its seat by means of a lever and weight. The lever is pivoted at one end to the valve case, and rests upon the

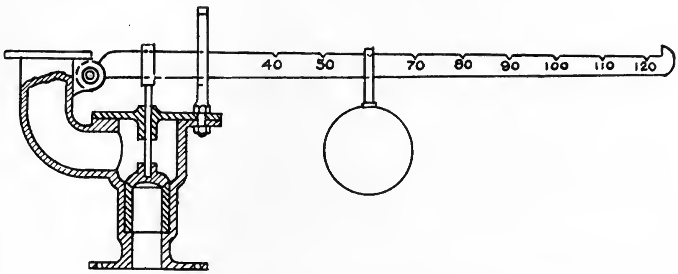



Fig. 119.—Lever safety valve.

end of the stem as shown, the weight serving to hold it down against the pressure on the under side of the disc which is tending to raise it. The lever is marked at a number of points with a number which indicates the pressure in the boiler which will open the valve when the weight is placed at that particular point. Thus the arrangement forms an adjustable safety valve which will open automatically when the pressure reaches a certain predetermined amount.

The point at which the weight should be placed in order for the valve to open under any desired pressure may be found as follows:

Let $a$ = area of opening in valve seat in square inches
$l$ = distance in inches of pivot point from point where stem touches lever
$P$ = pressure in boiler in pounds per square inch
$W$ = Weight of ball in pounds
$w$ = Weight of lever in pounds

$L$ = Distance in inches at which ball is placed from the pivot point

$X$ = total length in inches of lever bar.

Then $a \times P \times l = W \times L + W \times \frac{X}{2}$

$$\text{and } P = \frac{W \times L + W \times \frac{X}{2}}{a \times l}$$

This equation will give the pressure at which the valve will open for any given position of the weight, and the equation

$$L = \frac{a \times P \times l - W \times \frac{X}{2}}{W}$$

will give the distance which the ball must be placed from the pivot point in order to open at any given pressure.

**Example**: Where should the weight be placed on a lever safety valve which has a disc opening of 3-in. diameter, if the ball weighs 140 lb., the lever is 30 in. long and weighs 3 lb., the pivot point is 4 in. from the point at which the stem touches the lever, and the pressure at which it is desired that the boiler blow-off is 130 lb. per sq. in.?

*Solution:*

$$L = \frac{a \times P \times l - W \times \frac{X}{2}}{W}$$

$$L = \frac{\frac{3 \times 3 \times 3.1416}{4} \times 130 \times 4 - 3 \times \frac{30}{2}}{140}$$

$$L = \frac{7 \times 130 \times 4 - 45}{140}$$

$$= 25.7 \text{ in. from pivot.}$$

The lever safety valve is one of the oldest types to be used, and has the advantage of being simple in construction and reliable in action but it is easily tampered with and, as this is a dangerous featûre, it has caused this type of safety valve to fall into disuse for high-pressure boilers.

A common form of pop safety valve is shown in Fig. 120.

In the pop safety valve the disc is held firmly on its seat by the pressure of a stiff coil spring which may be adjusted to exert a greater or less pressure on the disc in order to make it open under a greater or less pressure. The greatest objection to these valves is that, when they are on the point of opening, they simmer or vibrate rapidly and make a very disagreeable humming noise. This may, however, be overcome to a great extent by placing on the valve a muffler, which consists of a number of perforated

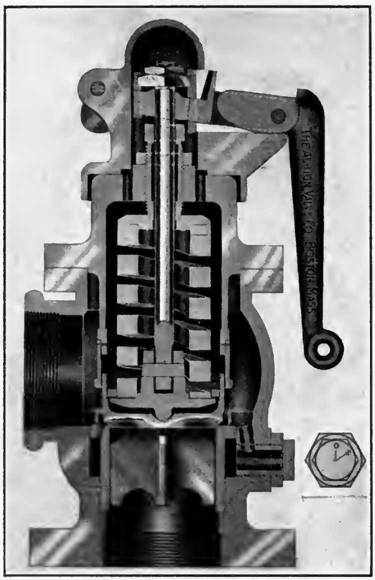


Fig. 120.—Pop safety valve.

plates for breaking up the streams of steam escaping from the valve.

Pop safety valves are adjusted by tightening or loosening the spring pressure on the valve disc. Some valves are provided with means for sealing or locking the case, in order to prevent them from being tampered with after they are once adjusted. The one shown in the figure above is of this type.

Pop safety valves are made in sizes up to 6-in. diameter; if a larger size than this is needed it is necessary to use two valves. In any case it is better to have two safety valves on a boiler, in order that if one should not be in working order, the other may operate. Nearly all safety valves have seats beveled off at an angle of 45 degrees, and the seats of the better grades are made of nickel to prevent corrosion. Pop valves are usually made to close when the pressure has dropped about 5 lb. below its opening pressure. This is done by making an extension on the valve so that when it is open it will present more area to the steam pressure than when closed.

Various rules of more or less merit have been proposed for finding the size of pop safety valve that should be placed on a boiler of given size, but the one given below is believed to be the best. This formula, which is based upon experiments made by Mr. D. G. Darling in 1908, is as follows:

$$D = .0095 \times \frac{W}{L \times P}$$

in which $D$ is the diameter of the valve seat in inches, which, in most valves, is approximately the same as the inlet diameter of the valve.

$W$ is the maximum number of pounds of water the boiler will evaporate per hour

$L$ is the lift of the valve in inches

and $P$ is the absolute pressure carried by the boiler in pounds per square inch.

This formula may be simplified and made to suit ordinary conditions by asuming a factor of evaporation of 1.1, a lift of the valve of .11 in. and assuming also that the boiler has a maximum capacity equal to twice its rated horse-power. The formula then becomes

$$D = 5.42 \times \frac{h.p.}{P}$$

in which $D$ and $P$ have the same meaning as before and $h.p.$ is the nominal horse-power rating of the boiler.

**Example:** What size pop safety valve should be placed on a 300 h.p. boiler which carries 125 lb. steam pressure?

$$D = 5.42 \times \frac{200}{125} = 8\tfrac{2}{3} \text{ in. (approximately).}$$

This boiler could be supplied with one 4-in. and one 5-in. valve. The diameter as given by the formula is the combined diameter of all the valves on the boiler, the combined diameter being the sum of the diameters of the separate valves.

A safety valve should not be tested by opening it by hand, but to insure its being in proper working order, the steam pressure should be raised until the valve begins to simmer and the pressure indicated on the gage noted. The pressure should then be further raised until the valve opens. The safety valve should be tested in this way at least once each day to insure its satisfactory action.

**182. Steam Gages.**—The ordinary form of a steam gage, often called a Bourdon gage, consists of a circular spring passing around the inside of the case, and this spring is attached by a series of

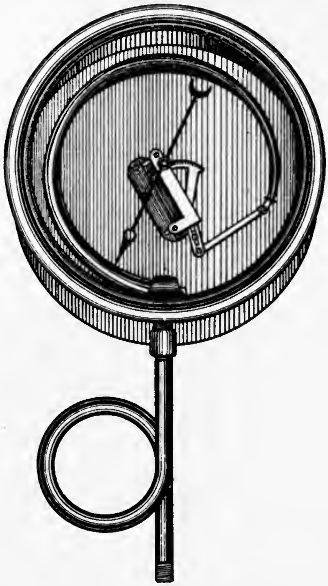


Fig. 121.—Steam gage mechanism.

levers to a train of gears which move the needle. See Fig. 121. The cross-section of the spring is in the form of an oval made by flattening a round tube. Any pressure applied to the inside of this tubular spring tends to make it assume a circular cross-section, but before it can do so, it must be straightened out. Since the spring is fastened rigidly at one end, while the other end, which is attached to the levers, is free to move, any pressure applied to the inside of it causes the free end to move and thus imparts motion to the levers and to the hand which moves over a graduated dial. A vacuum gage is made in the same way, except that the levers are pivoted in such a manner as to cause the hand to move in the opposite direction to what it would in a pressure gage.

One end of the spring in a steam gage is soldered directly to the case on the inside, while the pipe connection is fastened to the outside. At high pressures the temperature of steam is sufficient to melt a soldered joint and for this reason it is necessary to prevent the steam from coming in direct contact with the joint. This is done by connecting the gage to a loop of pipe which has water in it. When steam is admitted to the pipe, its pressure is exerted upon the water and the spring is then filled with water instead of steam.

Another class of gages, though not a very common one, is known as the diaphragm gage. In this gage the needle is moved by the vertical movement of a pin, the lower end of which rests on one side of a diaphragm while steam presses on the other side of it. The pressure of the steam causes the diaphragm, which is made of a thin sheet of corrugated metal, to be deflected upward and this motion is imparted to the pin which rests upon it.

**183. Water Gages.**—Water gages are for the purpose of indicating to the observer the height of the water level in the boiler. They consist of one connection above the water line and one below, fitted with valves and having a strong glass tube between the connections as shown in Fig. 122. If both gage cocks are open, the water will stand at the same height in the glass tube that it does in the boiler, and this forms a very ready means of noting the water level. Water gages are usually about 12 in. long, set so the middle of the tube is at about the ordinary water level. As any discoloring matter in the water will stain the glass tube and make it difficult to see the water level, water gages are usually supplied with a drain cock at the bottom through which they may be blown out. In order to blow out the glass it is only necessary to close the bottom connection to the boiler and open the blow-out cock, when steam will enter from the top and will blow through the tube. Sometimes the tube will become so badly stained that steam will not clean it, when it becomes necessary to clean the glass with hydrochloric or muriatic acid. The water gage should be blown out at least once a day and preferably oftener, to make sure that it is in proper working order; but after this is done one must be very careful to see that both cocks are open, else the gage will not indicate correctly. If the top cock is closed and the bottom one open, the pressure on the inside of the boiler will force the water too high in the glass. If the bottom cock is open and the top one closed, the steam entering the top will gradually condense and fill the tube with water, showing a higher water level than that actually in the boiler. If both cocks are closed, the gage will of course not indicate changes in the water level, and high or low water may result without the fireman knowing it. Fig. 123 shows the details of the packing at one end of a gage glass.

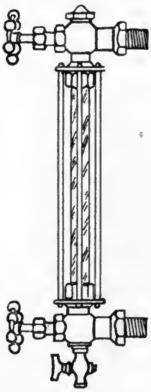


Fig. 122.

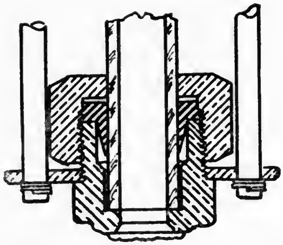


Fig. 123.

On account of both the water and the gage glass being colorless, it is sometimes difficult to see the height of the water in an ordinary gage. To overcome this difficulty a type of water gage shown in Fig. 124 has been designed in which the water in the gage shows black and the steam shows white. This result is secured by placing in front of the gage glass a plate of thick glass having facets cut in the back. These gages represent a decided improvement over the old form, making the water level easily seen.

Great care should be taken to prevent live steam or hot water from coming in contact with a cold gage glass, as the sudden expansion is likely to cause the glass to explode, sometimes causing serious injury to those standing nearby. When a gage glass becomes broken, it is a very disagreeable task to shut off the steam and hot water which is escaping through the cocks at the top and bottom. To obviate the nuisance of having to close gage cocks while steam is escaping, some gages are fitted with automatic valves at the top and bottom so that when the glass breaks, the valves close automatically and shut off the steam and water. Although these cost more, it is better to use them.

**184. Gage Cocks.**—From what has been said above, it can be seen that a water gage cannot be absolutely depended upon, and therefore some other means should be provided for indicating the height of the water level. This is usually done by providing three-hand operated valves which open directly into the boiler. These valves are called *Gage Cocks.* The lower one is usually placed 3 in. above the top row of tubes in a fire-tube boiler, the second being 3 or 3½ in. above the first, and the third 3 or 3½ in. above the second. The water should be kept between the second and third cocks. Upon opening one of these cocks, if water comes out the water level is above the cock, but if a mixture of water and steam comes out, the cock is just on the water line. The glass gage should not be depended upon entirely, but the gage cocks should be tried frequently to see that the gage is indicating correctly.

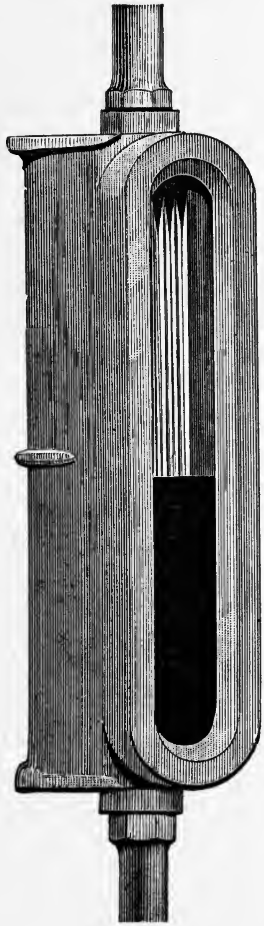


FIG. 124.

**185. Water Columns.**—The steam gage, water gage, and gage cocks are sometimes combined into one device called a water column. Such a device is shown in Fig. 125. It consists of a hollow cast-iron vessel connected at the top with the steam space and at the bottom with the water space of the boiler. The steam gage is mounted upon the top of the column, the gage glass on one side and the gage cocks on the other. Sometimes, as shown in Fig.125, there is placed on the water column a small whistle which is blown if the water becomes too low or too high, thus giving audible warning of these dangerous conditions. The whistle is usually operated by means of a float which will open the valve leading to it if the float reaches a predetermined upper or lower limit. A serious objection to such devices as this is that they tend to make the fireman careless. The fireman will come to depend on the automatic action of the water column to tell him when more water is needed and he does not watch the gage glass closely enough, with the result that sometimes the alarm will fail to operate, the water will become too low, and the boiler be injured or an explosion occur.

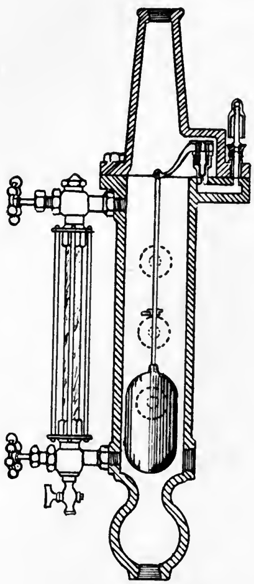


Fig. 125.

**186. Safety Plugs.**—This is another device for protecting a boiler from injury in case of low water. It consists of a brass or bronze plug which may be screwed into the shell of the boiler, the plug being bored out and filled with pure tin or some composition metal which has a melting-point but little above the temperature of the steam in the boiler. Fig. 126 shows one type of safety plug.

Safety plugs are placed in the rear or front heads, just a little above the top row of tubes in return fire-tube boilers and usually in the crown-sheet just over the grate in a locomotive type of boiler. The metal of the plug transmits the heat to the water so rapidly that its temperature does not rise if it is covered with water, but, if the water level sinks below the plug, the plug will become heated sufficiently to melt the soft metal core and allow steam to escape through it and give warning of the dangerous condition of the water level.

As soot will collect on the fire side of the plug and scale on the water side and both of these may prevent the plug from operating when needed, it is necessary to scrape them both outside and inside occasionally in order to keep them in good working condition. At the best, safety plugs are unreliable, but some states require them by law.

**187. Surface and Bottom Blow-offs.**—The surface blow-off is for the purpose of blowing off scum, foam, and floating matter from the surface of the water in the boiler, and to relieve excessive priming. It consists usually of a funnel placed near the rear head of the boiler and having its center about on the usual water level as in Fig. 127. The funnel connects with a pipe leading to the outside and provided with a valve. The end of the pipe inside the boiler is provided with a funnel in order to insure draining the scum when the water is at different levels.

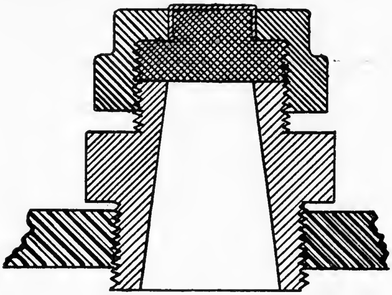


Fig. 126.—Safety plug.

The proper way to operate a surface blow-off is to open it for a few seconds about every 15 minutes or longer as required, rather than to open it for a longer period at longer intervals.

The bottom blow-off consists simply of a pipe opening into the boiler at its lowest point and provided with the proper

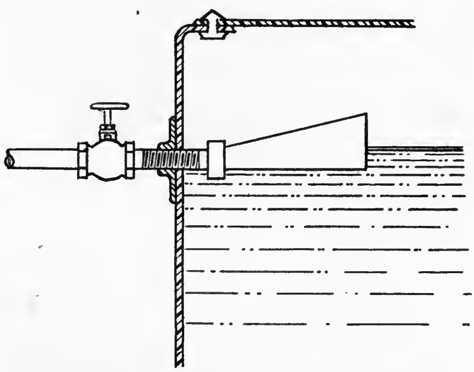


Fig. 127.—Surface blow-off.

valves. The boiler should be set so that the point of most sluggish circulation is also the lowest point, as the mud and sediment will be likely to settle at a point where the circulation is slowest. On a fire-tube boiler the bottom blow-off is usually placed at the back end which is a little lower than the front end.

On a water-tube boiler it is usually attached to a mud drum, which is arranged to catch the mud and sediment and which is generally placed at the lowest point of the boiler.

Blow-off valves will probably give more trouble than any other boiler fitting owing to the wearing and corroding action of the dirty water passing through them and to their liability to clog up. Ordinarily, an angle valve should be used where possible, as this offers a freer passage for the water and the valve is more likely to seat properly.

A very satisfactory valve for this purpose is made like a water cock but packed with asbestos to prevent leakage. This is simpler and less liable to get out of order than most forms of valves. The blow-off pipe should be provided with two valves, the one nearest the boiler being a special blow-off valve, and the other may be an ordinary gate valve. As the hot water passing through a blow-off pipe will disintegrate tile sewer pipe, the blow-off should never enter a sewer made from tile pipe until the water has been cooled somewhat. A very good arrangement is to blow the boilers off into a special iron tank provided with a coil of pipe through which the feed water flows on its way to the feed-water heater or the boiler. By this arrangement a part of the heat that would otherwise be lost is saved. After the blow-off water is cooled by the feed water it may be allowed to flow into the sewer.

Blow-off pipes are often run under floors or other out-of-the-way places where they cannot be readily seen. This should not be done, as a leak will not be detected and a leak in the blow-off valve is a dangerous thing, causing low water quickly, besides wasting a great deal of heat. If it is necessary to run a blow-off pipe where it cannot be readily seen, a tell-tale should be attached to it. A tell-tale may be constructed by placing a tee in the blow-off pipe, with one opening pointing downward. A 3/4-in. pipe provided with a valve is attached to the tee and run to the front of the boiler where its end may be easily seen. Then if a leak occurs, the water will pass through the tee and tell-tale pipe to the front of the boiler where it will attract attention. When the boiler is blown-off, the valve on the tell-tale pipe must be closed, but at all other times this valve is left open.

# CHAPTER XV

## BOILER ACCESSORIES

**188. Dry Pipes.**—A boiler will usually form wet steam, even when working at its rated capacity and, if it is forced, the steam may contain considerable moisture due to the violent bursting of the steam bubbles, which throw particles of water into the steam space when they remain suspended in the steam. If the boiler is forced very much or if certain impurities exist in the feed water, priming or foaming may occur, and allow large quantities of water to become mixed with the steam. If very wet steam is allowed to enter the engine cylinder, the water which it carries is liable to damage the engine. A further objection to allowing wet steam to leave the boiler is that wet steam contains less energy per pound than dry steam, hence a larger amount of steam must be handled in order to transfer a given amount of energy.

A device, called a "dry pipe," for preventing steam from carrying large quantities of water into the main pipe line is supplied with most boilers. Nearly all dry pipes operate on the same principle as the separating calorimeter; that is, by causing the steam to make a sharp turn before entering the main pipe line, thus separating the water from the steam by the action of centrifugal force. The shape of the dry pipe will depend largely upon the type of boiler with which it is to be used, since some boilers have a larger steam space than others, and can therefore accommodate a larger dry pipe.

One of the simplest forms of dry pipe is shown in Fig. 128. This dry pipe consists of a tee joined to the end of the main steam outlet, with a short length of pipe screwed into each end. These short lengths of pipe are provided with caps at each end and have a series of small holes bored near the top. The steam being admitted at the top, is taken from the driest portion of the steam space, and on entering the small holes a large part of the moisture is thrown out of the steam. The total area of all the holes should be about 50 per cent greater than the area of the outlet in order to prevent a loss of pressure as the steam enters the dry pipe. In addition to the holes in the top, a few small holes are bored in the bottom near each end for draining out any water that may enter the dry pipe. This form of dry pipe gives excellent results and is especially suited to those boilers which have a long and narrow steam space, such as the Babcock and Wilcox water-tube boiler.

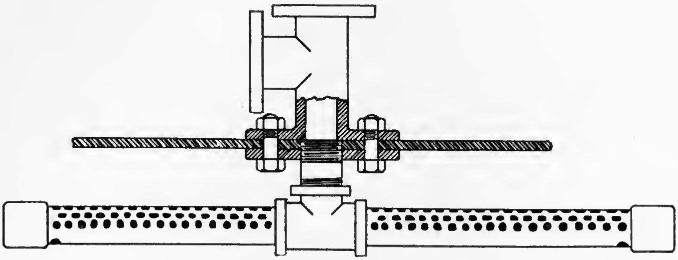


Fig. 128.

The dry pipe is frequently made in the form of a trough with the top of the boiler shell forming a covering for it. The edges of the trough come within about 1/2 in. of the boiler shell, and the steam is taken over the edge of the trough. A number of small holes are drilled in the bottom of the trough for draining the water from it.

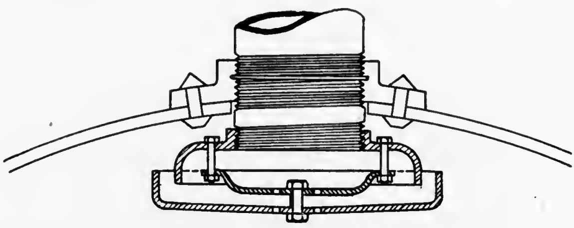


Fig. 129.

A form of dry pipe which does not require much space is shown in Fig. 129. It consists of three pans placed one above the other, the top one being inverted and screwed to a nipple which enters the main steam outlet. The pans are held at a fixed distance apart by ferrules which surround the supporting bolts. Steam enters over the edge of the lower pan and is forced to flow downward around the edge of the upper pan before it can enter the main steam outlet, thus having to turn through an angle of 180 degrees. The larger part of the moisture is thrown into the lower pan, from which it is drained back into the steam space through a number of small holes in the bottom of this pan. The bottom of the middle pan is also provided with a number of small holes for draining out any water that may pass the lower pan.

In many water-tube boilers the liberation of steam takes place over a very small area at the top of the front water leg and the main steam connection is made directly above this point. Under such conditions, large quantities of water would be thrown into the steam pipe if some provision were not made to prevent it. The

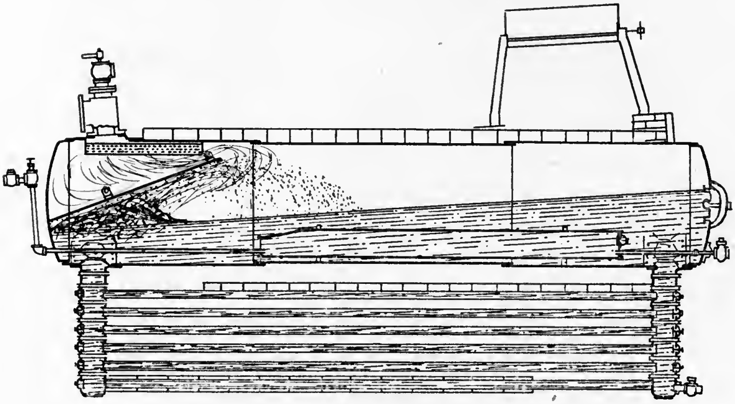


FIG. 130.

usual prevention consists of a *baffle plate* riveted to the shell and extending over the top of the water leg as shown in Fig. 130. This deflects the water away from the entrance to the steam pipe and causes the steam to make a sharp turn at its upper edge. A dry pipe is also provided for further separating the moisture.

**189. Superheaters.**—Superheaters are devices for heating steam to a higher temperature than that at which it is formed. In order to do this, the steam must be removed from the presence of water; therefore superheaters are so located that the steam will have to pass through them on its way from the boiler to the engine. If steam were heated above its saturation temperature in a closed vessel its pressure would increase, but this is prevented in a superheater by the engine taking a continuous supply. By superheating steam, its amount of energy is increased above that which it would have if it were only saturated.

Practically all superheaters are made in the form of a series of pipes, which form a part of the piping system between the boiler and engine, through which the steam must flow on its way to the engine. The pipes may be either plain or have extended surfaces. Those having extended surfaces are usually made of wrought iron or steel pipe with cast-iron fins fastened to them. Heat is applied to the outside of the pipes while the steam flowing through the inside absorbs it and has its temperature raised. The position of the superheater with reference to the boiler varies with different superheaters. In this country, superheated steam is seldom used at a higher temperature than 500° F., and 450° F. is perhaps a better average, while in Europe 600° F. is not uncommon. The difference in practice between this country and Europe is due to the fact that with very high temperatures of steam the ordinary slide and Corliss valves of engines, as used in this country, are liable to be warped. European engines are usually supplied with a type of valve which is not affected very much by high temperatures. With high temperatures some difficulty is experienced, also, with the lubrication of piston and valve rods. A steam temperature of 500° F. corresponds to about 165° of superheat at 100 lb. pressure and about 130° at 150 lb. pressure. This amount of superheat insures dry steam at cut-off in ordinary forms of steam engines, and as the greatest benefit from superheat is in securing dry steam during admission to the engine cylinder, it appears that the amount of superheat mentioned above is sufficient with present practice in this country.

Superheaters may be located directly in the boiler setting, in a flue leading from the boiler, or may be in an independent setting and fired independently. Standard practice in this country seems to favor placing the superheater directly in the boiler setting, from 80 to 90 per cent of all superheaters installed being so located. Wherever located, the successful operation of a superheater demands that it possess certain qualities, among which are safety, efficient use of heat, freedom for expansion, protection of joints from direct action of the fire, an arrangement whereby it may be cut out and cleaned, both internally and externally, and ease of application to existing plants as well as to new ones.

Of superheaters placed directly in the boiler setting perhaps the Foster, the Babcock and Wilcox, and the Stirling are most widely known in this country.

**190. Foster Superheater.**—The application of a Foster superheater to an Edge Moor water-tube boiler is shown in Fig. 131 and the construction of the superheater tubes is illustrated in Fig. 132. As shown in the above figures, the Foster superheater consists of a series of U-shaped tubes connected into steel headers at the ends. The tubes are double, consisting of an outer steel tube over which is placed a cast-iron covering in the form of a series of fins, and a steel inner tube closed at both ends and provided

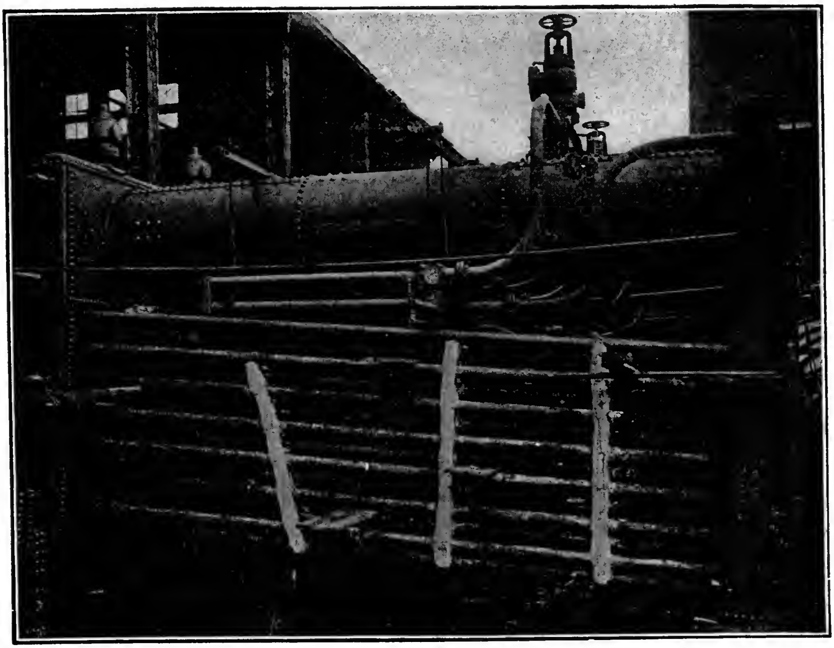


Fig. 131.—Foster superheater.

with a series of buttons to keep it centrally located with respect to the outer tube. The fins on the outer tube serve the double purpose of protecting the steel tube against being burned, and presenting a larger surface for absorbing heat. Steam flows through the space between the inner and outer tubes, the inner one serving to direct the steam along the surface of the outer tube, thus bringing it into direct contact with the heating surface.

Fig. 131 shows the superheater placed between the first and second passes of the boiler. This is a common location when applied to water-tube boilers, though it must not be inferred that this is the only location to which it is suited nor the only type of boiler to which it may be applied. The simplicity and small space occupied by this superheater adapt it to any style of boiler. When applied to water-tube boilers in which the flue gases pass across the tubes, it is usually placed as shown in Fig. 131; while in those water-tube boilers which have the flue gases passing along the tubes, it is usually located on top of the setting and near the steam drum. In the Stirling boiler, it is located between the second and third banks of tubes; and in return fire-tube boilers, it is located at the back of the combustion chamber where the

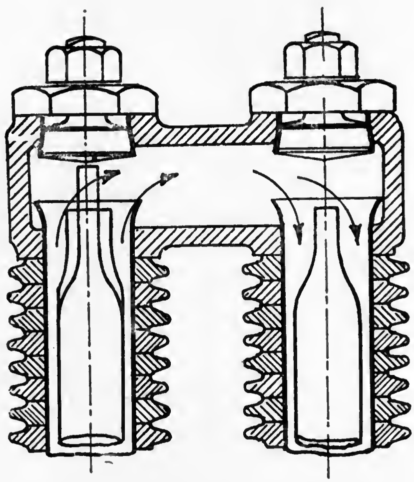


Fig. 132.

hot gases must pass through it before turning into the tubes. Although the Foster superheater is often conveniently located below the water line of a boiler, it is not necessary to flood it with water when the flow of steam from the boiler is reduced, because the cast-iron covering prevents injury to the tubes from this cause. Since the superheater is never flooded with water it is not necessary to make provision for cleaning the interior of the tubes.

**191. Babcock and Wilcox Superheater.**—The application of a Babcock and Wilcox superheater to a Babcock and Wilcox water-tube boiler is shown in Figs. 133 and 134. This superheater is similar in shape to the Foster superheater just described, but differs from it in construction. The Babcock and Wilcox super-

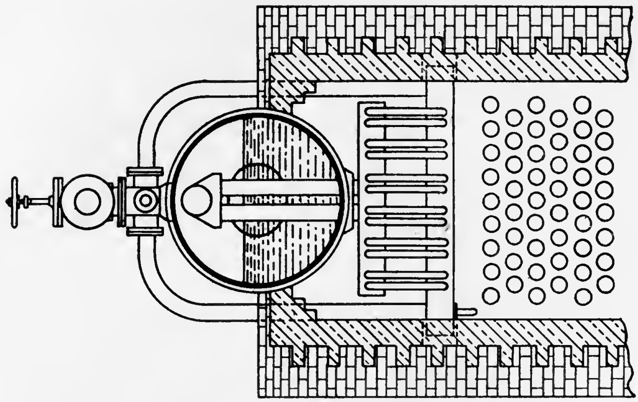


Fig. 134.

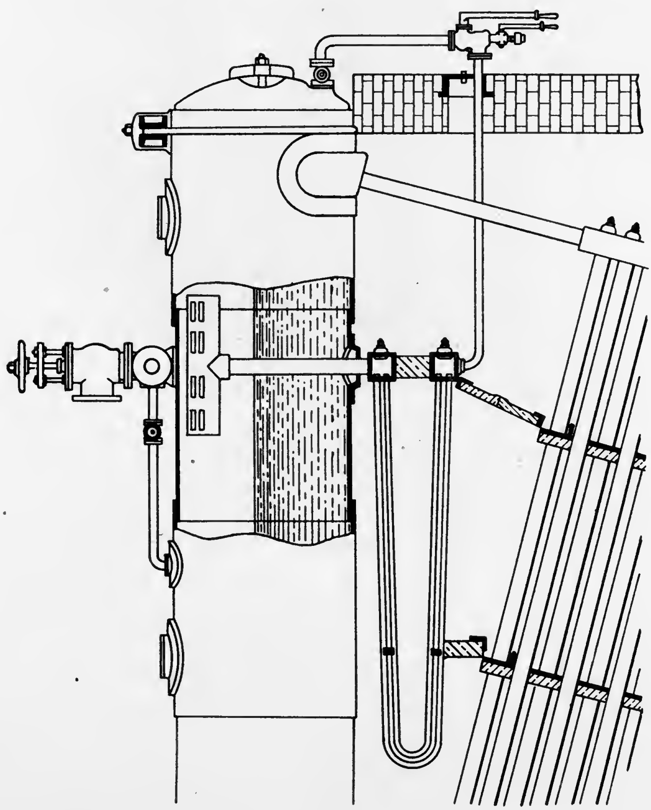


Fig. 133.

heater consists of a number of single U-shaped steel tubes with the ends connected into headers. The saturated steam is supplied to the top header through a short dry-pipe located near the top of the steam space. The connection between the steam space and the superheater is made by two tubes which pass down through the water space and through the bottom of the steam and water drum. From the top header, the steam flows through the tubes, receiving heat and becoming superheated. The superheated steam is taken from the bottom header.

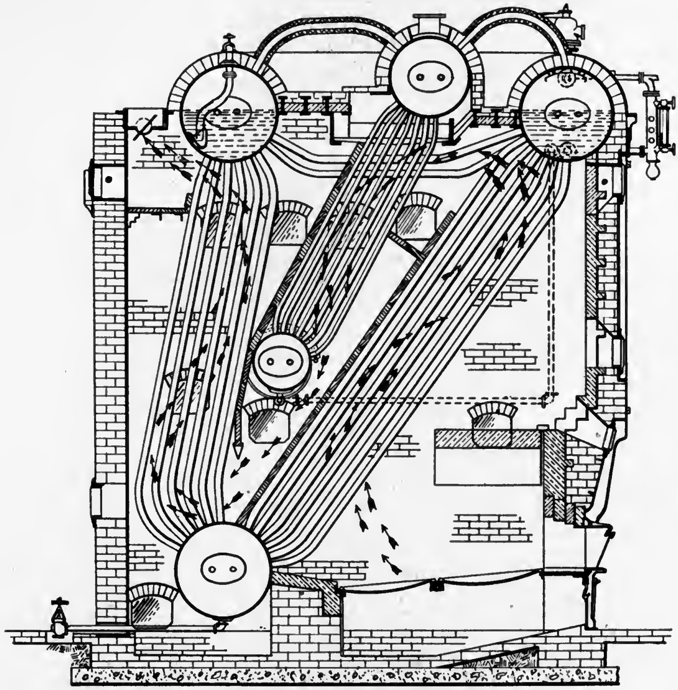


Fig. 135.—Stirling superheater.

Since this superheater is made of steel tubes, and is subjected to a high temperature, provision must be made for flooding it when steam is being raised or at such other times as the flow of steam through it is small. This is provided for by connecting the lower header with the steam space by means of a pipe, which passes through the rear wall of the setting and into the steam drum below the water line, as shown in Fig. 133. When it is desired to flood the superheater, a valve in this pipe is opened and the water will be forced into superheater tubes. Any steam that may be formed in the superheater while it is flooded will pass out of the top header and into the steam space of the boiler. When ready to resume operations the water may be drained from the superheater by closing the flooding valve and opening a drain cock in the flooding pipe.

**192. Stirling Superheater.**—The Stirling superheater, shown in Fig. 135, is designed for use only with the Stirling boiler. It consists of two drums connected by a number of 2-in. seamless steel tubes, and is placed behind the first bank of boiler tubes,

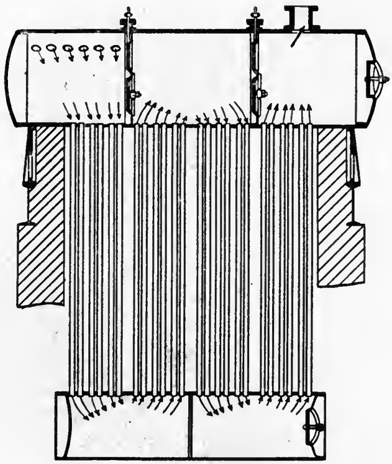


FIG. 136.

in the position occupied by the second bank in the regular Stirling boiler. The joints between the tubes and the drums are protected by a layer of asbestos to prevent burning at these points. The upper drum of the superheater is connected to the steam spaces of the boiler, from which it receives its supply of saturated steam. The upper and lower drums are divided into compartments so the steam is forced to pass through the tubes four times on its way through the superheater. A cross-section of the superheater showing the arrangement of the compartments is shown in Fig. 136. The saturated steam enters one of the end compartments of the top drum and superheated steam is delivered to the other end compartment of the top drum. Each compartment contains either a manhole or a removable partition so that all parts of the drums are accessible for cleaning the tubes.

Arrangement for flooding the superheater is made by a pipe and valves on the outside of the boiler setting, shown dotted in Fig. 135. The same connection to the lower drum allows the superheater to be drained.

The arrangement of the superheater shown in Fig. 135 is designed to give about 250° of superheat. When only about 100° of superheat is desired, the superheater is placed behind the last bank of boiler tubes. The Stirling superheater is also designed in a form to be separately fired.

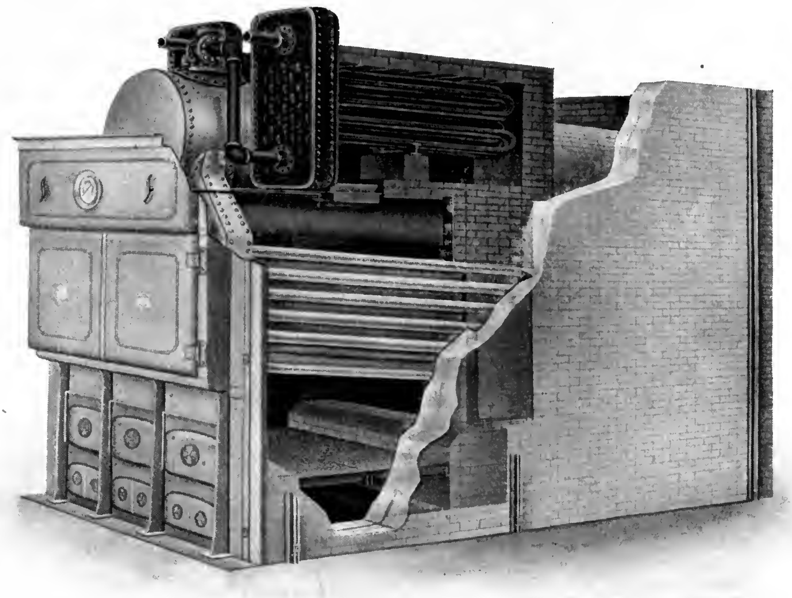


FIG. 137.—Heine superheater.

**193. Heine Superheater.**—The Heine superheater, shown in Fig. 137, is heated directly by the hot gases from the furnace, though it differs from the ones just described in that it is not placed directly in one of the passes but is located at the top of the setting by the side of the steam drum.

This superheater is made of a number of U-shaped seamless steel tubes ending in a steel header. The header is divided into three compartments by partitions which force the steam to flow through the tubes four times in passing through the superheater.

Saturated steam enters the bottom compartment and the superheated steam is drawn from the top one. A hand hole with inside cover plates is located in the front of the header opposite each tube, to allow access to the tubes for repairing them. Since the superheater is placed above the setting, it is not necessary to flood it and, therefore, the inside of the tubes will not require cleaning. Hollow stay bolts are used for joining the two end plates of the header. By inserting a steam blower through the hollow stay bolts, soot may be blown from the outside of the superheater tubes. The shape of the tubes allows freedom for expansion.

The Heine superheater receives its heat from gases taken directly from the furnace. In order to do this, the superheater is enclosed in a brick setting which has two openings in the bottom, one, not shown in the illustration, connecting directly with the furnace and the other, which is shown in the illustration, connecting with the smoke pass which leads to the chimney. A damper is provided in the latter opening for throwing the superheater out of operation. A portion of the hot gases from the furnace are taken into the superheater setting near the rear end, pass along the tubes and leave near the front end.

**194. Schmidt Superheater.**—One of the most commonly used independently fired superheaters is the Schmidt, shown in Fig. 138. The superheater consists of two sets of coils arranged so the steam flows first through one and then through the other. The saturated steam enters at the top of the upper set of tubes, passes through this set, and leaves at the bottom. It is then carried by the pipe *D* to the bottom of the lower set of tubes, and passes through these, the superheated steam leaving at the top of the lower set of tubes through the outlet *E*. This system of passing the steam through the tubes combines what is called the concurrent and the counter-current systems; the counter-current system, in which the steam flows in the opposite direction to the hot gases, is used in the upper set of tubes; and the concurrent, in which the steam flows in the same direction as the hot gases, is used in the lower set. While the counter-current system gives high efficiency, it is open to the objection that the hot gases from the fire meet the tubes where the superheated steam is hottest, and hence the tubes are liable to be burned through. The concurrent system overcomes this drawback, but does not secure maximum efficiency. The arrangement used in the Schmidt superheater combines the two systems, giving a very good efficiency without the danger of burning the tubes.

The junction boxes on the Schmidt superheater are placed outside the setting where they will not be in contact with the fire

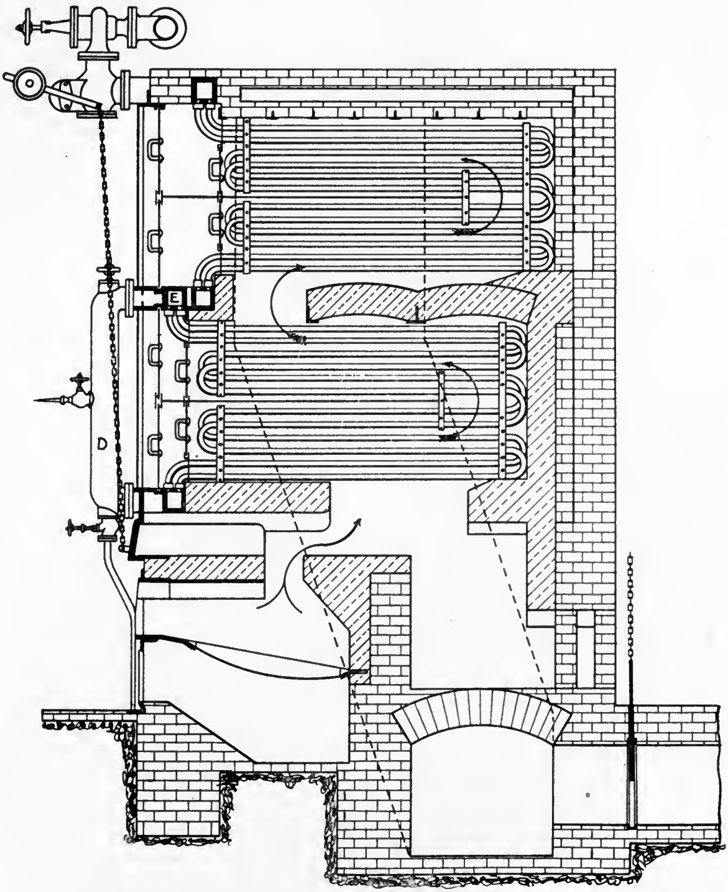



Fig. 138.—Schmidt separately fired superheater.

and where they will be more accessible. Should a tube become burned, its ends may be stopped with blank flanges, and the superheater continued in operation until such time as the tube may be replaced.

The advantages of independently fired superheaters are that they may be placed at any point desired, repairs may be made without shutting down the boilers, and the degree of superheat may be varied independently of the performance of the boiler. Its disadvantages are the extra space required, extra piping required, separate firing with the losses attending two furnaces instead of one, and extra labor required.

It must not be thought that because a superheater is located in the path of the flue gases, it does not require extra fuel to heat it. The higher the temperature to which the steam is superheated, the more fuel will be required, as shown in the following table:

| Degree of superheat | Additional fuel needed |
|---|---|
| 75° | 5 per cent |
| 100° | 7 per cent |
| 150° | 11 per cent |
| 200° | 15 per cent |
| 250° | 20 per cent |

Thus if a boiler is using 4 lb. of fuel to produce a pound of saturated steam, it will require $4 \times 1.15 = 4.60$ lb. to produce a pound of superheated steam when the steam is superheated 200°.

**195. Damper Regulators.**—To keep the pressure of the steam constant, the fireman must move the damper, opening it when the pressure falls or closing it when it rises. If more steam is required than a boiler is producing, the pressure will gradually fall and, to prevent this, coal must be burned at a higher rate. This is accomplished by opening the damper and thus allowing more air to be drawn through the fire, consuming more coal. Should the demand for steam decrease, the steam pressure would rise, and the damper should be closed to accommodate the new conditions. To do this automatically and to keep the pressure more nearly uniform, the damper regulator has been invented. The draft can be controlled by a regulator so that a practically constant steam pressure may be maintained. Damper regulators are economical and very useful, especially in plants where the demand for steam fluctuates rapidly. In the most common form, the boiler steam presses on a diaphragm which is connected to a lever that controls a small water valve. If the steam pressure falls, the water valve is opened, permitting water to escape from a hydraulic cylinder, thus lowering the plunger and opening the damper. If the steam pressure rises, water is admitted to the cylinder, which raises the plunger and closes the damper. When properly adjusted they work in a very satisfactory manner.

A damper regulator of this type is shown in Fig. 139. Full boiler pressure acts at all times upon a diaphragm in the chamber *A* and raises or lowers the weight *W* attached to the arm *D*. The arm *D* moves a valve *V* which controls the supply of water to the chamber *B*. A diaphragm in *B* raises and lowers the lever *E* as the water pressure varies. The end of *E* is connected with the damper. The steam diaphragm moves only .01 in. and the water diaphragm moves .5 in. A drop of 1/2 lb. in the steam pressure is sufficient to cause the damper to be opened to its maximum opening.

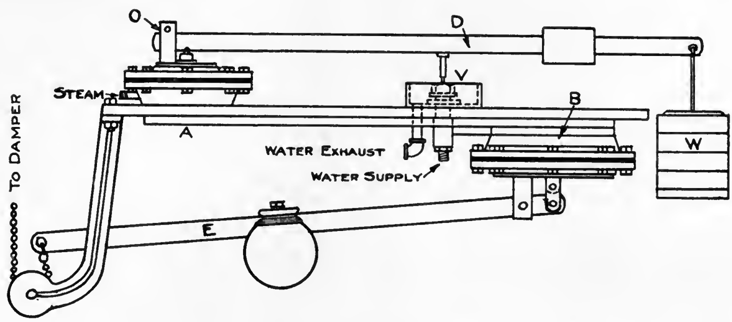



FIG. 139.—Damper regulator.

**196. Feed Pumps.**—Water is fed to boilers by means of both pumps and injectors. In determining which of these two methods shall be used, such things as quantity of water to be dealt with, the temperature of the supply, the height to be lifted and convenience of handling have to be considered.

When large quantities of water have to be dealt with, as, for instance, in feeding a battery of boilers, pumps are commonly used, while for supplying single boilers, injectors are often more convenient. Injectors are more tricky to operate than pumps, but they are much more efficient, as practically all the heat supplied to them is used either to move the feed water or to raise its temperature. While a pump is much more reliable than an injector it is very wasteful of steam. Its efficiency may be improved in many cases by using the exhaust to heat the feed water. If properly arranged, a pump will handle water of almost any temperature below the boiling-point. On the other hand, 110° F. is about as high a feed-water temperature as an injector can handle, and it must be less than this if the water is lifted a few feet.

Boiler feed pumps are usually either single or duplex, direct acting. In the single pumps there is one steam and one water cylinder placed in line with each other, both pistons being on a single piston rod. Duplex pumps have two steam cylinders placed beside each other and two water cylinders similarly placed. This makes the duplex pump resemble two independent single pumps placed one beside the other. In the duplex pump, the steam valve of one is operated from the piston rod of the other, thus making it almost impossible for the pump to stop on "center" as single pumps sometimes do. Duplex pumps have practically

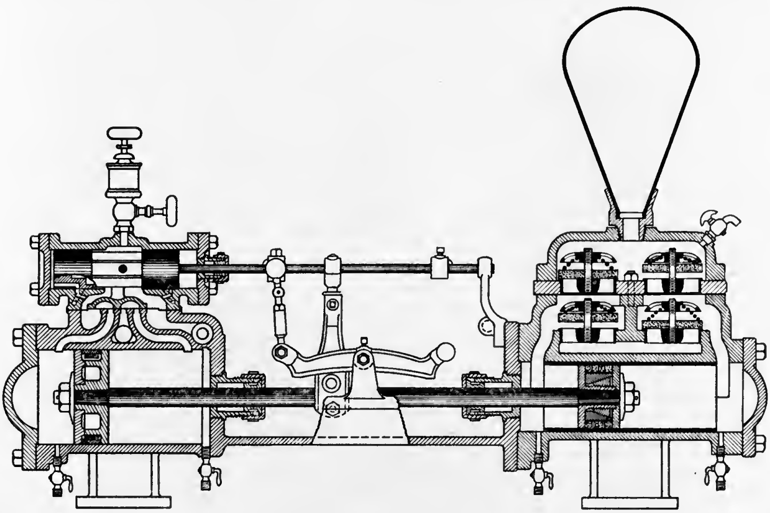


Fig. 140.—Single direct acting feed pump.

twice the capacity of single pumps of the same size cylinder, and they use practically twice as much steam.

There are two forms of single direct acting boiler feed pumps, which differ from each other in the operation of the steam valve. In one of these, the valve is operated by a system of levers outside the cylinder and in the other form, the valve is operated entirely by the steam inside the steam chest and there are no working parts on the outside.

A cross-sectional view of a single direct acting boiler feed pump, with valves controlled from outside the cylinder, is shown in Fig. 140. The construction may be described as follows: An auxiliary piston works in the steam chest and drives the main valve. This auxiliary or "chest-piston," as it is called is driven backward and forward by the pressure of the steam, and as it moves, carries with it the main valve, which controls the supply of steam to the main steam cylinder and thus operates the pump. The main valve is B-shaped and works on a flat seat. The main piston rod is supplied with a small roller which engages at the end of each stroke with one or the other end of the rocker which is pivoted to the middle of the pump frame. This rocker is connected to the valve rod in such manner that when the end of the rocker is raised a slight turning movement is given to the chest-piston. The turning movement places small steam ports, which are located in the under side of the chest-piston, in proper con-

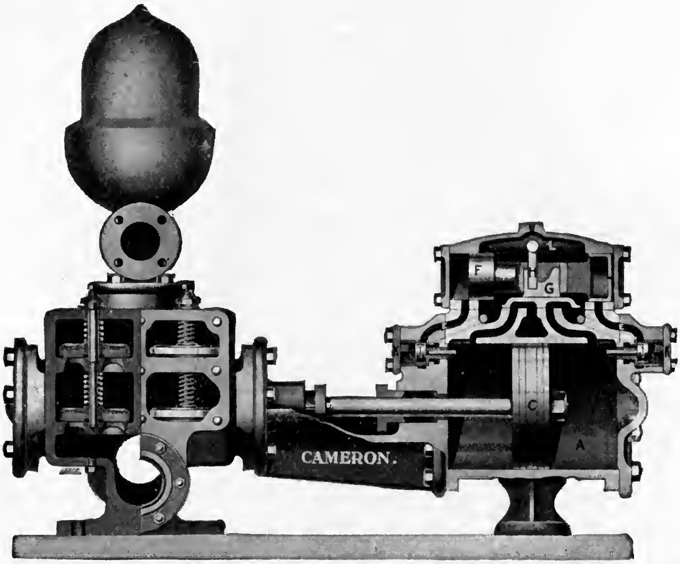


FIG. 141.—Single direct acting feed pump.

tact with corresponding ports cut in the steam chest. The steam entering through the port at one end and filling the space between the chest-piston and the head, drives the chest-piston to the end of its stroke and carries the main valve with it. When the chest-piston has traveled a certain distance, a port on the opposite end is uncovered and steam enters and stops it by giving it the necessary cushion. In other words, when the turning movement is given to the auxiliary or chest-piston by the mechanism, it opens the port to steam admission on one end, and at the same time opens the port on the other end to exhaust.

A single direct acting feed pump with valve controlled entirely by steam pressure, and no outside mechanism, is shown in Fig. 141. Referring to this figure, *A* is the steam cylinder; *C* the piston; *L* the steam chest; *F* the chest plunger, the right-hand end of which is shown in section; *G* the slide valve; *H* a lever by means of which the steam-chest plunger *F* may be reversed by hand when necessary; *I I* are reversing valves; *K K* are reversing valve-chamber bonnets; *E E* are exhaust ports leading from the ends of the steam chest direct to the main exhaust and closed by the reversing valves *I I*.

In operation, the piston *C* is driven by steam admitted under the slide valve *G*, which, as it is shifted backward and forward alternately connects opposite ends of the cylinder *A* with the live steam pipe and exhaust. This slide valve *G* is shifted by the auxiliary plunger *F*. *F* is hollow at the ends, which are filled with steam, and this, issuing through a hole in each end, fills the space between it and the heads of the steam chest in which it works. The pressures at the ends of the plunger *F* being equal, it is ordinarily balanced and motionless; but when the main piston *C* has traveled far enough to strike and open the reverse valve *I*, the steam exhausts through the port *E* from behind that end of the plunger *F*, passing into the main exhaust by the passage shown dotted, and thus reverses the pump. In its movement, the plunger *F* acts as a slide valve to close the port *E*, and is cushioned on the steam confined between the ports and steam-chest cover. The reverse valves *I I* are closed, as soon as the piston *C* leaves them by a constant pressure of steam, conveyed directly from the steam chest through the ports shown by the dotted lines.

**197. Duplex Pumps.**—A duplex pump consists of two single pumps placed side by side and working in parallel between the suction and discharge sides. The steam valve of one side is operated from the piston rod of the other side, causing the pistons to move in opposite directions. One piston is always in motion while the other is stopped at the end of the stroke, thus providing a practically continuous flow of water from the discharge. Fig. 142 shows the general form of a duplex pump, while Fig. 143 is a cross-section of the same pump, showing the details of its construction.

The steam valves of a duplex pump are very similar to those of a plain slide-valve steam engine, but they do not lap over the steam or exhaust ports when the valve is in the middle of its travel. In order to make the valve-travel as small as possible, thus reducing its friction, and at the same time give it sufficient bearing surface to prevent leakage of live steam from the admis-

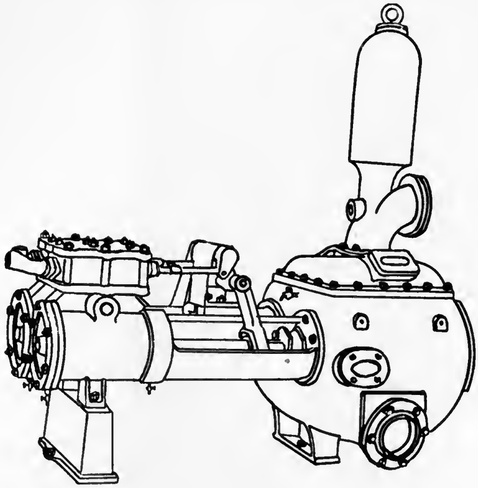


Fig. 142.—Duplex pump.

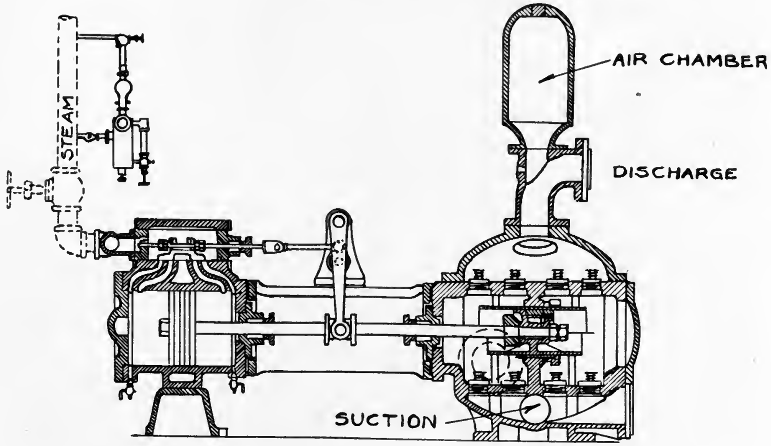



Fig. 143.—Cross-section of duplex pump.

sion to the exhaust sides, the exhaust ports are made separate from the admission ports, but placed very close to them. The separate exhaust ports also give a simple means of cushioning the piston near the end of its stroke, bringing it to rest without shock or pounding, and preventing it from striking the heads of the cylinder. When a valve has no lap on either the steam or exhaust sides, it closes the exhaust at the same time that it opens the admission; such a valve would have to act quickly and at the end of the stroke. This would not be advisable in a duplex pump where the valve on one side is operated from the piston on the other, as the pistons would reach the ends of their strokes together and there would be danger of the pump stopping on "center." To avoid this difficulty the valves are given considerable lost motion by allowing sufficient clearance between the lock-

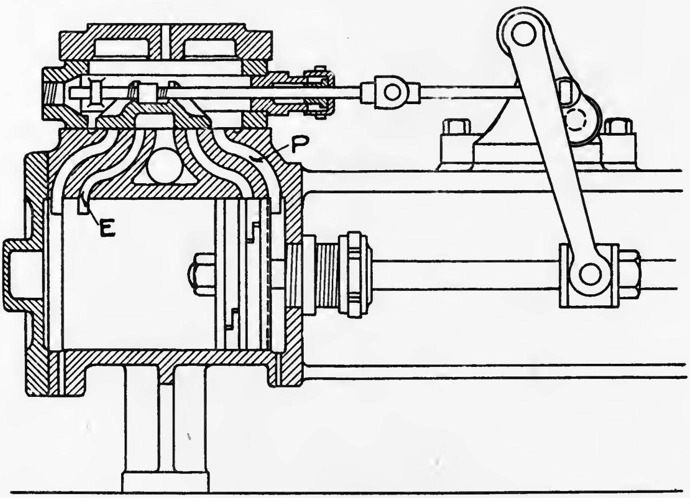



Fig. 144.—Steam cylinder and valve of duplex pump.

nuts on the valve stem. This permits the valve to remain stationary until the piston has nearly completed its stroke, and renders it impossible for the pistons to stop on center as they do not reach their extreme positions at the same time; therefore one of them is always in a position to be moved by the steam.

Fig. 144 shows a cross-section of one cylinder and valve of a duplex pump, with the piston beginning the forward stroke. The valve has been moved forward by the other piston rod so as to admit steam behind the piston and open the exhaust from the front end of the cylinder. As the piston moves forward, the valve remains stationary, due to the lost motion between it and its valve rod. When the piston is nearly at the end of its stroke the other piston rod begins to move the valve backward, closing the admission port $P$ and the exhaust port $E$. By this time the piston has covered the exhaust port on the front end of the cylinder and compresses the remaining steam into the end of the cylinder, thus stopping the piston gradually. By the time the piston has reached the end of its stroke the valve has been moved back enough to uncover the admission port on the front end and open the exhaust port on the back end, which causes the piston to start on its back stroke.

The water ends of both single and duplex pumps are practically alike and are illustrated in Figs. 140 and 143. They consist of a cylinder fitted with either a piston or a plunger, and two sets of valves, the lower ones being the suction and the upper ones the discharge valves. On the forward stroke of the plunger, the pressure in the right-hand end of the cylinder is reduced until water flows in through the suction valves, filling the cylinder. On the back stroke the water exerts a pressure on top of the suction valves, holding them closed. The pressure will increase until it is great enough to overcome the pressure on top of the delivery valves, when these will open and allow the water in the cylinder to be discharged.

The pistons or plungers of double acting pumps require packing to prevent water leaking from one side to the other and thus reducing the amount of water pumped. As leaks in the packing are not easily detected, great care should be used to prevent them. When cold water is to be pumped, the packing is usually of a soft material, but for hot water a metallic packing is better.

A common method of packing water pistons with soft packing is illustrated in Fig. 145. The packing consists of four rings of fibrous material held between the two halves of the piston. By screwing together the two halves of the piston the packing is squeezed out until it makes a water-tight fit against the sides of the cylinder. In cutting ring packing of this kind, the length of each piece should be shorter than the circumference of the groove into which it is to be placed. The reason for this is that the packing is cut dry, and after becoming wet it lengthens and, if cut long enough to reach around the groove, it will grip the cylinder too hard after it has become wet. To allow for this, the packing should be cut short by an amount equal to the thickness of the packing. Another method of placing the packing for a water piston is shown in Fig. 146. In this method, a number of grooves are cut in the circumference of the piston and a single strand of packing placed in each one. No provision is made for tightening the packing in this method. A cup leather packing is illustrated in Fig. 147. In this method of packing two leather washers are clamped into the piston and have the edges folded out in opposite directions along the sides of the piston. A special mold or clamp is used for shaping the leather washers correctly.

Fig. 148 shows the method of packing a water plunger. This

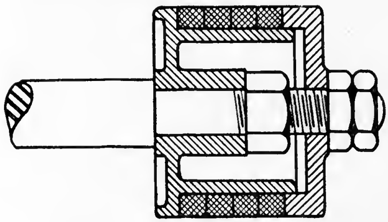


Fig. 145.

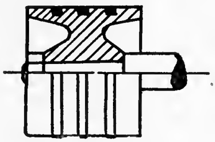


Fig. 146.

device amounts to an internal stuffing box and a pump packed in this manner is said to be "inside packed." An "outside packed" plunger is one in which the plunger extends through the head of the cylinder and is packed on the outside with a stuffing box in a manner similar to the packing of a steam engine piston rod. When the pump is double acting, the water cylinder is divided into two parts by a metal partition extending across its center.

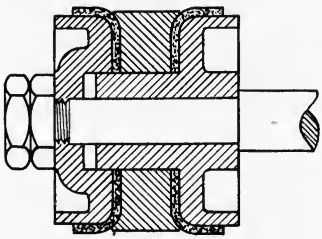


Fig. 147.

With this method of packing it is necessary to use two plungers, which are fastened together with tie rods on the outside of the cylinder in order to force the plungers to move together. Fig. 149 shows an outside packed plunger pump, the tie rods being shown dotted.

Since the movement of the pump piston is more or less intermittent, the flow of water through the discharge would vary unless an air chamber were connected to the discharge side of the pump. During certain portions of the stroke, the pressure developed is greater than normal, and the excess pressure at such times compresses the air which is contained in the air chamber. When the pressure falls below normal, the air expands and forces water through the discharge. Thus the air chamber tends

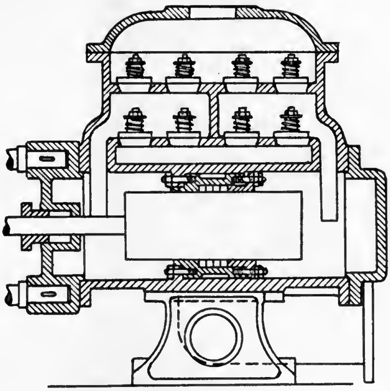


FIG. 148.—Inside packed water plunger.

to produce a steady flow of water through the discharge and prevents shock in the piping. The size of the air chamber will depend upon the ordinary running speed of the pump, being larger for high-speed pumps than for low-speed ones. On single cylinder pumps the air chamber should be from two to three and one-half times the volume displaced at each stroke of the

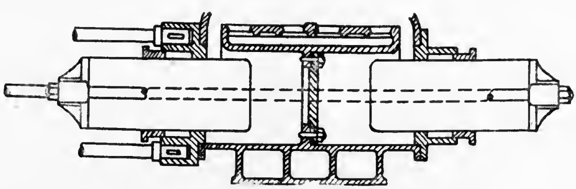


FIG. 149.—Outside packed water plunger.

plunger, and for duplex pumps it should be from one to two and one-half times the plunger displacement. The larger the chamber the more uniform will be the discharge pressure.

A vacuum chamber placed on the suction side of a pump assists in securing a uniform flow of water through the suction pipe and in filling the cylinder completely at each stroke. The vacuum chamber should have a volume slightly greater than that of the suction pipe, and should have great length rather than great diameter. A good location for the vacuum chamber is shown in Fig. 150.

With a tight suction pipe and cold water, a pump may lift its supply of water several feet, but if the pump is to handle hot water the supply should be above the level of the pump, so that the water may run into the water cylinder by the force of gravity. If the supply is placed below the pump, the suction stroke will reduce the pressure on the supply, thus lowering its boiling-point and causing the water to give off large quantities of vapor, which will flow into the cylinder and prevent its filling with water.

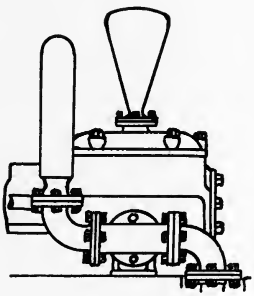


Fig. 150.

The water piston of a boiler feed pump is made smaller in diameter than the steam piston, in order that a higher pressure may be developed in the water cylinder than is supplied in the steam cylinder. This is done in order that the boiler pressure may be used in the steam cylinder, and the water deliverd at a high enough pressure to enter the boiler and overcome the resistance of the piping system.

If the water cylinder were completely filled with water at each suction stroke and there were no leakage, the amount of water pumped at each stroke would be equal to the piston displacement. Because of the cylinder not filling completely at each suction stroke and because of unavoidable leak, the amount of water delivered is always less than the piston displacement. The difference between the piston displacement and the volume of water actually pumped, expressed as a per cent of the piston displacement, is called the "slip." Thus, if the piston displacement of a certain pump is 200 cu. ft. per minute and the pump actually delivers only 170 cu. ft. per minute, the slip is $\frac{200-170}{200}=\frac{30}{200}=15$ per cent. The slip in a new pump will usually amount to about 10 per cent and increases with the length of time the pump is used, due to increased leakage.

In determining the size of pump to be used with a certain size boiler, the amount of water used by the boiler when working at its rated capacity should first be determined, and a size of pump chosen which, when working at 40 strokes per minute, will have a piston displacement equal to the volume of water required. By basing the capacity of the pump on 40 strokes per minute, sufficient allowance will be made for the slip of the pump and for any overload that may come on the boiler.

To illustrate this method of determining the size of feed pump, suppose a pump is to be purchased to supply water to a 200-h.p. boiler which generates steam at 150 lb. gage pressure from feed water at 130°.

200 h.p. will require $200 \times 34.5 = 6900$ lb. of water from and at 212° per hour. By referring to the table of Factors of Evaporation in Chapter VIII the factor of evaporation for 150 lb. and 130° is found to be 1.134 and the water actually required by the boiler will be

$\frac{6900}{1.134} = 6085$ lb. per hour or $\frac{6085}{60} = 101.4$ lb. per minute. Since a cubic foot of hot water weighs about 60 lb., 101.5 lb. will occupy a volume of $101.5 \div 60. = 1.69$ cu. ft. or $1.69 \times 1728 = 2910$ cu. in.

If the pump is to run 40 strokes per minute, its piston displacement per stroke will be $2910 \div 40 = 72.75$ cu. in.

A gallon of water contains 231 cu. in.; therefore the pump must have a capacity of $72.75 \div 231 = .315$ gallons per stroke. Referring to the table of pump sizes below we see that a 5½ in. ×3¾ in. ×7 in. pump will have a displacement of .34 gallons per stroke and will therefore be large enough.

TABLE OF SIZES AND CAPACITIES OF SINGLE BOILER FEED PUMPS

| Diam. steam cyl., inches | Diam. water cyl., inches | Length of stroke, inches | Gal. per stroke | Diam. steam cyl., inches | Diam. water cyl., inches | Length of stroke, inches | Gals. per stroke |
|---|---|---|---|---|---|---|---|
| 2½ | 1½ | 3 | .023 | 7½ | 5 | 10 | .85 |
| 3 | 1¾ | 3 | .031 | 8 | 5 | 12 | 1.02 |
| 3¼ | 2 | 4 | .05 | 10 | 6 | 12 | 1.47 |
| 3½ | 2¼ | 4 | .07 | 12 | 7 | 12 | 2.00 |
| 4 | 2½ | 5 | .11 | 12 | 8 | 12 | 2.61 |
| 5 | 3¼ | 7 | .25 | 16 | 10 | 16 | 5.44 |
| 5½ | 3¾ | 7 | .34 | 18 | 12 | 24 | 11.75 |
| 7 | 4 | 7 | .39 | 20 | 14 | 24 | 16.00 |
| 7 | 4½ | 10 | .69 | 24 | 16 | 24 | 20.80 |

In specifying the size of a pump, the first dimension refers to the diameter of the steam cylinder, the second dimension refers to the diameter of the water cylinder, and the third dimension to the common length of stroke.

The pipe connections on both the suction and delivery sides of a pump should be as short and direct as possible, and the steam connection made directly to the steam space of the boiler so that steam may be delivered to the pump even when the main valve on the boiler is closed.

Suction pipes should be at least as large as the pump opening, and if the suction pipe is long or has many bends, it should be even larger. A means of priming or charging the suction pipe for starting is also desirable. This may easily be done by connecting the discharge side to the suction side by a small by-pass fitted with a valve. The bottom of the suction pipe should be fitted with a strainer and a foot valve to prevent foreign substances entering the pump. It is especially important that there be no leaks in the suction pipe and, to this end, the joints should be very carefully made when erecting the piping.

**198. Injectors.**—Injectors are often used with small boilers and in some cases with large ones, where there is only one boiler. Injectors have the advantage over feed pumps that they utilize practically all the heat supplied to them, and are thus very efficient as boiler feeders; they deliver hot water to the boiler; and their cost is small when compared with feed pumps. However, they have the disadvantage that they cannot handle water at a temperature above 160° and, if they have to lift their supply of water, they cannot handle as high a temperature as this. They have to be accurately adjusted for the steam pressure to be used and they are sometimes uncertain in operation.

The action of an injector in pumping water into a boiler may be illustrated by Fig. 151, which shows the necessary parts of an injector. Steam from the boiler enters the injector at *A*, flows through the combining tube *D* to the opening *O*, from which it passes to the atmosphere through the overflow *G*. As the steam flows through the combining tube it draws air out of the suction pipe *B*, creating a partial vacuum in it and causing the water to rise to the injector and come in contact with the steam at the end of the steam nozzle *C*. The steam leaving the nozzle *C* has a high velocity and, as it is condensed by contact with the cold water rising through *B*, gives enough motion to the water to raise the check valve *H* and permit it to pass into the boiler. As soon as water begins to be delivered to the boiler, steam ceases to escape at the overflow *G*.

Injectors may be divided into two general classes—lifting and non-lifting. The non-lifting type has almost dropped out of

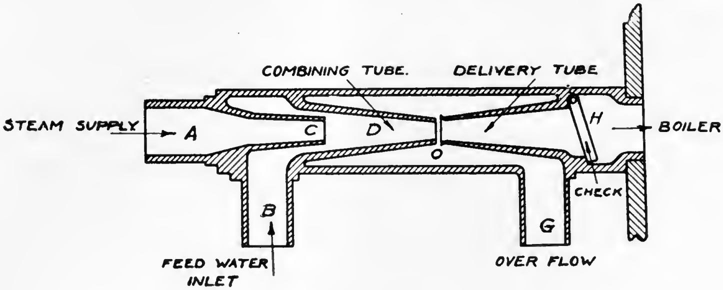



Fig. 151.

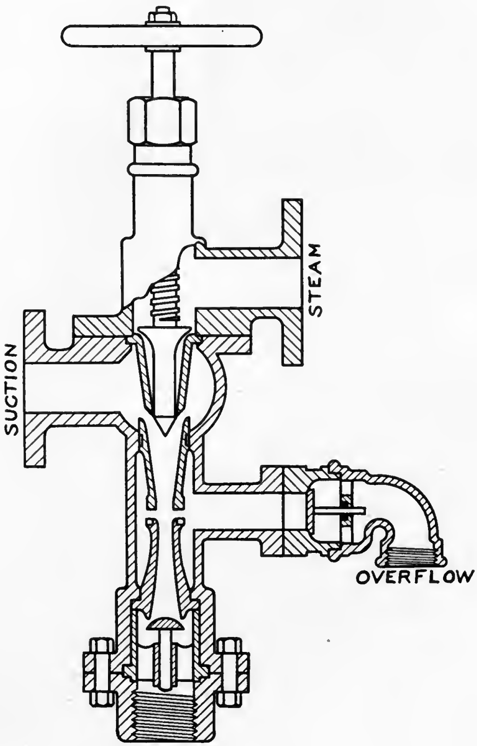



Fig. 152.

use, and is not of enough importance to consider here. In order that an injector be able to lift its supply of water, the pressure at the end of the steam nozzle must be less than that of the atmosphere. This result can be secured by properly shaping the steam nozzle. The difference between these two classes of injectors is therefore entirely in the shape of the steam nozzle.

Lifting injectors may be again divided into two classes—automatic and nonautomatic injectors. An automatic injector will restart automatically if its operation is momentarily interrupted, while a non-automatic injector must be restarted by hand. A simple form of non-automatic lifting injector is shown in Fig. 152. In this injector the steam nozzle is provided with a conical valve for regulating the flow of steam at starting. The overflow is provided with a check valve to prevent air

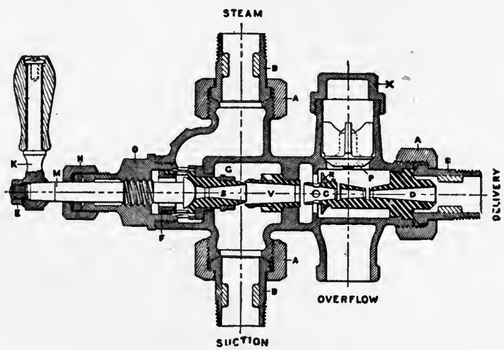


FIG. 153.—Automatic injector.

entering the boiler with the feed water. In starting this injector, the steam valve is opened slightly until water flows from the overflow; then the steam valve may be opened wide and the water will be forced into the boiler.

A common form of automatic injector is shown in Fig. 153. The features which make this injector automatic are a movable steam nozzle *S* for adjusting the opening between the steam nozzel and the combining tube *V*, and a check valve *R* for closing the first aperture in the combining tube. This injector works on the same principle as the non-automatic type, a partial vacuum being created in the suction by the steam drawing air through the opening between the steam nozzle *S* and the combining tube *V*. At starting, the steam and air pass into the overflow through the apertures in the combining tube and through the check valve P. As soon as the water is drawn up to the end of the steam nozzel it condenses the steam and is forced out the overflow. If, now, the steam valve is opened wide, the energy of the steam will carry the water through the tube *D* and into the boiler. When water begins to flow through the tubes *C* and *D* into the boiler, a suction through the two openings in the tube *C* is created which closes the check valve *P* and opens the flap valve *R*. Should the flow be interrupted, the valve *R* closes and the starting process is repeated automatically.

The injectors described up to this point are all of the single-tube type. An injector which is to lift water through a considerable height cannot handle very hot water, because different

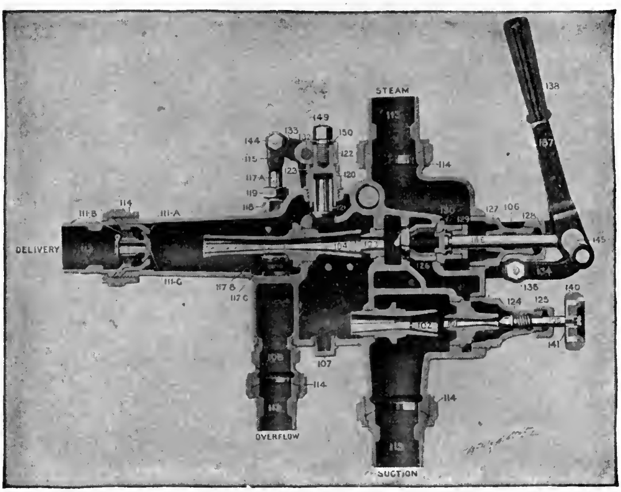



Fig. 154.—Hancock inspirator.

shaped tubes are required for lifting and for forcing hot water. Therefore, in order for an injector to lift and to feed hot water, it must have two tubes, one for lifting and one for forcing, thus making it a double injector. An injector of this type, known as the Hancock Inspirator, is shown in Fig. 154. In operation, the steam valve (140) is first opened, admitting steam to the lifting nozzle (102). The action of this nozzle is similar to that described for single-tube injectors. This delivers water under a slight pressure to the overflow check valve (121). Next, the steam valve (146) is opened and water is forced through the main combining tube (104) and into the boiler. The action of opening the valve (146), closes a valve in the overflow (117 *A*), by means of a lever connecting it with the main lever (137).

## CHAPTER XVI

### CHIMNEYS AND DRAFT

**199. Draft.**—The effectiveness of a chimney is measured by the draft which it can produce. The draft produced by a chimney is caused by the difference in weight of the air inside the chimney and that outside. The air inside a chimney has a higher temperature than that outside and is lighter, since warm air is lighter than cold air, and the lighter air inside the chimney will rise and cold air will flow in to take its place. If the cold air is heated as it enters the chimney, the draft will be continuous and there will be a current of air flowing in the chimney. That is what happens in a chimney connected to a boiler; the air is heated in passing through the furnace, and rises through the chimney, while cold air enters to take its place. Since the draft in a chimney is produced by the difference in weight between the column of air inside the chimney and that outside, the draft will be greater with a high temperature inside the chimney or with a tall chimney. In other words, with a given temperature outside the chimney, the draft is proportional to the temperature inside the chimney (measured from absolute zero) and to the height of the chimney.

The draft which a chimney will produce may be found by the following formula, which makes an allowance of 20 per cent for friction in the chimney:

$$D = .42\, H \times P\left(\frac{1}{T} - \frac{1}{T_1}\right)$$

in which $D$ is the draft produced by the chimney, expressed in inches of water.

$H$ = Height of top of chimney above grates, in feet

$P$ = Atmospheric pressure in pounds per square inch (14.7 at sea level)

$T$ = Atmospheric temperature expressed in absolute degrees (Fahrenheit plus 460)

$T_1$ = Temperature in chimney, expressed in absolute degrees (Fahrenheit plus 460°).

According to this formula, a chimney 100 ft. high with a temperature inside of 500° F. and outside of 60° F. would have a draft, at sea level, of

$$D = .42 \times 100 \times 14.7 \left(\frac{1}{520} - \frac{1}{960}\right)$$
$$= \text{about } .54 \text{ in. of water.}$$

By *Inches of Water* is meant that the draft is strong enough to support a column of water that many inches high. Thus, in the example just given, the draft pulls with a force strong enough to support a column of water .54 in. high. If the draft were applied to one end of a U-tube containing water, this water would stand .54 in. higher in one side of the tube than in the other.

The draft produced by a chimney is not all available for drawing air through the fire, which is its most important office, for it must also overcome the friction of the chimney, the breeching or connection between the chimney and boiler, the resistance of the boiler passes, and the resistance of the fire itself. After these things are provided for, there must be enough draft left to keep the fires burning properly. The above formula allows 20 per cent of the draft for overcoming the friction of the chimney, which seems to be a fair average value. The loss of draft in the breeching may be estimated as .1 of an inch of water for each 100 ft. length, with an additional loss of .05 of an inch for each right angle bend, and the loss in the boiler passes will vary from .3 to .6 of an inch, depending on the kind of boiler.

The draft necessary to force air through the fire will depend upon the kind of coal burned, upon the thickness of the fire, and upon the rate at which the coal is being burned, therefore it varies through a wide range. A coal that packs closely on the grate will require more draft to force air through it than a more open grade of coal; also, the thicker the fire, the more draft will be required, and a high rate of combustion requires more air and therefore a stronger draft than does a low rate of combustion. The curves shown in Fig. 155 give the amount of draft required for different kinds of fuels when burned at different rates of combustion and with the thickness of fire ordinarily used in practice. These curves were originated by the Stirling Company from results of a large number of tests.

To illustrate the method of determining the amount of draft required, suppose we have a boiler which burns 20 lb. of bituminous run of mine per square foot of grate surface per hour, the breeching being 50 ft. long with two right-angled bends. The draft required will be

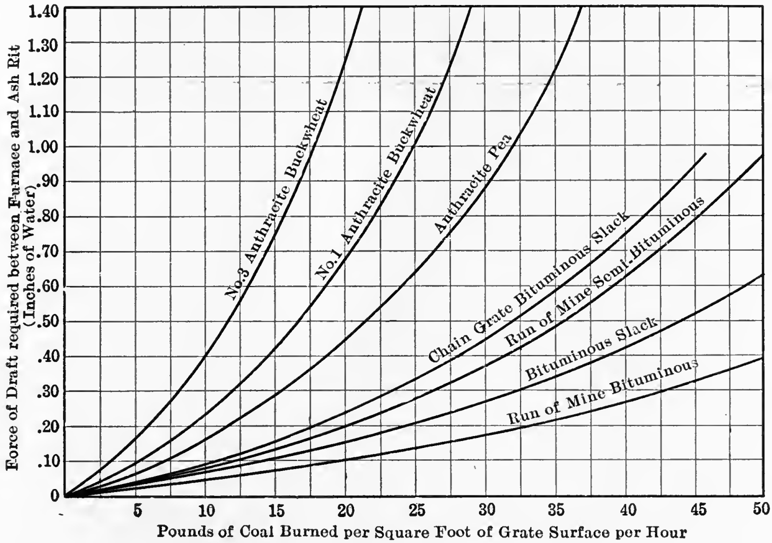



FIG. 155.

| | |
|---|---|
| For the breeching........................ | $.5 \times .1 = .05$ in. of water |
| For two bends in breeching................ | $2 \times .05 = .10$ |
| For the fuel (from curve)................... | .10 |
| For the boiler passes (average assumed).. | .45 |
| Total.................. | .70 in. of water |

Assuming a temperature of 90° F. in the boiler room and of 500° F. in the chimney, the height of the chimney may be found from the formula

$$D = .42\ H \times P\left(\frac{1}{T} - \frac{1}{T_1}\right)$$

$$.70 = .42\ H \times 14.7\left(\frac{1}{460+90} - \frac{1}{460+500}\right)$$

$$.70 = 6.174\ H \times .000776 = .00479\ H$$

$$H = \frac{.70}{.00479} = 146 \text{ ft.}$$

Shorter methods than the above have been used quite commonly for determining the height of chimney necessary, such shorter formulas usually being derived from experience. The following short formula for finding the height of chimney is suggested as giving very good results:

$$H = \frac{180C^2}{t}$$

in which $H$ is the height of chimney in feet
$t$ is the temperature of gases inside the chimney
and $C$ is the pounds of fuel burned per square foot of grate surface per hour.

Applying this formula to the above example, the height of chimney should be

$$H = \frac{180 \times 20^2}{500} = 144 \text{ ft.}$$

The volume of gases handled by a chimney depends on the area of cross-section of the chimney. It also depends on the height of the chimney, since a tall chimney will move the gases faster than a short one. The volume of gases to be handled depends on the amount of coal burned. The relation of these quantities can be reduced to the following simple formula:

$$A = \frac{F}{12\sqrt{H}}$$

in which $A$ is the area of cross-section of the top of chimney, in square feet.
$H$ is the height of the chimney in feet and
$F$ is the number of pounds of coal burned per hour.

If, in the problem given above, the boiler had 60 sq. ft. of grate surface, the total coal burned per hour would be $60 \times 20 = 1200$ lb., and the area of the chimney should be

$$A = \frac{1200}{12 \times \sqrt{146}} = 8.28 \text{ sq. ft.}$$

which would give a diameter of

$$D = \sqrt{\frac{A}{.7854}} = \sqrt{\frac{8.28}{.7854}} = \sqrt{10.54} = 3.25 \text{ ft. or 3 ft. 3 in.}$$

For square chimneys, the corners should be neglected, and the area taken as that of a circle which would fit inside the chimney. Thus if a square chimney was used with the above boiler, the chimney should be 3 ft. 3 in. square on the inside.

If the horse-power of the boilers and the rate of combustion are known, the same formulas may be used to determine the size of chimney required. Thus, suppose the height of chimney in order to provide enough draft, is to be 146 feet, as before, and we wish to find the diameter of a round chimney which will be large enough for 1000 h.p. of boilers which are of such type that 4 pounds of coal will be burned per horse-power.

1000 h.p. will require the burning of $1000 \times 4 = 4000$ lb. of coal per hour. Therefore the area of the chimney would be

$$A = \frac{4000}{12 \times \sqrt{146}} = 27.6 \text{ sq. ft.}$$

and its diameter would be

$$D = \sqrt{\frac{27.6}{.7854}} = \sqrt{35.14} = 5.93 \text{ or about 5 ft. 11 in.}$$

The area of the breeching should be about 20 per cent greater than the area of the chimney as calculated above. Thus, the breeching for the example which we have just worked would have an area of $1.20 \times 27.6 = 33.12$ sq. ft.

If there are a number of boilers, the size of the breeching would be reduced from each boiler to the next Thus, if there are two 500=h.p. boilers in the problem which we have just worked, the breeching would have an area of 34.2 sq. ft. between the chimney and the first boiler, and an area of $33.12 \div 2 = 16.56$ sq. ft. between the first boiler and the second. In all cases the breeching should be covered with a non-conducting material, to prevent a reduction in temperature of the gases before reaching the chimney.

**200. Chimneys for Oil Fuel.**—Chimneys for boilers which use oil fuel need be only about 90 ft. high and with a cross-sectional area about one-half as great as if bituminous coal were to be used. However, they are usually built as though bituminous coal were to be used for fuel. Then, if oil is abandoned as a fuel, it is not very expensive to change over to coal.

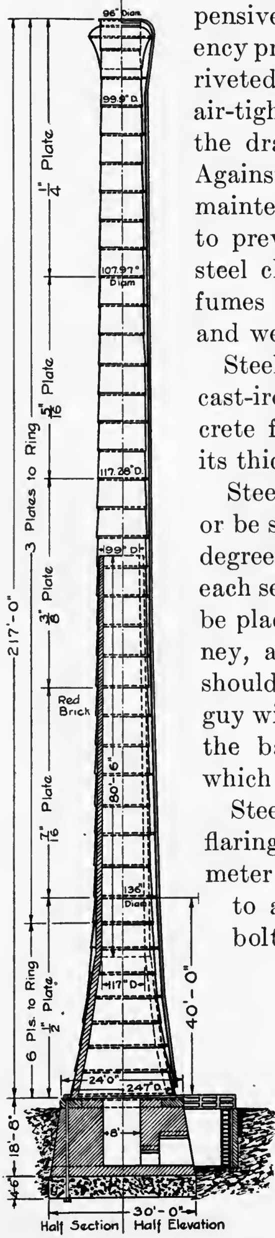
**201. Steel Chimneys.**—The materials most commonly used in chimney construction are steel, reinforced concrete, and brick.

Steel chimneys are being used very commonly as they have many advantages. Among these are, low cost as compared with other kinds, small space occupied, since they are not so thick, great strength for a given weight, less expensive foundation required, and great efficiency provided the plates are caulked after being riveted together, thus making them practically air-tight. Air leaking into a chimney reduces the draft and therefore makes it less efficient. Against these advantages are its higher cost of maintenance as it must be painted frequently to prevent its rusting. Unless properly lined, a steel chimney may be attacked by the sulphur fumes in the smoke, which eat away the steel and weaken the chimney.

Steel chimneys are usually placed upon a cast-iron or steel plate which rests upon a concrete foundation. If a cast-iron plate is used, its thickness should not be less than 1 in.

Steel chimneys may be sustained by guy wires or be self-sustaining. Four guy wires placed 90 degrees apart around the chimney are used in each set. If one set of wires is used, they should be placed at two-thirds the height of the chimney, and if two sets are used, the lower ones should be placed at one-third the height. All guy wires should be anchored at a distance from the base of the stack equal to the height at which they are attached to the chimney.

Steel chimneys are made self-sustaining by flaring the bottom part to about twice the diameter of the upper part, and bolting it securely to a steel or cast-iron base plate, which is bolted directly to the foundation. A chimney of this kind is shown in Fig. 156. These chimneys are usually lined with a second quality of fire brick for a height of about 50 ft. from the



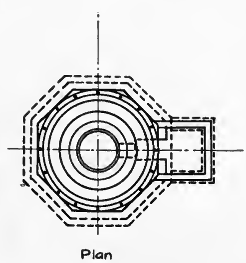




Fig. 156.—Steel chimney.

bottom, and above this with well burned red brick, if they are lined at all. It is better to line them, as this protects the metal from the sulphur fumes mentioned above. The lining should have a thickness of not less than 4½ in. at the top and increase in thickness 4½ in. for about every 30 ft. In any case the lining need be only thick enough to be self sustaining.

**202. Concrete Chimneys.**—Chimneys built of concrete, reinforced with steel rods, have been used to some extent in recent years and are proving very satisfactory. These chimneys are built of a thin wall of concrete having vertical steel rods placed near the outer wall and with steel rings placed horizontally, the rings having a diameter slightly less than the outside diameter of the chimney. Constructed in this way, a concrete chimney is very strong and yet weighs only about one-third as much as a brick chimney of equal capacity. Besides these advantages, it does not leak air, is very durable, costs practically nothing to keep in repair, and occupies less space than a brick chimney. It is also much less expensive to build than a brick chimney and can be constructed faster.

**203. Brick Chimneys.**—Most of the power-plant chimneys erected in the past have been built of brick, but this material is being largely replaced by steel, or steel and concrete combined. Brick chimneys are built round, octagonal, or square, the round ones having the best shape to produce draft and weighing less in proportion to their size, but the square ones costing less to build. Nearly all brick chimneys are built with a lining which extends either the entire height of the chimney or to a point about 50 ft. from the ground. The lining should be built independent of the outside of the chimney so it will not be injured by expansion and contraction of the outer walls, and so it may be repaired or replaced without tearing down the outer walls. The lining may be of hard burned common brick, though fire brick is better suited to this purpose. In some cases, where the chimney is built of good hard burned common brick, it is not lined at all, but such chimneys are apt to develop cracks due to changes of temperature, and therefore leak air, which lessens the draft. A good example of brick chimney construction is shown in Fig. 157.

Round chimneys are often built of radial brick, similar to those shown in Fig. 158. These brick, which have square holes through them, are larger than ordinary brick and are molded

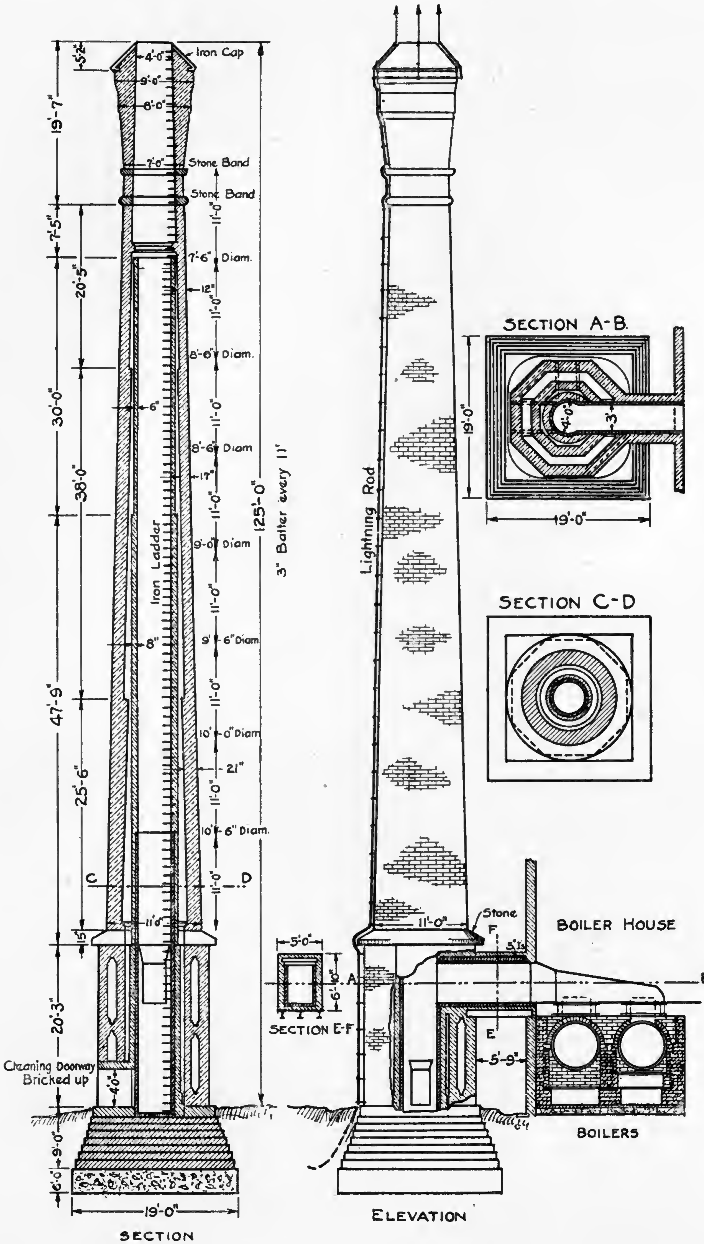



FIG. 157.—Brick chimney.

to fit into a certain place in the chimney. Their shape permits their being laid with thinner joints and, being of large size, the joints are not so numerous. The holes through the bricks do not allow the heat to pass through them so readily after they are placed in the chimney and they make a lighter chimney than if they were solid.

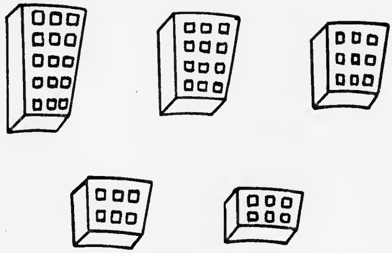


FIG. 158.—Radial brick.

**204. Artificial Draft.**—Besides natural draft, or that created by a chimney, there are two common methods of producing draft by artificial means. These methods are (1) by means of steam jets, and (2) by means of fans, or mechanical draft, as it is commonly called.

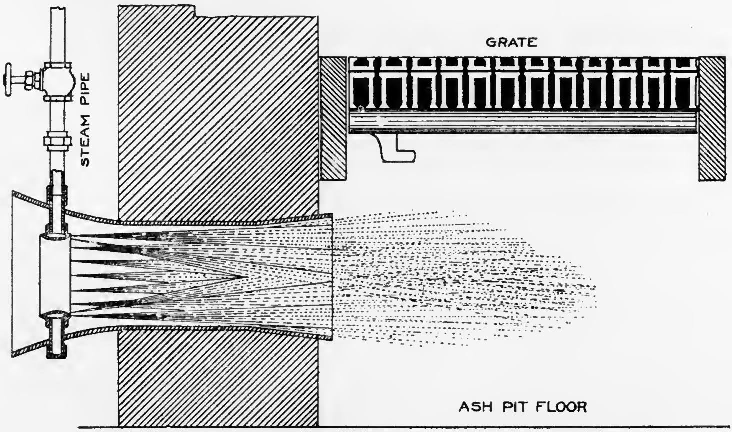



FIG. 159.

**205. Steam Jets.**—Fig. 159 illustrates one method of producing draft by means of steam jets In this method, the draft is produced by a jet of steam which discharges beneath the grates, forcing the air and steam up through the grates and fuel bed.

The jet is produced by a hollow ring with small holes of 1/16 to 1/8 in. in diameter bored in its side, the ring being connected directly to the steam space of the boiler instead of to the main steam pipe, so it may be operated at times when steam is not being taken from the boiler. All the small jets discharge in the same direction into a nozzle placed just below the level of the grates, and serve to draw air through the center of the ring and the nozzle, discharging it into the ash pit under the grates.

The same form of steam jet described above is sometimes placed in the base of the chimney and directed upward in order to produce a draft by drawing air through the nozzle. Unless large quantities of steam are used, the draft produced by this method will be small. The draft in a locomotive boiler is produced by this method, but in this case all the steam exhausted from the engine cylinders passes through the nozzles and produces a very powerful draft, often amounting to from 3 to 8 in. of water. In a locomotive boiler, the steam used in the draft nozzles does not represent a loss, as in stationary work, because the steam first does work in the engine cylinders and, if it were not used in the nozzles, would be wasted. Since the amount of steam passing through the nozzles, and therefore the draft, depends on the amount of work the engines are doing, the device is self-regulating.

Steam jets are sometimes placed in the bridge wall and directed toward the front of the furnace, or placed along the sides of the furnace and directed toward the center. In these positions, however, they serve simply to mix the air and gases more thoroughly, and thereby promote more complete combustion but do not increase the draft to an appreciable extent.

It may be said in favor of steam jets for producing draft that they are cheap to install and are convenient for taking care of sudden and very large overloads. They are very wasteful of steam, using from 5 to 21 per cent of the total steam generated by the boiler and, in addition to the loss from this source, steam admitted through the grates must be heated to the temperature of the flue gases, and the heat required to do this is wasted. Steam jets beneath the grates help to prevent clinkers from adhering to the grates, and, with certain varieties of coal, this may be an important feature, though it would not justify the waste of steam caused by running the steam jet all the time.

**206. Mechanical Draft.**—Under certain conditions, draft produced by a fan, or mechanical draft, has many advantages over the method of producing it by a chimney, and in some cases such as the production of draft for the boilers of a war vessel where a high rate of combustion must be secured and where the height of the chimney or funnel is limited, the fan has so many advantages as compared to other methods of producing draft that its use for this purpose is almost absolutely necessary.

**207. Forced Draft.**—There are two common ways of using a fan to produce draft, called the *forced draft system* and the *induced draft system.* In the forced draft system the air pressure beneath the grate is greater than that of the atmosphere and the air is forced up through the bed of fuel. The air may be supplied under pressure either by closing the firing room or stoke hole air-tight and forcing the air into it under slight pressure, or by closing the ash pit air-tight and discharging the air into it under a slight pressure. In the first, or closed stoke-hole system, the air gradually escapes into the ash pits under the boilers and then up through the grates and fuel bed and out through a chimney, which needs to be only tall enough to carry

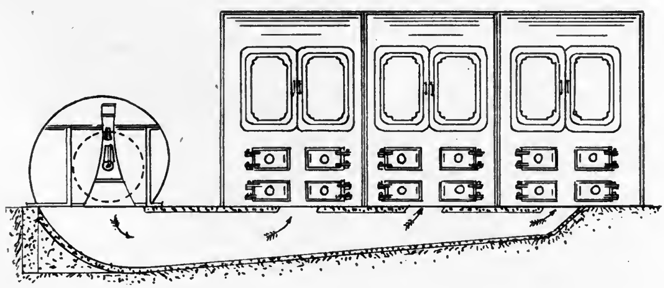


FIG. 160.—Closed ash pit systems of forced draft.

the gases out of the way. Ample ventilation is provided for the fireman by this method, as the fan discharges a large quantity of fresh air into the firing room. This method is well suited to war vessels, where the firing room can readily be made air-tight, and it has been widely adopted by the United States Navy.

The closed stoke-hole system is not well suited to stationary plants on account of the difficulty of constructing the firing room tight enough to prevent the loss of large quantities of air by leakage. For this kind of power plant the closed ash-pit system has come into common use. Fig. 160 illustrates one method of applying this system to a battery of boilers. The fan, which is driven by a small steam engine, is set at one side of the battery of boilers and discharges downward into a duct built under the floor and running under the fronts of the boilers, a branch leading into each ash pit, which is kept tightly closed. An objection to this method of construction is that cinders may fall into the air inlets and gradually choke up the duct. A better construction is to run the duct beneath the bridge walls of the boiler and place the inlet to the ash pit in the front of the bridge wall, as shown in Fig. 161.

In both of the constructions described above, the air supply to each boiler must be equipped with a damper for shutting it

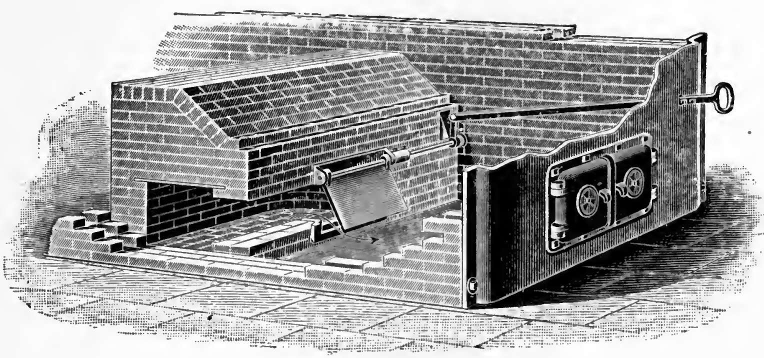


Fig. 161.

off when the furnace door is to be opened. Unless this damper is closed when the furnace door is opened the flame and smoke will be blown outward and there is danger of the fireman being burned.

**208. Induced Draft.**—In the induced draft system, a fan is connected in the breeching in such manner as to suck or draw air through the furnace. Fig. 162 shows the general construction of an induced draft system. The fan is usually placed about on a level with the tops of the boilers, so the breeching can lead directly into the center of the fan casing. The furnace gases enter the fan at its center and are discharged from its circumference directly into a short stack. The breeching is usually provided with a by-pass for leading the gases around the fan and directly into the stack in case of an accident to the fan. Dampers are provided for shutting off the gases from the fan and for opening the by-pass. In many installations, two fans, each with capacity enough to handle all the gases, are installed so that in case of accident to one the other may be used, each fan being used on alternate days or alternate weeks to keep both of them in good working order.

With the induced draft system, the pressure of the air inside the furnace and ash pit is always less than that of the atmosphere. Therefore it is not necessary to shut off the draft when cleaning the fires or ash pit, or when firing, and the fire burns more evenly over the entire grate and requires less attention than with forced draft. On the other hand, an induced system costs more than a forced draft system on account of its requiring a larger fan. A larger fan is required with an induced draft system because it handles warm air, while in a forced draft

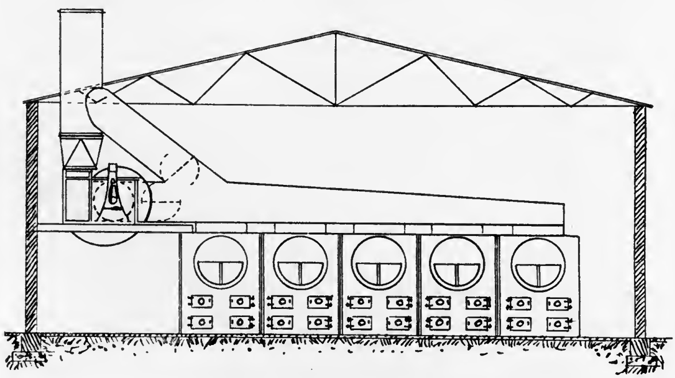


FIG. 162.—Induced draft system.

system, the fan handles comparatively cool air, which therefore occupies less volume; but it does not require as much power to move a cubic foot of warm air as it does to move a cubic foot of cold air, since the density of the warm air is less. Therefore, while the size of fan for an induced draft system is about twice that for forced draft for the same plant, it does not require twice as much power to run it.

Local conditions will usually determine whether it is better to use chimney or mechanical draft. A few street railway and lighting plants are provided with both chimney and fans, the fans being used when the heaviest load is carried, and the chimney alone used for ordinary loads.

Mechanical draft offers many advantages over natural or chimney drafts, especially with low-grade fuel. Since the amount of draft produced by a chimney depends upon its height and the temperature in it, its first cost becomes very great if a low grade of fuel is used which requires a strong draft. The first cost of a fan system will usually be much less than that of an equivalent chimney. With a fan system a very strong draft can be carried and, with it, a thick fire, which promotes complete combustion and requires less air per pound of fuel burned. The speed of a fan can be quickly changed to suit the load on the boilers and it can be speeded up to furnish enough draft for large overloads. Damp weather affects the draft of a chimney but makes no change in the draft produced by a fan.

One of the principal objections urged against mechanical draft is the cost of the power to run the fan. A fan requires from $1\frac{1}{2}$ to 5 per cent of the steaming capacity of the boilers to run it, depending upon the kind of engine used and the conditions under which it is operated. The cost of operation of the fan may be reduced if the exhaust from the fan engine can be used for heating the building or for heating the air supply of the furnaces.

**209. Economizers and Air Heaters.**—With either natural or mechanical draft the temperature of the waste gases will be about 500° F. A simple calculation will show the large loss resulting from this high temperature. Suppose 24 lb. of air are admitted to the furnace for each pound of combustible burned, the temperature in the boiler room being 90° and the temperature of the waste gases being 500° F. The specific heat of the waste gases will be about .25. For each pound of combustible burned there will be $24+1=25$ lb. of hot gases passing out the chimney, which will carry away and waste

$$.25\times 25\times (500-90)=2562 \text{ B.t.u.},$$

representing a larger per cent of the heat in the fuel.

If the draft is produced by a chimney, and an attempt is made to reduce this loss by lowering the temperature of the gases, the draft will be reduced, since the amount of draft depends upon the temperature in the chimney as well as upon its height. Therefore, unless the chimney is much too large for the plant it is serving, it will not be practicable to reduce the temperature of the waste gases.

If the draft is being produced by a fan, the above high temperatures are not necessary and may be reduced without affect-ing the draft. A method commonly used for saving a part of the heat which would otherwise be lost is by the use of an economizer.

An economizer is a feed-water heater which is placed in the flue leading from the boiler to the chimney and is heated by the hot flue gases. Economizers are usually made up of a number of 4-in. pipes placed in a vertical position and connected at the top and bottom by headers. Cold water enters the pipes at one end of the enconomizer and the hot gases passing between the pipes heat the water. As the flue gases usually have a

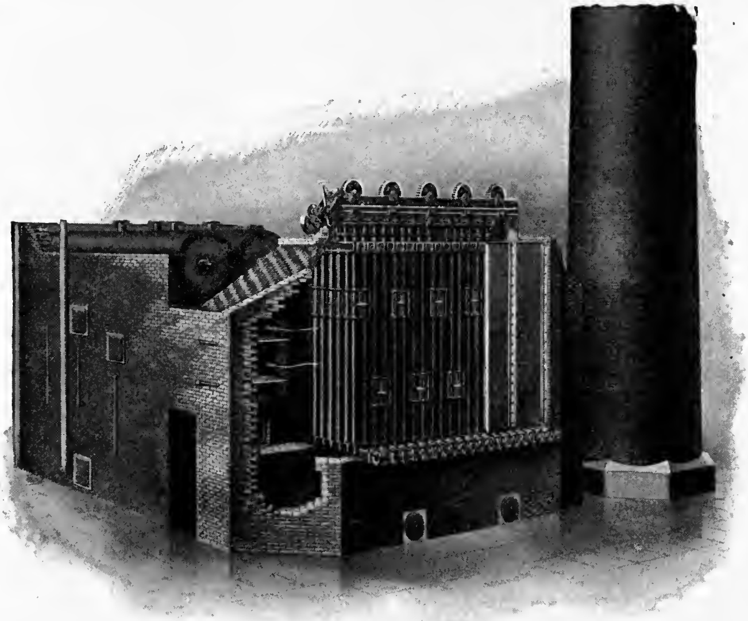


FIG. 163.—Economizer connected to boiler.

temperature of from 450° to 500° the feed water may be heated to the boiling-point, but in order to do this the water must be under pressure and the heater closed, otherwise steam would be generated. The heat utilized by an economizer is heat that would otherwise be wasted and, therefore, whatever heat is given to the feed water by it represents a direct saving, and the amount of this saving is considerable. Economizers are commonly used with mechanical draft systems, in which case they are placed directly in the breeching between the boiler and chimney, as shown in Fig. 163. The economizer is usually set in such manner that the gases may be by-passed around it in case it is shut down for repairs. When induced draft is used, the fan is usually placed so as to draw the gases through the economizer, but with forced draft, of course, the fan blows through furnace, boiler, and economizer.

The principal objection to economizers comes from the difficulty of keeping the tubes clear, both inside and outside, and from the difficulty of preventing leakage, brought about by excessive expansion of the economizer due to the high temperature to which they are subjected. If soot is allowed to remain on the tubes, it retains moisture and seems to have an acid action on the tubes, gradually corroding them. As the water in an economizer is subjected to a high temperature, impurities will be deposited in it from impure water, and it is necessary to clean the tubes on the inside to keep them working efficiently. For this purpose handholes through which they may be cleaned are placed over each tube.

It often happens that there will still be an excess of heat in the flue gases, even after passing through the economizer and heating the feed water. This heat, which would otherwise be wasted, may be used to heat the air which is fed into the furnaces, by providing a device built like an economizer, but arranged to pass air instead of water though the pipes. Cold air admitted to a furnace chills the fire by taking some of the heat to raise its temperature, hence there is an advantage in using warm air if it can be readily obtained.

## CHAPTER XVII

### BOILER FEED WATERS

**210. Scale.**—The waters of our lakes, rivers, springs, and underground streams contain more or less mineral substances that have been dissolved by the water in its passage through the earth, and also more or less dirt, mud, and vegetable matter which have been taken up and carried along by the water. When water is evaporated in a boiler, all of these impurities are left behind and are usually deposited in solid form. In some cases

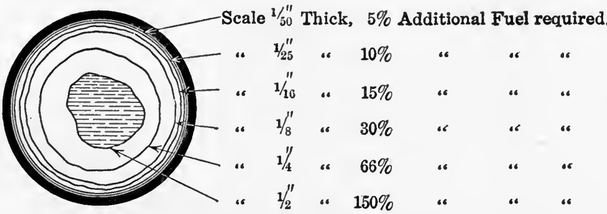



Fig. 164.

these substances merely settle as a soft mud and can be blown off, but more often they form a hard scale on all the heating surface, which is difficult to remove. The scale thus formed is a very poor conductor of heat and its presence, therefore, reduces the efficiency and capacity of a boiler by reducing the amount of heat that can pass through the heating surface. Fig. 164 shows how great may be the effect of a small amount of scale. In the case of water-tube boilers, scale collecting in the tubes greatly hinders the circulation of water and liberation of steam. Besides increasing the coal bills, scale causes the boiler to wear rapidly. Due to the presence of the scale, heat cannot pass through the metal readily and be taken up by the water, hence, the metal becomes overheated from the storage of heat in it, and may be burned or it may even reach a temperature at which it will bag or burst, due to the pressure within the boiler. Some forms of scale contain certain acids which may attack the iron and corrode or eat it away.

It is much better, as far as possible, to prevent the scale-forming substances from entering the boiler, as, once inside, they will form a more or less hard scale which must be removed. Even though the scale formed is soft and easily removed, its presence involves a certain expense in laying off the boiler and cleaning it. To prevent the formation of scale, requires a knowledge of the chemistry of feed water and of the proper treatment by which the mineral salts may be removed before feeding the water into the boiler, or they may be changed in nature so they will not form a hard scale but will settle as a soft scale or as mud which can be blown off or easily removed.

**211. Impurities in Feed Waters.**—Practically all waters available for boiler feeding contain some impurities. The effects of these impurities vary considerably but they are always injurious.

The impurities most often found, and found in the largest quantities, are given below together with their chemical formulae:

| | |
|---|---|
| Calcium carbonate | $CaCO_3$ |
| Magnesium carbonate | $MgCO_3$ |
| Calcium sulphate | $CaSO_4$ |
| Magnesium sulphate | $MgSO_4$ |

The impurities less frequently found and in smaller quantities are:

| | |
|---|---|
| Iron carbonate | $Fe_2CO_3$ |
| Magnesium chloride | $MgCl_2$ |
| Calcium chloride | $CaCl_2$ |
| Potassium chloride | $KCl$ |
| Sodium chloride | $NaCl$ |

Besides these there may be some iron oxides, calcium phosphate, silica, and organic matter, which usually occur in very small quantities.

**212. The Carbonates.**—Calcium carbonate and magnesium carbonate do not dissolve very readily in pure water, but most water contains some carbonic acid ($CO_2$) and if this is present, the carbonates dissolve very readily. The carbonates unite with the carbonic acid and form the bicarbonates of calcium and magnesium, which are very soluble. This combination can, however, be broken up by heating, which drives off the carbonic acid gas and returns the carbonates to the insoluble form, when they will be deposited. The action described above, begins when the water is heated to 180° F. and by the time it has reached 212° F., the greater part of the carbonates will be deposited. It requires a temperature of about 290° F. to deposit all of the carbonates, but the larger part is deposited between the temperatures of 180° and 212° F.

If the feed water enters the boiler at a temperature lower than 180° F. the carbonates will be deposited inside the boiler but, if some device is used whereby the feed water is heated to a temperature of about 210° or 212° before it enters the boiler, there will be very little of the carbonates deposited in it and it will be easily cleaned. As exhaust steam has a temperature of at least 212°, it may be used to heat the feed water to a high enough temperature to deposit most of the carbonates. Such a feed-water heater should have enough storage capacity to allow the water to remain in it some time, as the carbonates settle slowly.

Calcium carbonate and magnesium carbonate form a porous deposit which does not adhere closely to the metal; therefore, they are not particularly troublesome in themselves, but often there is some other substance present which mixes with the deposit and cements it into a hard scale. Magnesium carbonate sometimes breaks up, forming magnesium hydrate, which is a very active cement. This is usually present in sufficient quantities to bind the carbonates into a scale, even though there is an absence of other cementing substances. If there are no cementing substances present, the carbonates form a scale which is not difficult to remove.

**213. The Sulphates.**—Calcium sulphate and magnesium sulphate are the most troublesome impurities, as they form an exceedingly hard scale which is difficult to remove. The sulphates remain in solution until a temperature of about 300° is reached, when they become insoluble and settle. Since they remain soluble up to a high temperature they cannot be removed from the feed water as easily before entering the boiler as can the carbonates. The sulphates possess very active cementing qualities, and not only form a very hard scale themselves, but become mixed with mud and other sediment, cementing it also into a very dense, hard scale. Calcium and magnesium sulphate may be removed from the feed water in a *closed* heater, which is supplied with steam at a gage pressure of about 55 or 60 lb. per sq. in. as steam at this pressure has a temperature of about

300° F. They may also be removed from the feed water by heating in an open feed-water heater before entering the boiler and then adding certain chemicals which change the nature of the sulphates. The best and cheapest chemical for this purpose is carbonate of soda which is also known by the names of soda ash, soda crystals, sal soda, washing soda, Scotch soda, concentrated crystal soda, crystal carbonate of soda, black ash, and alkali. At temperatures above 200° F., carbonate of soda or soda ash acts on the sulphate of calcium and magnesium, and also sodium sulphate. The carbonates thus formed become insoluble and deposit at this temperature, as explained above. The sodium sulphate thus formed remains in solution and passes into the boiler where it gradually accumulates in the water till it can hold no more, when it is deposited. Before it begins to deposit, however, the boiler may be blown down and refilled with fresh water. The Hartford Steam Boiler Inspection and Insurance Company states that with an average water, such as that of Lake Michigan, requiring 1 lb. of soda ash per 10-hour day for a 75-h.p. horizontal return tubular boiler, the boilers should be blown down two gages every 12 hours, and should be emptied and refilled with water not less than once in 3 weeks.

**214. Chlorides.**—Magnesium chloride gives trouble because of its cementing properties. The other chlorides such as calcium, sodium, and potassium give little trouble from incrustation unless allowed to concentrate until the water will hold no more in solution, when they are deposited and increase the bulk of the scale. They may, however, cause foaming, which will be greater as the solution becomes more concentrated. Magnesium chloride is generally supposed to have a corrosive action on the steel plates of the boiler. It is thought that it reacts with the water, under the influence of heat, so that magnesium hydrate and hydrochloric acid are formed, the acid then attacking the metal of the shell and tubes.

**215. Effects of Impurities.**—The effects of various impurities depend on the nature of the substances precipitated or in solution. They will all fall under one of the following four heads:

(1) Precipitation of mud, etc.

(2) Formation of scale.

(3) Formation of scum which causes excessive priming or foaming.

(4) Corrosion of the metal.

**216. Mud.**—As far as possible, mud should be removed from feed water before it enters the boiler. This can be done by filtering the water or passing it into tanks which are large enough to allow the water to remain in them some time, when the mud will collect on the bottom. Such tanks should be cleaned from time to time. If allowed to enter the boiler, provision should be made to catch the mud and blow it off before it has a chance to become baked on the heating surface. If there is any part of the boiler where the circulation is sluggish the mud will settle there, and on some water-tube boilers a mud-collecting chamber is provided. Such a chamber is shown in Fig. 19 at the bottom of the back header of the Babcock and Wilcox water-tube boiler. If the mud is collected and blown off, the only evil effect from it is the loss of heat while blowing off but, if the mud is allowed to bake on the heating surface, it lowers the heat transmitting power of the metal very much and, besides a loss of capacity and efficiency, it may cause the metal to be blistered or burned.

**217. Preventing Scale.**—The formation of scale and the troubles caused by it have already been explained. The feed water should be analyzed and steps taken either to prevent the scale-forming elements from entering the boiler or to cause their deposit within the boiler in a form that will not adhere to the metal but can readily be blown out. If scale has already formed within a boiler, chemicals should be introduced to soften the scale and then it should be removed by washing, if softened sufficiently, or if not, by mechanical means. If the scale is very hard and flinty it indicates that there is a considerable percentage of the sulphates present. The carbonates form a very soft scale.

The amount of scale that will be deposited in a boiler by even good water is surprising. Suppose a 100-h.p. boiler is using water containing only 8 grains of solid matter per gallon. The amount of water used per month will be about $(100 \times 30 \times 12 \times 30) \div 8\frac{1}{3} = 130{,}000$ gal. This amount will deposit about $(130{,}000 \times 8) \div 7000 = 149$ lb. of scale, and if the boilers are operated 24 hours a day there will be about 300 lb. of scale deposited each month.

**218. Foaming and Priming.**—A boiler is said to foam if the steam space is partially filled with unbroken bubbles of steam, and to prime if the steam carries water with it from the boiler.

Foaming is caused by any materials, either dissolved in the water or suspended in it, which retard or interfere with the free escape of steam from the water in the boiler. A collection of scum on the surface of the water is also a common cause of foaming. Scum may be caused by oil, vegetable matter, or sewage which collects on the surface of the water, forming a coating which is hard for the steam bubbles to break when they rise to the surface. If the water contains an alkali, and any animal or vegetable oil becomes mixed with it, the alkali will change the oil into soap, which forms suds and causes foaming. In many power plants the exhaust from engines or pumps is condensed, collected into hot wells, and fed back into the boilers. If the cylinders are lubricated with animal or vegetable oil, there is danger of it getting into the boiler and causing foaming. For this reason, only a mineral oil should be used in the cylinder but, even with this, great care should be taken to prevent its entering the boiler, as it is a frequent cause of burned plates. Oil extractors placed in the exhaust pipe are very efficient in removing oil. Open feed-water heaters are usually provided with oil extractors, and feed water taken from such heaters is almost entirely free from oil.

Foaming may also be caused by the concentration of certain salts in the water. If an impure water is fed into a boiler, the salts will be left behind when the water is evaporated. The continued evaporation of such water soon causes the boiler to contain so much mineral matter that it can no longer remain dissolved in the water but is precipitated in the form of a fine powder, and the presence of these small particles of salts may cause foaming and priming. Alkalies, especially, cause foaming. Sodium sulphate also has this effect and this salt is produced as a by-product when calcium is precipitated with soda ash or sodium carbonate. If the water contains considerable quantities of carbonate of lime and no treatment is given it before it enters the boiler, this lime may be precipitated in the boiler itself, since it deposits at boiling temperatures, due to the release of carbonic acid gas which holds it in solution. When released, this carbonate of lime is in a very finely divided state and may cause foaming and priming.

Concentration of salts in a boiler may be prevented by frequently blowing the boiler down and refilling with purer water. There is sometimes a prejudice against blowing boilers down, on account of the heat which is wasted in the hot water. Considering the fact that economy of coal is more dependent upon a good heat exchange from the burning coal to the water in the boiler than upon any other factor, and that the heat exchange is very much reduced in efficiency by any sediment in the boiler, it will be seen that an occasional blowing down is an economy, as well as preventing, in a large degree, foaming and priming.

Foaming has been found to occur in some cases where a boiler was coated with scale and was afterward fed with a very pure water. This action may be explained by the fact that pure water will sometimes dissolve the scale, leaving the metal of the boiler bare in places. Such bare spots transfer heat much faster than surrounding parts covered with scale, hence there is very violent boiling over the bare spots which may result in foaming or priming.

Chemical treatment of feed water does not necessarily create priming conditions, for if the boilers have sufficient capacity and are properly handled it is possible to feed large quantities of chemicals into them without trouble. At the same time, certain types of vertical boilers are especially liable to prime on account of their small disengagement surface. Priming is, in general, caused by the following conditions, all of which should be looked after:

Overloading,
The way in which the engine is operated,
Presence of oil,
Method of controlling boiler feed pumps,
Location of feed-water inlet,
Method of firing under forced draft,
Failure to blow down regularly and sufficiently,
Failure to clean the boilers regularly,
Type of boiler,
Water level.

**219. Corrosion.**—Corrosion is most often caused by the presence of a free acid in the feed water. The free acid may result from the supply of water being contaminated, from adulterants in the cylinder oil which find their way into the boiler, or from the splitting up of certain salts in the water.

Water coming from a mine or passing through a vein of ore containing sulphur may become charged with sulphuric acid which will attack the metal in the boiler. Certain acids of vegetable origin may find their way into the feed water if the supply passes through a marsh or bog which contains decaying vegetable matter. Even well water which is supposed to be pure may contain acid from either of the sources mentioned above. Some grades of cylinder oil contain adulterants which form fatty acids capable of attacking metal. Sea water contains magnesium chloride and this salt is readily decomposed, forming hydrochloric acid. A similar effect is also produced in some waters contaminated with sewage.

All water contains more or less air, which is liberated when the water is heated and which attacks metal surfaces. Air absorbed in water is more active in attacking metal than free air. This is probably due to the fact that more oxygen than nitrogen is absorbed by the water and this extra quantity of oxygen attacks the metal more rapidly than a like quantity of free air. As air is driven out of solution at a lower temperature than that required to form steam under the ordinary pressures, the corrosion from this cause will be greatest in those parts of the boiler where the circulation is sluggish.

The ordinary ingredients of scale, carbonate and sulphate of lime, have little or no direct corrosive action unless the scale becomes too thick and causes overheating. In fact a slight coating of these salts acts as a protection and, in some cases when the water fed into the boiler is exceptionally pure, the interior of the boiler may be lime washed at cleaning time with advantage.

In most cases the corrosive effect of water containing acids can be diminished by neutralizing the acid with an alkali such as caustic soda or soda ash, but care must be exercised in using alkali because, when the water contains any alkali, any copper surfaces with which it comes in contact will be rapidly corroded if the circulation is poor, since the alkali will dissolve the copper as fast as it oxidizes, thus keeping a fresh surface exposed to the action of the oxygen.

Another frequent cause of pitting and corrosion is a galvanic action which goes on in some boilers. This may be stopped by placing pieces of zinc in various parts of the boiler. The zinc will be eaten instead of the steel and, therefore, will need replacing frequently.

**220. Treatment of Feed Waters.**—In case the feed water is known to contain impurities, a sample of it should be submitted to a chemist who makes a specialty of analyzing feed water, for analysis and prescription for the remedy to be applied. This course should also be followed in the case of a new plant. When the location for a new plant is to be chosen, particular care should be taken to secure a sufficient supply of good water.

The term "good" as applied to feed water is only relative, but the following designations are generally used, based on the number of grains of incrusting substance in each gallon of the feed water:

| | |
|---|---|
| Less than 8 gr. per gallon | Very good. |
| From 8 to 12 gr. per gallon | Good. |
| From 12 to 15 gr. per gallon | Fair. |
| From 15 to 20 gr. per gallon | Poor. |
| From 20 to 30 gr. per gallon | Bad. |
| More than 30 gr. per gallon | Very bad. |

This table applies to calcium carbonate, magnesium carbonate, and the chlorides. For water containing sulphate of calcium or magnesium in large percentages of the total impurities, divide the number of grains by 4 for the same rating.

Water containing as much as 20 to 30 gr. of incrusting materials to the gallon should never be used unless the water is first purified.

Very often the trouble with impure feed waters may be lessened considerably by intelligent action on the part of those in charge of the boilers.

There are three courses of procedure open, viz.:

(1) To neutralize the acids and remove the solids before the water is allowed to enter the boiler.

(2) To treat the water with chemicals after it has entered the boiler, with a view of lessening or preventing the formation of scale.

(3) To evaporate the water and remove, at regular intervals, the deposits which form within the boiler.

Unless the water is very good the first course is the best.

Free acids should always be neutralized before the water enters the boiler, as it can be done easier outside than inside the boiler. This may best be done by adding carbonate of soda to the water, but no more should be used than is absolutely necessary because, as noted above, it will cause foaming if used to excess. Water that is suspected of containing acid may be tested by dipping a piece of blue litmus paper in it; if acid is present the paper will turn red. If there are scale-forming impurities present with the acid, a sample of the water should be submitted to a chemist and the proper treatment determined.

After the water enters the boiler it may be treated by the addition of certain substances which will cause the impurities to be deposited in a less objectionable form than if left untreated. When prepared by a competent chemist for the particular water to be treated, these reagents are of great value, but the indiscriminate use of boiler compounds or "cure-alls" is not to be recommended.

As indicated before, carbonate of calcium and carbonate of magnesium may be precipitated by the application of heat to the feed water before it enters the boiler. They may also be precipitated by the addition to the water of caustic lime, $Ca(OH)_2$, which reduces them to a practically insoluble carbonate. Sodium hydroxide, or caustic soda, NaOH, accomplishes the same purpose.

The sulphates of calcium and magnesium may be converted into carbonates by the addition to the feed water of soda-ash, $Na_2CO_3$. After being converted into carbonates or chlorides they are harmless and require only an occasional blowing off in order to prevent too great an accumulation.

If the continued use of impure water has allowed a scale to form, some form of solvent must be used to loosen it. This should be done by feeding in a small portion of the solvent gradually rather then a large quantity at long intervals. The introduction of 30 lb. of soda-ash once a month would probably cause violent foaming for a few minutes, but if only 1 lb. a day is used no harmful effects will be noticed. The proper way to introduce the solvent is to attach to the feed-pump suction an apparatus to feed it, just as cylinder oil is fed to an engine. There are a number of such devices on the market or one can easily be made.

For convenience of reference, the different impurities to be found in feed water and the remedies to be applied are collected in the following table:

| Troublesome substance | Trouble | Remedy |
|---|---|---|
| Sediment, mud, clay, etc. | Incrustation | Filtration, blowing off. |
| Readily soluble salts | Incrustation | Blowing off. |
| Bicarbonates of lime, magnesium and iron. | Incrustation | Heating feed. Addition of caustic soda or lime. |
| Sulphate of lime | Incrustation | Addition of carbonate of soda, or barium chloride. |
| Chloride and sulphate of magnesium. | Incrustation and corrosion. | Addition of carbonate of soda. |
| Carbonate of soda in large quantities. | Priming | Addition of barium chloride. |
| Acid | Corrosion | Alkali. |
| Dissolved carbonic acid and oxygen. | Corrosion | Heating feed water. Addition of caustic soda or slacked lime. |
| Grease (from condensed water). | Foaming | Slacked lime and filtering. Carbonate of soda. Substitute mineral oil. |
| Organic matter (sewage) | Priming | Precipitate with alum, or ferric chloride, and filter. |
| Organic matter | Corrosion | Precipitate with alum, or ferric chloride, and filter. |

**221. Boiler Cleaning.**—Even though some method of feed-water treatment is used, a boiler will need cleaning from time to time, as it is almost impossible to prevent some of the scale-forming material from entering the boiler. Some of the methods of feed-water treatment noted above provide for feeding certain chemicals into the boiler for the purpose of changing the nature of the deposit from a hard to a soft scale. Other methods remove the subtsances which form the softer scale before the water is fed into the boiler, leaving the materials which form hard scale to be deposited inside the boiler. While these methods may reduce somewhat the amount of scale, they cannot entirely prevent its formation, hence the necessity for cleaning the boiler occasionally. At the same time that scale is collecting on one side of a tube, soot is collecting on the other side, and it is necessary therefore to clean both the inside and the outside of a boiler, since both soot and scale interfere with the passage of heat and lower the efficiency of the boiler.

The scale deposited in boilers varies all the way from a soft porous scale, that can be removed easily, to a hard, dense scale which is difficult to cut even with a cold chisel. Fortunately, the carbonates, which are the most common feed-water impurities, deposit a rather soft scale, while the less common sulphates form a very hard scale which is difficult to remove.

While the removal of hard scale is sometimes a very tedious job, it should never be slighted, and before leaving a tube the one in charge of the cleaning should make sure it is thoroughly cleaned.

The method of cleaning the boiler will vary somewhat, depending upon the kind of scale to be dealt with and also the type of boiler. In general, however, the boiler can be cleaned better and in less time by the use of mechanical cleaners, which may be passed through the tube, than by the use of hand operated scrapers, which were used to a considerable extent some years ago.

There are two distinct kinds of mechanical cleaners, those which hammer upon the inside of the tube and break the scale by the vibrations in the tube, and those which remove the scale by means of rotary cutters, the former being best adapted to cleaning fire-tube boilers and the latter to cleaning water-tube boilers.

Mechanical cleaners are operated by means of water, compressed air, or steam. Those operated by water are better for cleaning the inside of tubes in a water-tube boiler, as the waste water from the cleaner serves to wash the scale out of the tube as it is removed. Compressed air cleaners are suitable for removing soot from the inside of the tubes of fire-tube boilers where the soot has become so hard that it cannot be removed by scraping. In this case the air exhausted from the cleaner will blow the particles of soot out of the tube as fast as they are loosened, whereas water would cause them to gum and stick to the tubes, where they would be baked when the boiler is used again. Steam may also be used to operate cleaners in fire-tube boilers if the boiler is hot, but it should not be used if the tubes are cold, as it condenses and causes the soot to gum and stick to the tubes.

A hammer type of mechanical tube cleaner, with which either air or steam may be used, is shown in Fig. 165. The stem or air pipe is connected to the coupling *A*, and the steam or air admitted to the valve chamber *B*, where the valve *C* distributes it through the ports *D* and *E* to first one side and then the other of the piston *L*, giving it a backward and forward motion across the body of the cleaner. The stem *G* of the hammer passes through the piston and is pivoted at *H*. The end of the stem rests in a recess of the valve and serves to move the valve across the ports *D* and *E*. While the steam or air is being admitted to one side of the piston it is being exhausted from the other side, passing through the port to the inside of the valve and leaving the cleaner through the opening *M*. In operation, the cleaner is inserted in the end of the tube to be cleaned; the steam or air is then turned on, causing the piston to move back and forth, carrying with it the hammer *J* which strikes the tube a hard blow first on one side and then on the other. As the hammer strikes from 3000 to 4000 blows per minute, vibrations are set up in the boiler tube which loosen the scale, and break it into small pieces. The speed of the hammer is regulated by admitting a greater or less quantity of steam or air.

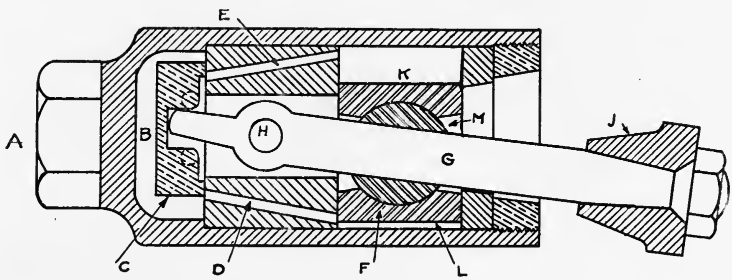



Fig. 165.—Hammer type of tube cleaner.

These cleaners are made in several sizes to suit the common sizes of boiler tubes, the barrel of the cleaner being slightly smaller than the inside of the tube. Since the hammer moves in a straight line across the tube, it is necessary to keep turning the cleaner in order to remove the scale from all parts of the tube. As the cleaner loosens the scale by vibrating the tube, it is best to have the inside of the tube clean before the cleaner is inserted, in order that the hammer may strike directly on the metal instead of on a layer of soot which would lessen the force of the blow. As an objection to the hammer type of cleaner it is claimed that they eventually distort the tube and cause it to crystallize and weaken.

A common form of rotary tube cleaner, especially adapted for cutting the scale from the inside of tubes of a water-tube boiler, is shown in Fig. 166. This type of cleaner is known as a hydraulic turbine cleaner because it is run by a small water turbine located in the casing. The cleaner is made in different sizes to suit the different sizes of boiler tubes, the casing being a little smaller than the inside of the tube. In operation, water is led into the rear end of the casing through a flexible hose. From the chamber located in the end of the casing the water passes through a number of guide channels in the casing *A*, which direct it into the curved passages in the turbine runner *B*. This causes the cutter head, which is fastened to the runner, to revolve at a high speed. After passing through the turbine, the water is discharged from the front end of the cleaner and serves to wash the loosened scale from the tube. The cutter head consists of a main body which revolves about the central axis *F*, and of three arms *M* which carry the cutters and which are pivoted by the pins *O*. When the cutter head revolves, the arms *M* are thrown outward by centrifugal force, causing the

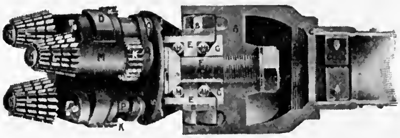


FIG. 166.—Turbine tube cleaner.

cutters to press against the scale and cut it away. Each cutter arm is provided with two cutters, the front ones being tapered, and the rear ones straight. Different styles of cutters for various kinds of scale are supplied with each cleaner.

In preparing to clean boilers, the first thing to do is to cut the boiler out of service. The fires should then be drawn and the ash pit and firing doors closed tightly to prevent the entrance of cold air, which would injure the boiler by cooling it too quickly and would cause the surface of the fire-brick lining to spall, or split off. The stack damper may be left open to carry away the small amount of air that leaks into the furnace. The boiler should then be left in this condition to cool slowly, requiring from 12 to 24 hours. The slower the boiler is allowed to cool the less danger will there be of injuring it. If for any reason the boiler must be cooled more quickly, it can best be done by allowing the water to leak slowly through the bottom blow-off, at the same time pumping in cold water fast enough to keep the water level at the same height. This will cool the water in the boiler gradually and uniformly and is not likely to injure the boiler from unequal contraction.

As soon as the boiler has cooled enough to permit it, the ashes and soot should be blown from the tubes. To keep the fire side of the heating surfaces clean is of equal importance with keeping the water side clean. Soot is a poor heat conductor and if allowed to accumulate on tubes will greatly reduce their power to transmit heat. In no case should the layer of soot be allowed to exceed 1/16 in. in thickness. In the case of a water-tube boiler, the cleaning can best be done by means of a steam nozzle inserted through openings in the side walls. This operation should not be delayed until the boiler is cold, as the steam will then be condensed on the tubes, and wet the soot and ashes, causing them to adhere more closely than ever. In the case of a fire-tube boiler the soot and ashes may be removed from the tubes by passing a scraper, made especially for this purpose, back and forth through them. To prevent chilling the tubes, the fire and ash pit doors should be kept closed while the soot is being removed. After the boiler is cooled, the water may all be drained out and the inside washed with cold water. Before starting to remove a manhole or handhole cover, care should always be taken to see that there is no pressure in the boiler and that there is no vacuum in it. This may be done by opening the top gage cock. Many serious accidents have happened from neglect of this precaution.

In using an hydraulic tube cleaner, the largest size of turbine that will pass through the tube should be used. The turbine is inserted in the tube, the operator having a firm grasp on the hose connection 6 or 8 in. from the end of the tube that is being cleaned. The water is then turned on and the cutters begin revolving at a rapid rate, cutting the scale. The operator should then immediately begin to move the cleaner up and down or forward and backward in the tube and this should continue as long as there is any scale in the tube. As the scale is removed, the water from the turbine washes it through the tubes, where it can be collected and removed. The cleaner should be pushed forward as the scale is removed, but this should not be done too fast, as the cleaner will jam and its speed and cutting power be reduced. The operator should learn to judge from the sound what kind of surface the cleaner is working on. After a mechanical cleaner has been used it should be washed off and stored away in a pail of oil to prevent it from rusting.

Certain kinds of scale will bake very hard on the tubes and their removal is extremely difficult. In such cases it is often best to soften the scale before attempting to remove it with a cleaner. This may be done by introducing from 40 to 80 lb. of carbonate of soda (ordinary soda-ash), depending upon the size of the boiler. The safety valves should then be blocked open so no pressure can accumulate and the water should be heated until it begins to simmer. In bad cases, this boiling should be continued for several days. The scale will then be softened so that it may be easily cut. The boiler must be thoroughly washed out after using the soda-ash, or excessive foaming will result.

Kerosene is also often used to soften scale. The best way to introduce kerosene is to fill the boiler almost full of water, and then pour a gallon or two of kerosene on top of it. As the kerosene is lighter than the water it will stay on top. By opening the blow-off, the water in the boiler will gradually sink and a film of oil will be spread over all the inside surfaces. The kerosene will attack the scale and loosen it, after which it may be readily removed. Kerosene for this purpose should be entirely free of acid and it should always be tested by inserting blue litmus paper. If the paper turns red there is acid present and the kerosene should not be used. Before entering a boiler after kerosene has been used, it should be thoroughly ventilated, as very explosive gases are given off by the evaporation of the kerosene.

If cylinder oil should get into a boiler, it may be removed by placing soda-ash in it and raising about 15 lb. steam pressure. Occasionally some of the water should be drawn off and fresh water added. Under no circumstances should a boiler be run if there is oil in it, as oil on the heating surface is much worse than scale.

## CHAPTER XVIII

### FEED-WATER HEATERS

**222. Feed-water Heating.**—The office of a boiler is to evaporate water and the heat supplied to it should be used only for this purpose. If, in addition to evaporating the water, the boiler is also called upon to heat the feed water to the boiling-point from some lower temperature, the capacity of the boiler will be reduced unless it contains enough additional heating surface to supply heat to the feed water. In other words, the higher the temperature of the feed water, the greater will be the capacity of a boiler which contains a given amount of heating surface. If some device is supplied for heating the feed water outside the boiler, it is equivalent to increasing its capacity, but the gain in capacity is secured at a lower cost, because a feed-water heater of given capacity can be bought cheaper than enough boiler heating surface to secure the same result.

With hot feed water there will also be less wear on the boiler from strains due to unequal expansion and contraction resulting when cold feed water is discharged in one part of the boiler while other parts are hot. If heat which would otherwise be wasted is used for heating the feed water before it enters the boiler, there will be a clear gain in efficiency, in addition to the advantages mentioned above. The gain in heat, from heating the feed water with waste heat, will amount to about 1 per cent for every 10° F. which the water is heated and this gain in heat will be shown by a reduction of an equal per cent in the amount of coal used. While the purpose of a feed-water heater is primarily to heat the feed water, in many cases it also serves to purify it by causing certain impurities to be deposited, as noted in the preceding chapter.

**223. Methods of Heating Feed Water.**—The methods commonly employed for heating feed water are (1) by means of the waste furnace gases, (2) by means of exhaust steam, (3) by means of live steam.

**224. Economizers.**—The heat in the waste furnace gases may be utilized for heating feed water by the use of an economizer, which has been previously described. The heating surface in an economizer practically forms another boiler, working within lower limits of temperature, and is thus able to use heat which would be of no further use in the main boiler. The saving effected by an economizer depends upon its being entirely separate from the boiler and on its using heat that would otherwise be wasted. An economizer heats the feed water entirely within itself by means of heat which cannot be used in the boiler, and then discharges the hot water into the boiler to be evaporated.

Economizers are built in sizes ranging from 32 to about 800 tubes, the section being 4, 6, 8, 10, or 12 tubes wide and varying in depth by 4 tubes. Each tube contains about 12.5 sq. ft. of heating surface and has a volume of approximately 1 cu. ft. and, therefore, will hold about 62 lb. of water. In order to give satisfactory efficiency, the economizer for a boiler plant should have sufficient capacity to supply one hour's feed. Thus a boiler plant which uses 30,000 lb. of water per hour would require an economizer containing about $\frac{30000}{62}=480$ tubes, approximately. Another approximate rule for obtaining the proper size of economizer for a given boiler plant is to install 6 sq. ft. of economizer heating surface for each boiler horsepower. On an average, the feed water will be heated by an economizer about 1/2° for each degree difference in temperature of the flue gases entering and leaving the economizer. Thus, if the flue gases leaving the boiler and entering the economizer have a temperature of 500° F. and the waste gases leaving the economizer have a temperature of 200° F., the feed water will be increased in temperature about one-half of the difference, or $(500-200) \div 2 = 150°$. The feed water should not be supplied to an economizer at a lower temperature than about 90° F., as the tubes will be chilled to such an extent that moisture will condense on them and make it difficult to remove the soot. If the supply of water can be obtained only at a lower temperature than 90°, some means should be provided for heating it before it enters the economizer.

**225. Exhaust Steam Heaters.**—The exhaust from engines and feed pumps is extensively used for heating feed water. The feed water may be heated entirely by exhaust steam, or the exhaust steam heater may be used in connection with an economizer, in which case the feed water is heated as much as possible in the exhaust heater and is then passed through an economizer, in which its temperature is raised further.

It has been shown in the preceding chapter that heating the feed water serves to purify it of certain impurities, but the principal function of an exhaust feed-water heater is to utilize heat which would otherwise be wasted. This saving will amount to about 1 per cent for every 10° that the feed water is heated. More exactly, the per cent of saving from heating the feed water by exhausted steam may be calculated by the formula

$$G = 100 \frac{(t_1 - t_0)}{H - (t_0 - 32)}$$

in which

$G$ = the per cent of gain or saving
$H$ = the total number of heat units above 32° in 1 lb. of exhaust steam
$t_0$ = the temperature of the feed water before being heated
$t_1$ = the temperature of the feed water after being heated by the exhaust steam.

**Example:** What would be the per cent of saving from heating feed water which has a temperature of 40° F. by means of exhaust steam having a pressure of 16 lb. per sq. in. absolute, the final temperature of the feed water being 205° F.?

*Solution:* The total heat of 1 lb. of steam at 16 lb. pressure is 1148 B.t.u.

$$G = 100 \frac{(205 - 40)}{1148 - (40 - 32)} = 100 \times \frac{165}{1140} = 14.47 \text{ per cent}$$

It must be understood that this formula gives only the saving of heat and does not take into account the first cost of the heater nor its cost of operation. These, however, are small compared with the benefits derived, so there will usually be a considerable net saving. Besides the direct saving of heat noted above, an additional advantage is gained by feeding hot water to a boiler, in that the strains from unequal expansion and contraction will not be so great.

Exhaust steam feed-water heaters may be classified according to construction as: (1) *open heaters,* in which the water and steam mingle in the same chamber and the steam gives up its heat by condensation; (2) *closed heaters,* in which the water and steam are in separate chambers or pipes and the steam gives up its heat by conduction. Open heaters may also be classified according to the method of connecting them to the exhaust piping as: (1) *induced heaters,* in which only enough steam to heat the feed water passes into the heater, the remainder going through a by-pass; (2) *through heaters,* in which all of the exhaust passes into the heater, that which is not condensed in heating the feed being allowed to pass out of the heater again. Closed heaters are nearly always connected as through heaters.

**226. Open Heaters.**—A common form of exhaust steam open heater is illustrated in Fig. 167. This heater, which is known as the Cochrane heater, consists of a cast-iron case into the top of which is fitted a series of trays over which the feed water trickles, and at the bottom of which there is storage space for the hot feed water, and filtering material for catching any impurities which may be thrown out of the water by heating it. The steam enters through the exhaust inlet at the side, where it strikes a baffle which catches most of the oil carried by the exhaust steam and drains it into the oil reservoir located at the side and near the bottom. The oil reservoir is provided with a float valve which automatically empties it when the oil and water reach a certain height. The exhaust steam then passes around the baffle and enters the heater just below the series of pans, where it rises to the outlet, mingling with and heating the feed water trickling from the pans. As the water is heated, certain impurities are deposited, part collecting on the pans and part falling to the bottom of the heater, wheie they are filtered from the water before it enters the boiler. The pans may be removed for cleaning.

The water in the storage space is maintained at a constant level by means of a float valve attached to the cold water supply and by means of an overflow which empties into the oil reservoir. Any oil that may pass the oil separator will collect on top of the water in the storage space and will be skimmed off through the overflow and be discharged into the oil reservoir. Fresh water enters through a pipe near the top and is discharged into the pans. If the heater is connected to a heating system, as is often done, the condensation from the radiators is returned directly to the pans and only enough fresh water is added to keep the water in the storage space at a constant level.

Fig. 168 shows an open heater of the type just described, connected as a through heater and supplying a heating system with exhaust steam. The exhaust from the main engine enters the heater directly, while the exhaust from the feed pump is connected

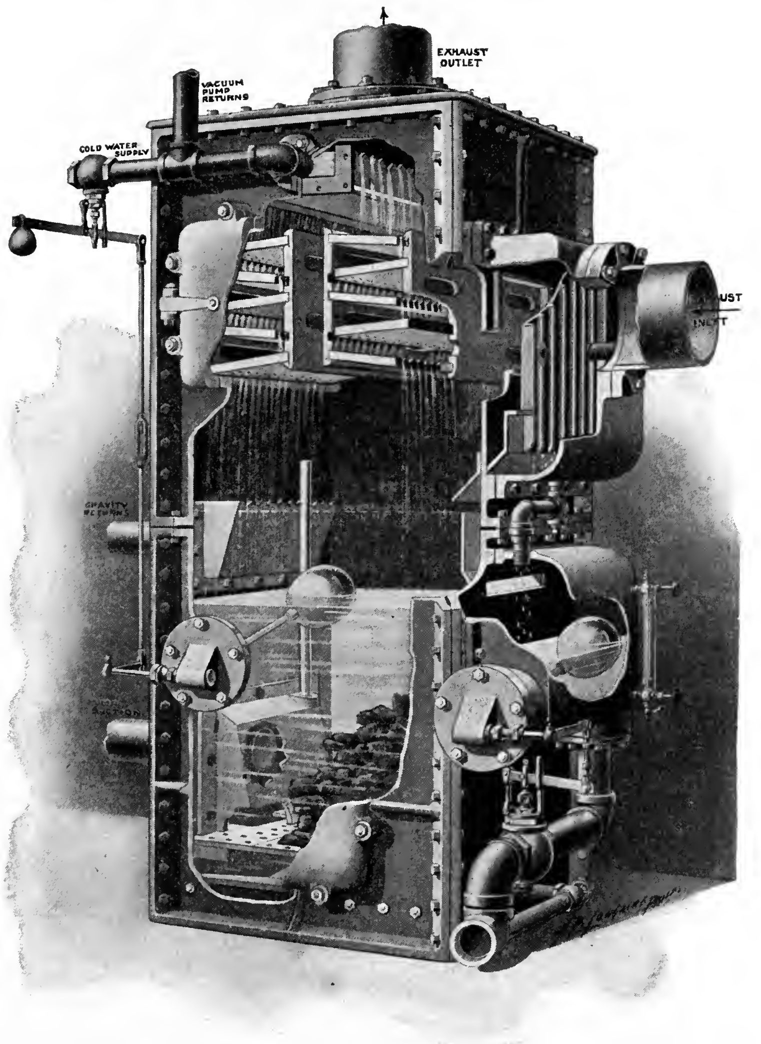



Fig. 167.—Open feed-water heater and purifier.

into the exhaust from the main engine and is thus also utilized in heating. Whatever steam is needed for heating the feed water is condensed in the heater, falls into the storage space with the feed water, and is thus returned to the boiler. The remainder of the exhaust steam passes into the heating system through the main exhaust pipe, which also extends oustide the

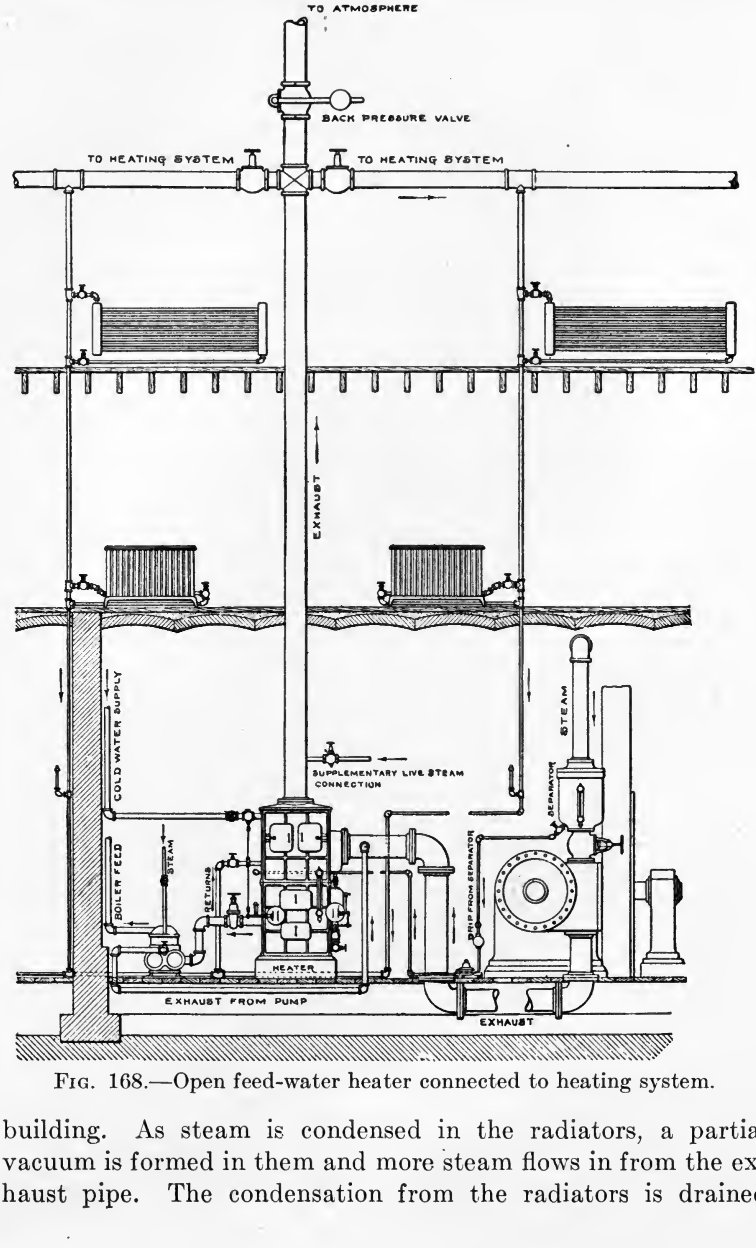



FIG. 168.—Open feed-water heater connected to heating system.

building. As steam is condensed in the radiators, a partial vacuum is formed in them and more steam flows in from the exhaust pipe. The condensation from the radiators is drained back to the heater, where it is heated by the exhaust steam and is again fed into the boiler. If there is more exhaust steam than is needed to heat the feed water and the building, the remainder passes to the atmosphere through a back pressure valve which is held closed by a weight and by the pressure of the atmosphere as long as the pressure in the heating system is less than a fixed amount, but which opens automatically as soon as the pressure rises above that amount. In case there would not be enough exhaust steam to heat the building at all times, a

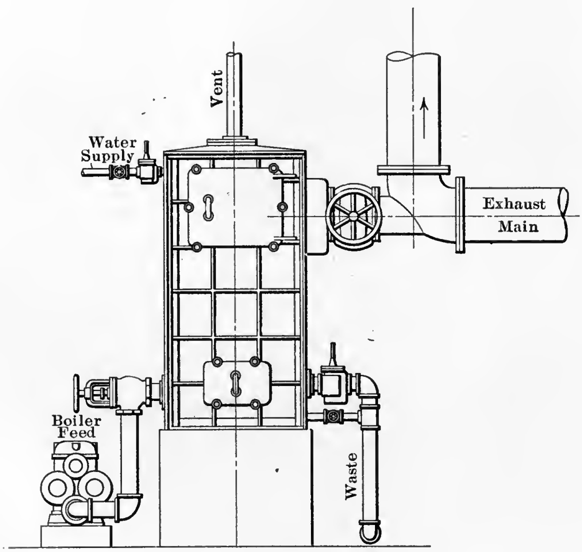



Fig. 169.—Open induced heater.

supplementary live steam connection is made between the boiler and the exhaust pipe after it leaves the heater, in order to supply more steam to the heating system when needed. The heating system does not necessarily form a part of the exhaust system as shown. If no heating system is connected, the exhaust pipe from the heater passes directly to the atmosphere.

Fig. 169 illustrates the method of connecting an open induced heater, in which only enough steam to heat the feed water enters the heater, the remainder passing directly to the heating system or to the atmosphere. In connecting a heater in this manner, it is necessary to provide a vent pipe at the top of the heater to prevent it from becoming air-bound. The principal advantage in connecting a heater in this manner is that the heater may be cut out of service for cleaning or repairs without shutting down the plant.

Fig. 170 shows the Pittsburg heater, which is the same in principle as those already shown but which differs somewhat in construction. This heater has circular pans and shell, the feed water is sprayed on the pans from above, trickles over their edges and falls in finely divided particles to the storage space below. The exhaust steam rises through the falling water,

Fig. 170.—Pittsburgh feed-water heater.

which it heats. The pans are cleaned through a door in the side of the heater, and it is not necessary to remove them for this purpose as they are pivoted to a central stem, about which they may be revolved, thus making all parts of them readily accessible. These heaters are provided with an oil separator on the outside of the shell, and with a skimmer inside for removing oil from the surface of the water. These heaters may be connected either as through or as induced heaters.

Another common form of open feed water heater which may be connected either as a through or an induced heater is shown in Fig. 171. This Hoppes heater, as it is called, consists of a cylindrical shell placed horizontally, and fitted with a series of trough-shaped pans placed one above another. In the larger size of heaters these pans are made in sections for ease of handling. The feed water enters the top pan, filling it and overflowing the edges and through openings in the center, while the steam circulates among the pans, heating the feed water as it drops from one pan to another. As the water overflows from the pans it flows in a thin sheet along the bottom of the pans

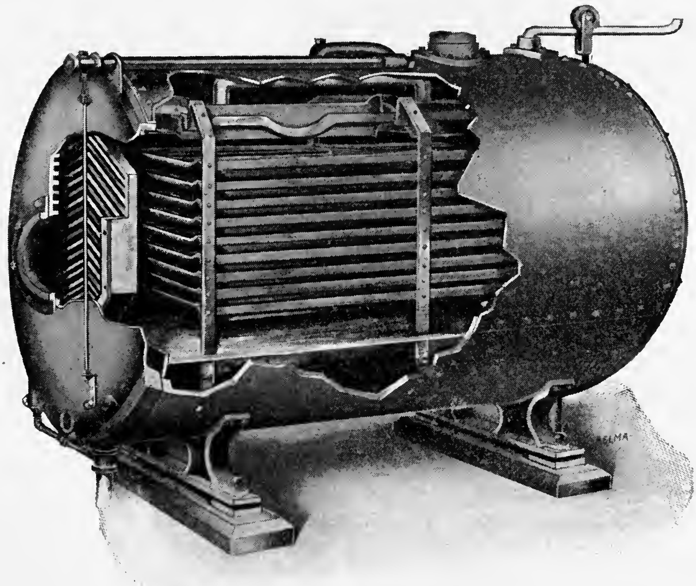


Fig. 171.—Hoppes feed-water heater.

until the lowest point is reached, when it drops to the pan beneath. The scale-forming material that is removed by the heat collects both inside the pans and on the bottoms. The head of the heater is bolted on and may be removed, thus allowing access to the pans, which may be readily removed for cleaning. When used with exhaust steam these heaters are fitted with a baffle plate oil separator placed inside the shell and in front of the exhaust steam inlet. A skimming device is also supplied with these heaters for removing any oil that may collect on the surface of the water inside the heater.

**227. Temperature of Feed Water.**—If there is sufficient steam, the feed water in an open heater may be heated to a temperature within 3° or 4° of that of the steam. Thus with steam supplied at atmospheric pressure, the temperature of the water leaving an open-feed water heater may be as high as 209° F. The amount of steam condensed in heating the feed water will depend both upon the pressure of the steam in the heater and upon the temperature of the entering feed water.
This amount may be calculated by the following formula

$$S=\frac{W\times(t-t_o)}{.9\times(H-t+32°)}$$

In which $S$ = weight of steam condensed in heating the feed water
$W$ = weight of feed water to be heated
$t$ = temperature of feed water leaving heater
$t_o$ = temperature of feed water entering heater
$H$ = total heat of 1 lb. of steam at the pressure existing inside the heater.

This formula allows for a loss by radiation and leakage of 10 per cent of the heat.

**Example:** A power plant consists of 500 h.p. of engines using 24 lb. of steam per horse-power per hour, and pumps which use 15 per cent as much steam as the engines. The exhaust from both engines and pumps, having a pressure of 16 lb. absolute, is turned into the heater. How much exhaust steam will be condensed in heating the feed water if the water entering the heater has a temperature of 110° F. and is heated to 212° F.?

*Solution:* $W = 500\times24\times1.15 = 13800$ lb. of feed water to be heated per hour
$H = 1147.9$ from steam tables
$t = 212°$
$t_o = 110°$

$$S=\frac{13800\times(212-110)}{.9\times(1147.9-212+32)}=1616 \text{ lb.}$$

As this only is $\frac{1616}{13800}=11.7$ per cent of the exhaust steam, the remaining 88.3 per cent or 12,185 lb. per hour could be used in a heating system, or wasted into the atmosphere.

**228. Closed Heaters.**—Closed heaters may be classified as (1) steam-tube, in which the steam flows through the tubes while the water circulates on the outside, and (2) water-tube, in which the water flows inside the tubes while the steam is on the outside.

**229. Steam Tube Heaters.**—The steam-tube class of heaters is illustrated by the Otis feed water heater shown in Fig. 172 This heater consists of a vertical cylindrical shell fitted with two sets of seamless drawn brass steam tubes. The exhaust steam

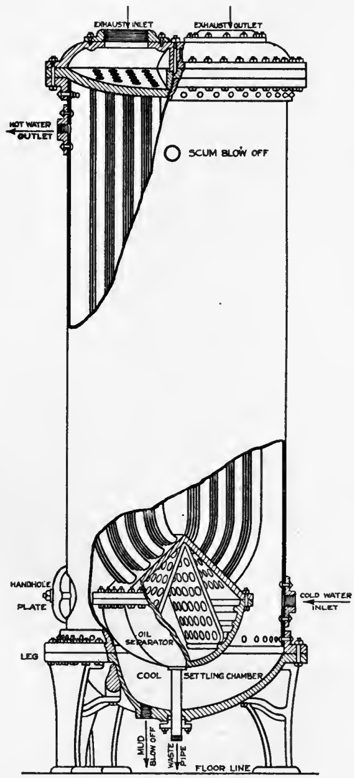



Fig. 172.—Otis feed-water heater.

enters at the top and passes down the first set of tubes to the chamber at the bottom. It then rises through the other set of tubes to the outlet, thus passing the length of the heater twice. The chamber at the bottom is for the purpose of catching the oil and water, which may be drained from the heater by means of the waste pipe. The tubes are curved to take up the expansion. The feed water enters near the bottom of the shell, circulates around the steam tubes, and leaves near the top.

Another type of steam-tube feed water heater is shown in Fig. 173, which represents a Baragwanath steam jacketed heater. This heater consists of two vertical cylindrical drums, placed one within the other, the inner one being fitted with a series of straight tubes which pass from one end of it to the other. Exhaust

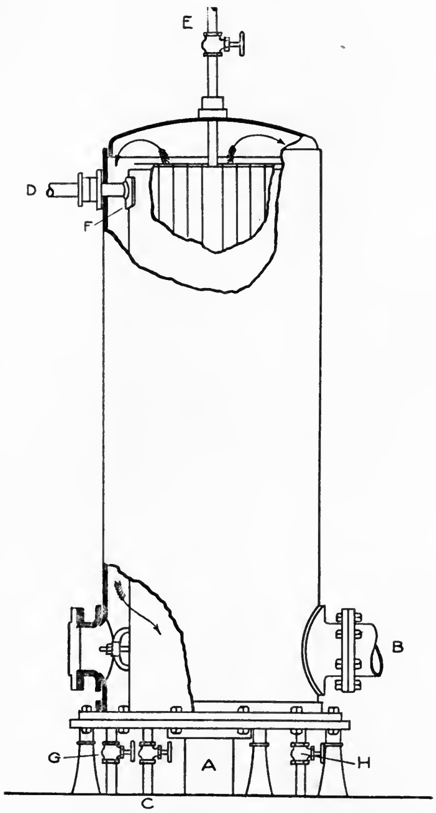



FIG. 173.—Baragwanath steam jacketed heater.

steam enters at the bottom through *A*, passes up through the set of tubes to the top, and then to the bottom again through the annular space between the two drums. The feed water enters the inner drum through *C*, filling the space around the steam tube, and leaves near the top at *D*. *E* is a scum blow-off for the inner drum, *G* is the bottom drain for the inner drum, and *H* a drain for the jacket or space between the two drums. Since steam circulates through the tubes and around the inner drum, they will be at approximately the same temperature and there will be very little unequal expansion between them; hence there is no necessity for allowing for expansion in the tubes.

Steam-tube heaters that are to be used with exhaust steam should have an oil separator connected in the exhaust pipe between the engine and heater, in order to remove the oil before it reaches the tubes. Oil collecting on the inner surface of the tubes greatly reduces their power to conduct heat, and hence lowers the efficiency of the heater. A serious objection to the use of steam-tube heaters with water containing lime, is the difficulty of removing the deposit of lime which collects on the outside of the tubes and which has the effect of reducing their power to conduct heat.

**230. Water-tube Heaters.**—Water-tube heaters are made in a variety of forms, having straight tubes or coils. Fig. 174 represents the Goubert straight tube heater. It consists of a vertical cylindrical shell fitted with a series of brass tubes. The tubes are held in steel headers and, being shorter than the shell, a compartment is left at each end of the heater. These compartments are divided by a number of partitions which divide the tubes into sets and thus cause the water to circulate through them several times. The feed water enters at the bottom, flowing upward through the first set of tubes, downward through the second, and so on till the outlet at the top is reached. Exhaust steam enters the shell near the bottom, fills the entire space around the tubes, and leaves near the top. A drain is provided for each compartment and also for the steam space. Since the shell is in contact with steam while the tubes are in contact with both steam and water, the shell will expand more than the tubes. This unequal expansion is taken up by a flexible connection between the top tube plate and the shell, the bottom tube plate being fastened rigidly to the shell, thus forcing all the movement to take place at the top connection.

Fig. 175 illustrates the National water-tube heater, in which the tubes are bent into coils. The coils are made of copper pipe and their ends are brazed to gun metal manifolds. Exhaust steam enters the heater at the bottom of the casing, surrounds the tubes, and leaves at the top.

The efficiency of water-tube heaters is also greatly reduced if oil is allowed to collect on the tubes, and for this reason it is


Fig. 174.—Goubert feed-water heater.

necessary to place an oil separator in the exhaust pipe leading to them, if exhaust steam is used to heat the water. The greatest objection to these heaters is the difficulty of removing scale from them, if used with impure feed water.

Any of the closed heaters described here may be connected into the exhaust of either a condensing or noncondensing engine, but if the engine exhausts into a partial vacuum, care must be taken that the heater is air-tight between the steam and water sides, as there is danger of the vacuum being destroyed by the leakage of air.

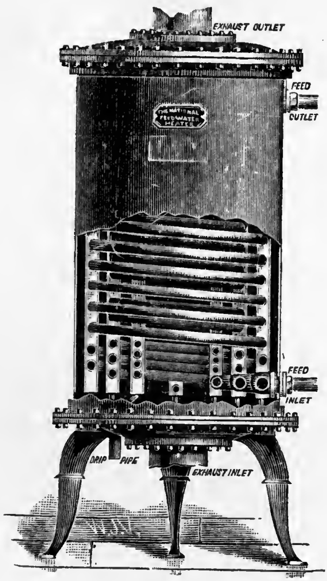



FIG. 175.—National feed-water heater.

**231. Live Steam Heaters.**—There is no gain in economy from heating the feed water with live steam, because the heat is taken from the boiler, put in the feed water, and returned directly to the boiler. In fact, there will actually be a loss of heat by radiation in such a process. For this reason, live steam feed-water heaters are installed only when the water can be purified by heating it to a high temperature. Besides purifying the feed water, certain indirect advantages are derived from heating the feed water with live steam, consisting in preventing stresses due to cold feed water being fed to the boiler, and increased capacity by feeding hot water.

Any of the closed feed-water heaters previously described could be used with live steam if built strong enough to withstand the pressure, and if provided with a safety valve and an air vent, but with the water-tube type there would be a serious difficulty in removing the scale. The open heater shown in Fig. 171 is often constructed and used as a live steam heater and purifier. When so constructed, it is provided with a safety valve to relieve the pressure if it should become too high and the shell and heads are made of steel plates. An air vent is also necessary, as the feed water will contain some air which will be released in the heater and would cause it to become air-bound unless relieved. When used with live steam, the action of this heater is the same as with exhaust steam, except that the water is heated to a higher temperature. No provision need be made for oil separation, as the steam is taken directly from the boiler.

An open live steam heater should be installed so its lowest part is 2 or 3 ft. above the water line in the boiler, in order that the water may run into the boiler by the force of gravity. The feed pipe leading to the boiler should be taken from the bottom of the heater and should run straight down below the water line of the boiler before any branches are taken off. It should be provided with a check valve to prevent water from flowing in the wrong direction, and also stop valves and a by-pass so the heater may be cut out of the feed system for cleaning, and water pumped directly into the boiler.

An economical arrangement is to provide two of these heaters, one connected to the exhaust from the pump and heating the feed water with exhaust steam, the pump taking its supply of water from this heater and pumping it into the second heater, which is supplied with live steam from the boiler. By doing this, the live steam heater will remove only the harder scale-forming materials from the water and it will not require cleaning so often. In addition to this, the heat in the exhaust from the pump will be utilized and a supply of hot water will be available when the live steam heater is cut out for cleaning.

# CHAPTER XIX

## INSPECTION AND CARE OF BOILERS

**232. Defects in Boilers.**—A study of defects in boilers as revealed by inspection and examination after explosion is both interesting and instructive. It shows what defects are most likely to occur and, therefore, informs the fireman what details need particular attention in his care of the boiler; it also informs the inspector where defects will most likely be found and, therefore, what things should receive closest attention. The following table, showing a summary of results of boiler inspections made by the Hartford Steam Boiler Inspection and Insurance Company during the year 1907, is instructive, as it shows the number of boilers in which various defects were found and also the number and per cent that were in a dangerous condition.

SUMMARY OF REPORT OF INSPECTIONS FOR 1907, HARTFORD STEAM BOILER INSPECTION AND INSURANCE CO.

| | Number found defective | Per cent of total number | In dangerous condition | Percentage of dangerous to defective |
|---|---|---|---|---|
| Cases of deposit of sediment | 18,917 | 11.88 | 1,315 | 6.95 |
| Cases of incrustation and scale | 38,427 | 24.01 | 1,333 | 3.47 |
| Cases of internal grooving | 3,010 | 1.89 | 258 | 8.57 |
| Cases of internal corrosion | 12,802 | 8.04 | 528 | 4.13 |
| Cases of external corrosion | 10,230 | 7.04 | 768 | 7.53 |
| Defective braces and stays | 2,219 | 1.39 | 578 | 26.10 |
| Defective settings | 6,363 | 3.99 | 699 | 11.00 |
| Furnaces out of shape | 7,564 | 4.74 | 396 | 5.17 |
| Fractured plates | 3,551 | 2.23 | 568 | 16.00 |
| Burned plates | 4,878 | 3.06 | 499 | 10.22 |
| Laminated plates | 898 | .56 | 92 | 10.23 |
| Cases of defective riveting | 3,582 | 2.25 | 823 | 23.00 |
| Defective heads | 1,764 | 1.11 | 238 | 13.49 |
| Leakage around tubes | 11,357 | 7.14 | 1,599 | 14.09 |
| Cases of defective tubes | 8,266 | 5.18 | 3,054 | 37.00 |
| Tubes too light | 1,947 | 1.22 | 563 | 28.93 |
| Leakage at joints | 5,557 | 3.49 | 430 | 7.74 |
| Water gages defective | 3,008 | 1.89 | 707 | 23.46 |
| Blow-offs defective | 4,216 | 2.67 | 1,250 | 29.63 |
| Cases of deficiency of water | 413 | .25 | 156 | 37.78 |
| Safety valves overloaded | 1,231 | .77 | 415 | 33.70 |
| Safety valves defective | 1,211 | .76 | 407 | 33.60 |
| Pressure gages defective | 7,651 | 4.8 | 465 | 6.08 |
| Without pressure gages | 194 | .12 | 194 | 100.00 |
| Unclassified defects | 27 | .02 | 10 | 37.04 |
| Total | 159,283 | | 17,345 | |

The defects noted in this table may be roughly divided into three classes as: (1) those due to the feed water, (2) those due to the mechanical features and management, and (3) those due to defective boiler fittings. Of the defects shown in this table, about 53 per cent were due to the feed water and external corrosion, while the mechanical features and management were the cause of about 41 per cent and the defective fittings caused only about 6 per cent. Of those found defective from the feed water only a comparatively small percentage were in a dangerous condition, showing that the troubles arising from impure feed water are well known and that precautions are generally taken to clean the boilers when impure water is used. Of those boilers which were defective from mechanical causes, a large percentage were in a dangerous condition, which shows that such defects are more likely to be overlooked by the firemen, perhaps because they are more apt to be hidden and not give warning of their existence. A very large percentage of the boilers found defective due to the condition of the fittings, were in a dangerous condition, which points to the fact that these small parts of a boiler plant should receive very careful attention from the fireman.

Most of the defects resulting from the use of impure feed water have been considered in another chapter and the means of preventing them indicated. However, grooving occurs under such a variety of conditions that a consideration of it has been left until this time.

**233. Grooving.**—Internal corrosion and grooving are often found together. Corrosion is sometimes aggravated by slight local movements which take place in certain parts of the boiler and which are caused by changes in pressure or temperature. These slight movements loosen particles of rust as fast as they are formed, thus exposing a fresh surface for the formation of more rust and the corrosion from this cause is increased. If the corrosion thus produced is confined to a particular spot instead of being spread over an extended surface it produces grooving. Grooves and cracks may also be started by the movements above noted taking place, often weakening the metal or "fatiguing" it, as it is called, until the metal is finally split.

Grooving is most likely to occur in corners in such locations as where the head of a boiler joins the cylindrical part of the shell. In such cases it is often due to the movement of the head from changes in pressure and temperature, while the shell is stationary. An example of this kind of grooving is shown in Fig. 176. Cases of grooving like this may be prevented by bracing the head to prevent any movement between it and the shell. It most often occurs below the water line, but is sometimes found above the water line when the steam space is small

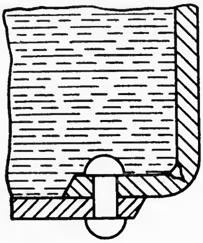


Fig. 176,

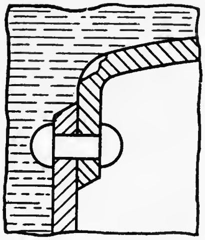


Fig. 177.

and the surfaces above the water line apt to be wetted by the boiler's priming. Sometimes grooving is found at the rounded corners of locomotive type boilers where the crown sheet is bent over to meet the side sheets, as shown in Fig. 177. In some cases, also, grooving occurs at the bottom of the water leg in this type of boiler, especially if the bottom of the water leg is fitted with a solid mud ring. An example of this is shown in Fig. 178.

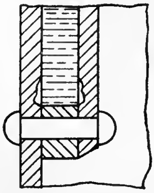


Fig. 178.

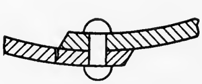


Fig. 179.

Grooving is often found along the side seams of boilers which have lap joints running the length of the boiler, as shown in Fig. 179. This is more often found in boilers of small diameter, such as small vertical boilers, and is due to the bending which occurs in a lapped seam when under pressure. These grooves are never found where double strapped butt joints are used for longitudinal seams.

**234. Patches.**—Many of the defects due to mechanical features of a boiler arise from repairs and may be largely avoided if the repairing is carefully done. Patches are one of the most fruitful causes of trouble and often lead to serious results. Patches are often required where plates have been burned or corroded from the use of impure feed water. When it is necessary to apply a patch, the defective part should be cut away and not simply covered by the patch, as is often done. Such a repair may be justified in some cases when it is only temporary, but it should never be used permanently because it arouses a false sense of security. Patches should always be applied to the inside of a boiler shell if below the water line, because, if placed outside, a

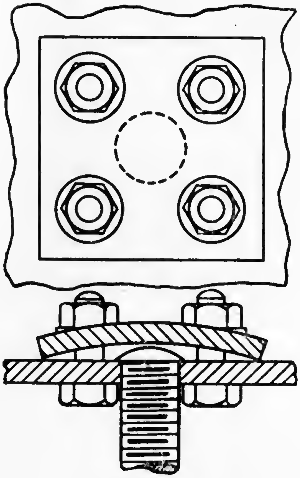


Fig. 180.

small pocket of a depth equal to the thickness of the plate is formed inside and soon fills with sediment, which causes the patch to become burned.

Fig. 180 shows a defective method of stopping leakage from a screwed stud stay, by the application of a "cupped" patch. Such a patch cannot add strength to the stay while it may conceal serious weakness and usually involves more trouble to apply than would a sound repair. This repair should have been made by cutting out the defective plate, placing a sound patch over the portion cut away, and boring and tapping a hole in the patch for the stay to be screwed into. If the thread on the stay is defective, then a new stay should be inserted. When patches are applied, care should be exercised to make the rivet holes in the patch come in line with those in the plate. If they are not in line and need adjustment, a reamer, and not a taper drift pin, should be used. Joining together a thin and thick plate should be avoided, especially if the joint is exposed to the fire. A joint of this kind will be quickly burned.

**235. Lap Fractures.**—Lap fractures are particularly liable to occur in externally fired boilers in the parts exposed to the fire, and are usually caused by using a drift pin too freely. The fractures may extend from the rivet holes to the edge of the plate, in which case they are not particularly dangerous, unless too numerous, and then the cracked part of the plate should be cut out and replaced by a patch. Sometimes these cracks extend into the body of the plate and are apt to grow longer. They may

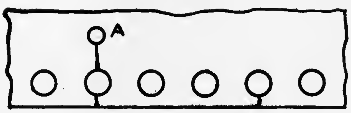



Fig. 181.

be stopped by drilling a hole at the end of the crack and inserting a stop rivet as shown at *A* in Fig. 181. Lap fractures are also apt to occur along the seam and they may grow from one rivet hole to another until they produce a seam rip. These are more dangerous than those extending to the edge of the plate, and should receive attention as soon as discovered.

**236. Screwed Stay Repairs.**—The ends of screwed stays are liable to corrosion and often need repairing. The repair should

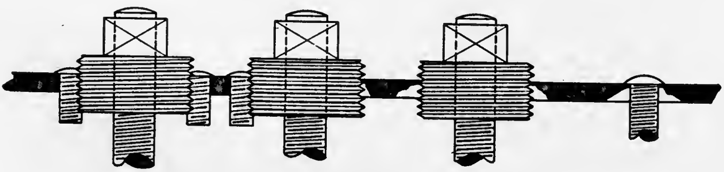


Fig. 182.

be made by replacing the stays with new ones if the threads are corroded. If the plate is corroded, the hole should be bored larger and a new stay of larger size used. The enlargement of stay holes, however, can easily be carried too far, as shown by Fig. 182. This shows where adjoining stay holes were enlarged in order to cut away the corroded plate, and enlarged stay ends were used. After being used a while, the stays again began to leak, and the leaks were stopped by inserting smaller screwed pins at the edges of the stays. So much of the metal between the stays was removed in this way that they finally gave way under the pressure in the boiler.

**237. Hammer Test.**—Many of the mechanical defects mentioned above may be detected by the sound of a hammer blow struck on the defective part. With a little practice of the ear in the sound made by a hammer blow, this test becomes very useful in locating defects. It aids in the inspection of places which are too inaccessible to be inspected, and forms a ready means of discovering broken or cracked stays and bolts, and loose or slack rivets or tubes.

**238. Hydraulic Test.**—The hydraulic test is applied to boilers to determine their strength without running the risk of an explosion, as would be the case if the pressure was applied with steam or air. As water can be compressed only slightly, a boiler which gives way under water pressure simply lets the water run out without producing an explosion. This kind of test is practically always applied to new boilers and is usually one of the conditions upon which they are bought. The hydraulic test is used with old boilers to determine if they are suited for the pressure they are to carry and also to determine their tightness and the tightness of patches and other repair work.

The pressure usually placed upon a boiler during an hydraulic test is 50 per cent more than the pressure which the boiler is to carry. Thus, if a boiler is to carry a pressure of 100 lb. per sq. in. it would be placed under an hydraulic pressure of 150 lb. per sq. in. during the test.

In order to perform an hydraulic test on a boiler, it is entirely filled with cold water and a small hand pump attached to some fitting in order to place the water under pressure. While the boiler is being filled, some part of it near the top should be opened in order to let the air out, as this would collect on top of the water and be compressed. If a boiler should give way while it contains compressed air, there is apt to be an explosion from the energy stored in the compressed air. As the water used in filling the boiler will contain a little air, a few extra strokes of the pump will be necessary after the boiler is filled, in order to put it under pressure. Warm water should not be used in filling the boiler as small leaks are difficult to detect with it, owing to the evaporation of the water as fast as it passes through the leak. It is usual to maintain the hydraulic pressure for about half an hour after being applied, and to give the boiler a careful examination ior leaks and bulges during this time.

**239. Defective Fittings.**—Fittings may be defective in a great many ways, but space permits of only a few being mentioned here.

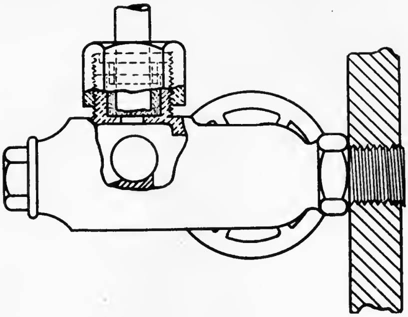


Fig. 183.

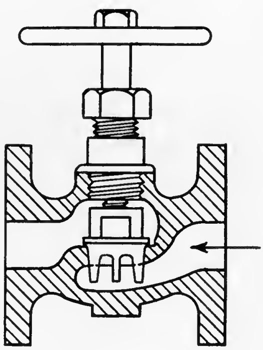


Fig. 184.

The fittings most commonly found defective are gage glasses, blow-off valves, safety valves, and steam gages. Trouble is often experienced with a gage glass from the stoppage of the passages leading from the boiler to the glass, causing the gage to indicate a false water line. Stoppage of these passages may be due to deposits of mud or sediment from impure feed water, or to the lack of a recess for the glass tube packing as shown in Fig. 183, whereby the packing may be squeezed under the end of the tube when the follower nut is screwed down.

The most common defect with blow-off valves is leakage of water past the valve, which may quickly result in a dangerous condition of low water. Only the best types of valve should be used on the blow-off, and the use of two of them is an advantage. Each time the boiler is emptied, the blow-off valves should be taken apart and examined for defects. When a globe valve is used in the blow-off, it sometimes happens that the valve is set with the wrong end toward the boiler, which allows sediment to collect under it until it becomes choked, as illustrated in Fig. 184. This valve should be set so the boiler pressure will act on top of the disc.

Safety valves are a fruitful source of trouble and require careful watching to keep them in good condition. The stems of lever safety valves are apt to stick or become rusted where they pass through the casing or, if there is packing at this point, the follower nut may be screwed down too tightly, causing the packing to grip the stem and thus hold the valve. Spring safety valves are less liable to defects, but sometimes the stems of these become rusted or, if of the outside spring type, the springs may be screwed down too tightly.

Steam gages often read wrong after being in use awhile, due to wear or slipping of the mechanism, and for this reason they should be tested from time to time and the pointer reset to indicate correctly. Injury sometimes results from the use of a defective steam gage by opening the boiler too soon, there being pressure in the boiler even though the pointer stands at zero. Before a boiler is opened, the safety valve should always be lifted if the boiler has been under pressure a short while before.

**240. Care of Boilers.**—While no two boilers are exactly alike, each having a sort of individuality of its own, and requiring a little different treatment than others, yet there are certain general rules regarding the care of boilers which apply in all cases. By observing these rules, the safety, economy, and life of the boiler may be greatly increased, and the plant kept in better condition and handled with more ease than will be the case if the rules are not regarded. Most of these rules are to be found in the Engineer's Manual issued by the Fidelity and Casualty Insurance Company.

**241. Safety Valves.**—These valves should be of ample size and kept in working order. The valves should be tried daily; this is best done by allowing the pressure to rise gradually until the valves just "simmer," noting the pressure by the steam gage at the moment. Freedom of action may, of course, be ascertained by hand, but it cannot be known by this means that the valve will blow off when the proper pressure is attained. Neglect and overloading of this most important adjunct are prolific causes of boiler explosions. Each boiler should have its own safety valve and no stop valve should be permitted between it and the boiler.

**242. Pressure Gage.**—It is absolutely necessary that the pressure gage should be trustworthy and if there is any reason to question its readings, it should be compared with one known to be accurate. The gage should be fitted to a "loop" filled with water, which transmits the pressure and prevents contact of steam with the gage spring. Attach the gage directly to the boiler and not to a steam pipe, to prevent fluctuations of pressure readings.

**243. Water Level.**—Before starting, make sure that there is plenty of water in the boiler by trying the gage cocks. While running, do not depend on the gage glass but try the gage cocks often. The water line should be kept at a regular height, and should never be less than 3 or 4 in. above the fire line, or above the top row of tubes in a return fire-tube boiler. The gage glass should be blown out frequently to see that it is not choked. It is an excellent plan to try the gage cocks every 15 minutes. Both the gage glass and cocks must be kept clean.

**244. Dampers.**—Do not close the damper entirely while there is fire on the grates, as gas may collect in the tubes and cause a serious explosion. Make liberal use of the damper in regulating the generation of steam. Remember that steam going out of the safety valve means money lost.

**245. Feed Pump or Injector.**—These should be kept in order and should be of ample size for all requirements. The feed pump, however, ought not to be so large as to render it difficult to feed the boiler continuously at a slow rate of speed. It is always safer to have two means of feeding. An injector should be used when no feed water heater is provided, as it prevents the contraction of tubes and plates where the feed water comes in contact with them.

**246. Low Water.**—The blow-out apparatus should be kept tight, as any leakage here may cause low water, with the result of overheating the plates. In case of low water, fresh coal, or, better still, wet ashes, must be thrown on the fire at once. Do not turn on the feed (though, if already in motion, allow it to continue), or start or stop the engine, or lift the safety valve, until the boiler has cooled down. After a case of low water, the tube ends in the upper rows should be examined for leaks.

**247. Incrustation and Corrosion.**—Boilers should be kept free from scale, as its presence increases the liability of burning or cracking the plates and may lead to explosions. The surest method of preventing internal corrosion is to abandon the use of the water which causes it, but if this is impracticable the water should be treated and a sharp lookout should be kept for defects. Leaks at seams and fittings, drippings from pipes, exposure to the weather, contact of the boiler with brick-work, etc., are causes of external corrosion and should be remedied at once.

**248. Galvanic Action.**—Sometimes boilers may be protected by means of zinc from the action of corrosive agents present in the water. As a rule 1 sq. ft. of surface of zinc to every 50 sq. ft. of heating surface in the boiler is sufficient. The plates should be placed in perfect metallic contact with the iron and renewed as they are wasted.

**249. Blisters, Cracks, and Burnt Plates.**—When these occur they should receive attention at once. Burnt places and blisters should be cut out and a patch put on the inside of the boiler to avoid making a pocket for the collection of sediment. Bags should be repaired immediately. If not down too far and the metal is sound, they can sometimes be driven back; otherwise it will be necessary to cut them out and patch.

**250. Fusible Plugs.**—These are required by law in some states. To keep them in efficient condition their surfaces, both on the fire and water sides, must be often scraped clean, but notwithstanding all precautions, they are unreliable.

**251. Covering.**—Radiation from the dome and the top of the boiler is a source of waste. A covering of asbestos or other suitable non-conducting material should be provided as a protection.

**252. Green Walls.**—Firing a boiler with green walls will invariably crack the setting, hence, it is absolutely necessary to dry out the brick work properly. If circumstances permit, it is advisable as soon as stack connections are made, to block open the ash pit doors and the damper so that circulation of air will aid in drying the brick work. The next step is to fill the boiler with water and put in a light fire of shavings, which may gradually be increased by using some wood, continuing until the walls are thoroughly dried inside and out. This will require several days, but by close observation, the walls, if carefully built, can be dried out without cracking.

When steam is available, an excellent method of drying the brick work is to connect, temporarily, a small steam supply pipe to the new boiler, and to attach a trap or other drainage apparatus to the blow-off pipe. The new boiler, when filled with steam, will act as a radiator and will heat the air around it; hence, if ash-pit doors and damper be left open, there will be a steady current of warm air passing through the setting and the brickwork will be gradually and effectively dried. The steam supply should be very small at first and be increased as the drying-out proceeds.

**253. Cutting Boiler into Steam Main.**—Under no circumstances whatever should a boiler be "cut-in" with other boilers unless the pressure within it is identical with that in the main. Before opening the boiler stop valve or header valve, be sure that there is no water in the length of pipe between these two valves. Steam valves should always be opened or closed very slowly and the valves should first be eased from their seats slightly for some moments to permit a circulation to become established before valves are fully opened.

**254. Starting the Engine.**—Engines should be started slowly in order not to make a violent change in the condition of the water and steam in the boiler and, when possible, the engine should be stopped gradually. The sudden opening of a large stop-valve may produce a violent rush of steam and water against that part of the boiler whence the steam is drawn, the percussion of which may be sufficient to rupture the boiler.

**255. Firing.**—The fire should be kept level and of somewhat greater thickness at the bridge wall. This promotes a uniform consumption of fuel, as the air passes more freely through the fire near the bridge wall and the greater thickness retards its passage. Fuel supplied regularly in small quantities, combined with an even distribution, produces the best results. When anthracite coal is used, the average thickness of the fire should be 6 to 8 in.; with bituminous coal it should be 8 to 10 in.; with coke 10 to 12 in. If the draft is poor, however, a thin fire must be used. Do not fire with large lumps. No fragment should be larger than a man's fist.

Complete combustion is attained only when the fuel is burning with a bright flame all over the grate. Blue flames, dark spots, and smoke are evidences of the lack of the necessary air which ought to be supplied above the grate. Fires should be "cleaned" no oftener than necessary. In using a caking coal it is advantageous to make use of a "coking fire"; *i.e.*, firing in front, breaking up with a slice bar, and shoving back when coked. The practice of wetting coal before throwing it on the fire is a bad one, as it wastes heat and promotes corrosion.

**256. Banking Fires.**—Contraction and expansion, caused by change of temperature, shorten the life of a boiler. For this reason it is better to bank the fires at night instead of drawing them.

**257. Rapid Firing.**—Steam should be raised slowly in a boiler having thick plates or seams exposed to the fire, else overheating or burning will result. The greatest effect of the fire on a boiler bottom takes place immediately behind the bridge wall, and, if a seam is located at this point, there is liability of burning the lap. It is best in such cases to change the position of the bridge, so the seam comes over the bridge, or better still, over the furnace.

**258. Feeding.**—Wear and tear of a boiler, arising from unequal expansion and contraction, is increased by allowing the feed water to enter at too low a temperature. If the use of cold water is unavoidable, the feed pipe should always be extended well into the interior of the boiler and should enter horizontally through the front head near one side, and a few inches below the water line. By this means the feed water is heated nearly to the temperature of the water in the boiler, and is discharged at the coolest part of the boiler. The use of an injector or feed-water heater renders this extension of the feed pipe unnecessary.

**259. Foaming.**—In case of foaming, close the throttle and open the fire doors for a few minutes, when the water will usually settle and its height may be determined. The trouble, if caused by dirty water, can easily be overcome by feeding and blowing. Where there is a surface blow it can be used to good advantage.

**260. Blowing Out.**—The bottom blow-off cock should be kept tight to prevent loss by leakage. A plug cock is the simplest, surest, and most durable valve for this purpose. When the feed water is of a hard or muddy nature the boiler should be blown out frequently. A boiler should never be emptied while the brickwork is hot, as this will bake the sediment on the plates and make its removal difficult. A boiler should be emptied every week or two, and filled afresh. The blow-off valve should be opened wide for a moment each day. This will aid in keeping boiler and blow-off pipe clear. Never open the blow-off valve or cock with a jerk, as it is liable to let go and cause a serious accident. Do not blow off under pressure when intending to clean boilers, as the heat of the boiler and brickwork will bake the mud and scale on the shell and tubes, making it extremely difficult to remove. The proper manner to use a surface blow-off is to open it for about fifteen seconds every hour rather than for a longer time at greater intervals.

**261. Feed Water Heating.**—Heating the feed water, either by means of exhaust steam or the waste gases in the chimney, adds to the economy of a steam plant. Each increase in the temperature of the feed water of 10° F. means a saving of fuel of 1 per cent. No saving in fuel is effected by the use of an injector, but the employment of one promotes the longevity of a boiler by introducing the feed water at a temperature so high that no injurious contractions are caused in any part of the boiler.

**262. Cleaning.**—The heating surfaces of a boiler, both inside and out, should be kept clean, in order to prevent a serious waste of fuel. The thickness of the soot or scale which is allowed to accumulate ought never to exceed 1/16 in. After allowing the boiler and brickwork to cool, the boiler should then be drained and thoroughly cleaned and washed out both from the top and bottom.

**263. Leaks in Brickwork.**—Cracks or openings in the brickwork should be carefully stopped. The admission of air, except at the places provided for it, impairs the draft, cools the gases on their way to the tubes, and sometimes causes jets of flame to impinge so strongly on the shell as to injure the plates.

**264. Moisture.**—The exterior of a boiler should be protected from moisture, as it brings about corrosion and consequent weakening of the boiler.

**265. Disuse of Boilers.**—If a boiler remains idle, it will deteriorate much faster than when in use, unless it receives proper attention as soon as its use is discontinued. Hence, the following instructions should be carefully observed. Before emptying the boiler, place in the shell or steam drum several gallons of crude oil so that when the blow-off is opened the oil will form a light covering over the tubes and inside surfaces of the shell. Before the boiler is used again this oil must be removed with soda ash. Dry the boiler thoroughly when emptied. If the boiler cannot be emptied, fill it completely with water to which has been added a quantity of soda-ash, then boil off the air and close the boiler air tight. Clean off all accumulations of ash and soot with a scraper or wire brush and give the exterior of all tube and shell surfaces a coat of boiled linseed oil. Smear all brass or finished work with vaseline slush or a mixture of white lead and tallow. Cover the stack tops with a water-tight hood and see that no water can reach the boiler through breechings, openings in roof, or other sources.

# CHAPTER XX

## BOILER TESTING

**266. Object of Tests.**—Besides the tests described in the preceding chapter for determining the physical condition of a boiler, its strength and ability to carry a certain pressure, other tests are often made to determine its efficiency and power. Such tests are often called "evaporative tests," since the more water a boiler will evaporate the greater will be its power and the efficiency depends upon the amount of water evaporated with a certain amount of fuel.

**267. Methods of Testing Boilers.**—The simplest form of boiler test consists in weighing each day the coal used and the water fed to the boiler. Some boiler plants are provided with weighing apparatus for this purpose and the fireman is able to keep a record of the performance of the boiler. However, such a test as this gives only approximate results as there are many features about the operation of a boiler which vary from day to day and which would change the results if they were taken into account. Some of these variable features are: the load; the quality of the steam produced by the boiler; the heating value of the coal used; the amount of unburned coal dropping through the grates; and the temperature of the feed water.

In order to obtain accurate and full results from a boiler test, and to arrange such results so that one boiler may be compared with another, even though they are located at different places and are operated under entirely different conditions, engineers have agreed upon a standard method of testing, and of computing results, and a standard form for reporting the results of tests.

In order to make a test of this kind, it is necessary to weigh the water fed to the boiler during the time of the test and obtain its temperature, to weigh the coal fired during the test and obtain an average sample of it to be analyzed later, to weigh the ashes and refuse taken out of the ash pit during the test, to read the steam pressure at frequent intervals, and to measure the quality of the steam delivered by the boiler. Other data which it is advisable to take if possible to do so, but which are not necessary for the calculations, are: force of draft in the furnace and between the damper and the boiler; temperature of the gases leaving the boiler, and the analysis of the flue gas.

A boiler test should extend for 24 hours in order to obtain good average results. If it is impossible to do this, the test may last for 12 hours, but should not be conducted for less than 10 hours in any case. If the test is made in less than 10 hours there is apt to be serious error in obtaining the weight of ash and this will affect the computed results to such an extent as to make them of little value.

**268. Observations.**—The two principal quantities to be determined by a boiler test are the number of pounds of water evaporated by the boiler and the number of pounds of fuel necessary to evaporate it. In order to determine these two quantities it is necessary to weigh the feed water fed into the boiler and the coal fed into the furnace. The greatest care should be exercised in taking these weights because any error in them affects directly the results of the test.

**269. Weighing the Coal.**—A good method of handling and weighing the coal is to fill a barrow or car which holds about 500 lb., and weigh both the car and coal on a platform scales placed in front of the furnace. The furnace should be fired directly from the car which should be weighed again after firing. The difference between this and the first weight will be the weight of coal fired. When all the coal in the car has been fired, the car itself is weighed. The time of taking these weights together with the weights themselves are recorded on a sheet of paper ruled especially for this purpose. This sheet of paper containing the date is called the *log*. The reason for arranging the log in this way, is so that any error may be detected, since the sum of the separate charges must be equal to the difference between the sums of the weights of the car when filled and when empty.

**270. Sampling the Coal.**—From each car of coal should be taken a small shovelful to be used as a sample. The sample should be taken before the coal is weighed, and it should be stored away in a cool place until the end of the test. At the end of the test, all the samples taken should be thoroughly mixed and the lumps broken into pieces about the size of pea coal. The sample of coal should then be spread out and divided into quarters. One of the quarters should be retained and again mixed and quartered, and this process should continue until the sample consists of about enough to fill a quart fruit jar. This final sample should then be sealed in an air-tight jar to prevent loss of moisture, and sent to a chemist for proximate analysis and determination of heating value.

**271. Weighing Water.**—The water may be conveniently weighed by means of two tanks as shown in Fig. 185. Two tanks are arranged one above the other, the top one resting on platform

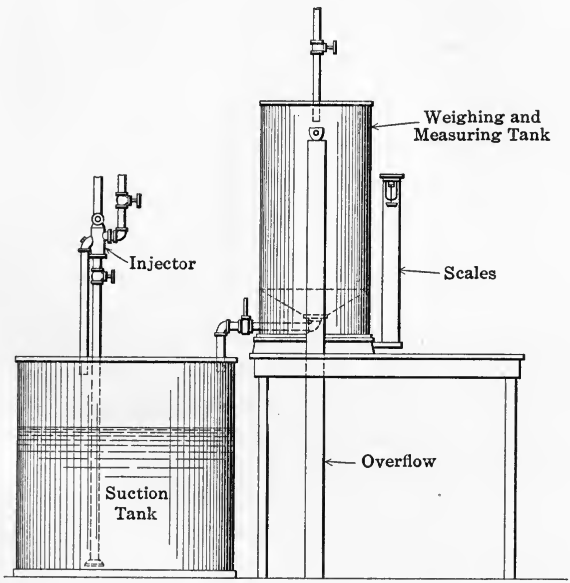



Fig. 185.

scales. The upper tank is used for weighing the water, after which it is allowed to flow into the lower tank and is fed from there directly into the boiler. The supply of feed water is led by a pipe of generous size to a point directly above the upper tank so the tank may be filled quickly. This tank has a conical bottom, so that all the water will run out at each emptying. The discharge pipe, which should be about 3-in. in diameter, is connected to the center of the bottom and is fitted with a quick opening valve or cock so that the tank may be emptied quickly. The upper tank has an overflow so that it may be filled to the same height each time. Instead of an overflow, the tank may be marked at a certain height and filled to this mark each time. If, before the test is started, the upper tank is filled to the mark and the water weighed, filling it to this mark each time serves as a check on the weighing. The bottom tank should be somewhat larger than the upper one. The suction of the feed pump or injector is placed in the lower tank and ends near its bottom. The feed-water temperature may be taken by placing a thermometer in this tank.

In operation, the upper tank is filled and weighed and then emptied into the lower one. While the water is being fed into the boiler from the lower tank the upper one is again filled and weighed. If the amount of water fed into the boiler is very large, two weighing tanks emptying into one lower tank will be an advantage. One of the weighing tanks may then be filled and weighed while the other is emptying.

**272. Ash.**—The time of cleaning fires and the weight of ash removed from the ash pit each time should be recorded, and a sample of the ash preserved for analysis, in order that the amount of unburned coal in it may be determined. The ashes should be kept dry, as any moisture in them would be weighed and make their weight appear greater than it should be.

Although the principal data is that relating to the feed water and coal, the other data should be taken just as carefully, and recorded. The readings of steam pressure, feed-water temperature, and calorimeter temperature and pressure should be taken at the same instant. It is especially important to secure the readings of gage pressure, calorimeter pressure, and calorimeter temperature at the same time.

**273. Starting and Stopping the Test.**—There are two standard methods of starting and stopping a boiler test, called the *standard method* and the *alternate method*. The alternate method is the one more commonly used and is recommended as being convenient and accurate.

**274. Standard Method.**—Steam having been raised to the working pressure, remove rapidly all fire from the grates, close the damper and clean the ash pit, and as quickly as possible start a new fire with weighed wood and coal, noting the time and also the water level in the gage glass while the water is quiet, just before lighting the fire. The height of the water level in the gage glass should be marked so the water may be brought back to the same level at the end of the test. At the end of the test remove the whole fire, which has been burned low, clean the grates and ash pit, and note the water level when the water is quiet, and record the time at which the fire is hauled. The water should be as nearly as possible at the same height as at the beginning of the test. If it is not the same, a correction should be made by adding, to the weight of water pumped into the boiler, an amount sufficient to bring the water back to its original height; this weight also may be calculated.

**275. Alternate Method.**—While the boiler is being operated, the fires are to be burned low and well cleaned. Note the amount of coal left on the grate as nearly as it can be estimated; note the pressure of steam and the water level. This time should be noted as the starting time, immediately fresh coal should be fired, and, if necessary, more water fed into the boiler. The ash pit should be thoroughly cleaned immediately after starting. Before the end of the test the fires should be burned low and cleaned in such manner as to leave the coal on the grates in the same condition and of the same depth as at the start. When this condition is secured, note the time and record it as the stopping time. The water level and steam pressure should previously be brought as nearly as possible to the same point as at the start.

When starting and stopping a boiler test, great care must be exercised in reading the water level, as it is easily affected by the condition of the fire. The water level should be read immediately after cleaning the fire and when the boiling is least violent. If the fire is burning brightly, the water will boil violently and thus raise the water level. Another necessary precaution is to see that the fire contains the same amount of ash at the end as at the beginning of the test. A small error in the weight of the ash makes a large percentage of error, since the total weight of ash is small.

**276. Results.**—The method of calculating results can best be shown by an example. In the example which follows is shown a good form on which to record results. This form is shown filled in with both the data which would be taken during the test and the calculated results, the data being printed in Roman, and the calculated results in **bold face type.** Following the report is found the method of working out the calculated results, the items being numbered to correspond with those in the report.

## Data and Results of Evaporation Test

Made by *J. H. Smith of Milwaukee, Wis.*

Type of boiler *Aultman & Taylor water-tube* (*B. & W. Type*). Located at Milwaukee, Wis.

Purpose of Test *To determine efficiency*
Kind of Fuel *Bituminous*
Kind of Furnace *Roney stoker*

| | | |
|---|---|---|
| 1. Date of test *March* 6, 1912. | | |
| 2. Duration of test | 20 | hours |

### Dimensions

| | | |
|---|---|---|
| 3. Grate surface. Width 10 ft. Length 6 ft. Area | **60** | sq. ft. |
| 4. Water heating surface | 2500 | sq. ft. |
| 5. No. of tubes...... Diameter 4 in. Length.. | | |

### Average Pressures

| | | |
|---|---|---|
| 6. Barometer......28.5 in. of mercury | **14.0** | lb. per sq. in. |
| 7. Steam gage | 95.7 | lb. per sq. in. |
| 8. Absolute steam pressure | **109.7** | lb. per sq. in. |
| 9. In calorimeter | 1.8 | in. of mercury |
| 10. Draft between damper and boiler | 0.37 | in. of water. |

### Average Temperatures

| | | |
|---|---|---|
| 11. Escaping gases | 415 | degrees |
| 12. Feed water entering boiler | 172 | degrees |
| 13. Inside calorimeter | 268 | degrees |

### Fuel

| | | |
|---|---|---|
| 14. Where mined | *Carterville, Ill.* | |
| 15. Size and condition | *Pea*, No. 3 | |
| 16. Fixed carbon | 60 | per cent |
| 17. Volatile matter | 28.22 | per cent |
| 18. Moisture | 4.2 | per cent |
| 19. Ash | 7.58 | per cent |
| 20. B.t.u. per pound of dry coal | 12,300 | B.t.u. |
| 21. B.t.u. per pound of combustible | **13,360** | B.t.u. |
| 22. Weight of coal as fired | 32,200 | lb. |
| 23. Weight of dry coal fired | **30,850** | lb. |
| 24. Weight of ash and refuse | 2870 | lb. |
| 25. Per cent of combustible in ash | **15** | per cent |
| 26. Weight of combustible burned on the grates | **27,980** | lb. |
| 27. Dry coal fired per hour | **1543** | lb. |
| 28. Dry coal fired per square foot of grate surface per hour | **25.7** | lb. |

| | | |
|---|---|---|
| 29. Combustible burned on grates per hour...... | **1399** | lb. |
| 30. Combustible burned on grate per square foot grate surface per hour.................. | **23.3** | lb. |
| 31. $CO_2$...........Per cent of volume......... | 8.0 | |
| 32. $O_2$ ...........Per cent of volume......... | 9.9 | |
| 33. CO ...........Per cent of volume......... | .2 | |
| 34. Total..........Per cent of volume......... | 18.1 | |
| **Quality of Steam** | | |
| 35. Quality of steam.......................... | **98.2** | per cent |
| 36. Superheat.............................. | **0** | degrees |
| **Water** | | |
| 37. Total weight of water fed to boiler.......... | 250,500 | lb. |
| 38. Water actually evaporated, corrected for quality of steam and for moisture......... | **246,700** | lb. |
| 39. Factor of evaporation..................... | **1.082** | |
| 40. Equivalent water evaporated into dry steam from and at 212°....................... | **267,000** | lb. |
| **Water per Hour** | | |
| 41. Water evaporated per hour, corrected for quality of steam....................... | **123,330** | lb. |
| 42. Equivalent evaporation into dry steam per hour from and at 212°.................. | **13,350** | lb. |
| 43. Equivalent evaporation per hour from and at 212° per square foot of heating surface.... | **5.34** | lb. |
| 44. Horse-power developed.................... | **387** | h.p. |
| 45. Builders rated horse-power on basis of 10 sq. ft. per horse-power..................... | **250** | h.p. |
| 46. Percentage of builders' rated horse-power developed............................ | **154.8** | per cent |
| **Economic Results** | | |
| 47. Water apparently evaporated under actual conditions per pound of coal as fired...... | **7.78** | lb. |
| 48. Equivalent evaporation from and at 212° per pound of coal as fired.................. | **8.29** | lb. |
| 49. Equivalent evaporation from and at 212° per pound of dry coal...................... | **8.65** | lb. |
| 50. Equivalent evaporation from and at 212° per pound of combustible.................. | **9.62** | lb. |
| **Efficiency** | | |
| 51. Efficiency of boiler (heat absorbed per pound of combustible burned on the grate divided by the heating value of 1 lb. of combustible)............................. | **69.5** | per cent |
| 52. Efficiency of boiler and grate (heat absorbed per pound of dry coal fired, divided by the heating value of 1 lb. of dry coal)......... | **67.9** | per cent. |

**277. Calculation of Results.**—

*Item* 6.—The barometer pressure in pounds per square inch, which represents the pressure of the atmosphere, equals $28.5 \times .4908 = 14$ lb. per sq. in.

*Item* 8.—The absolute steam pressure is found by adding the atmospheric pressure to the pressure shown by the gage, or $14 + 95.7 = 109.7$ lb. per sq. in.

*Item* 21.—The combustible part of the coal is made up of ail the parts that will burn; therefore, the ash and moisture are excluded. In a pound of dry coal there is less than a pound of combustible matter, therefore the heating value per pound of combustible is greater than the heating value per pound of dry coal. In this case the combustible matter is

$$\frac{60+28.22}{60+28.22+7.58} = \frac{88.22}{95.80}$$

$=92.1$ per cent of the weight of the dry coal. Therefore, the heating value of the combustible is $\frac{12300}{.921} = 13{,}360$ B.t.u. If the heating value of the coal had been given as 11,800 B.t.u. per pound of wet coal or as fired, the per cent of moisture would have been added to the denominator, or combustible matter $= \frac{60+28.22}{60+28.22+7.58+4.2} = 88.22$ per cent of the wet coal, and the heating value of the combustible would be $\frac{11800}{88.22} = 13{,}375$ B.t.u. per pound.

*Item* 23.—If the coal fired had been dry, it would have weighed only $100 - 4.2 = 95.8$ per cent as much as when wet, or when containing 4.2 per cent of moisture. Therefore, the weight of dry coal fired is equal to Item $22 \times \left(\frac{100 - \text{Item } 18}{100}\right) =$ $32{,}200 \times \left(\frac{100-4.2}{100}\right) = 32{,}200 \times .958 = 30850$ lb.

*Item* 25.—In firing a boiler there is always more or less loss of combustible material through the grates in the form of small particles of coal and coke. According to the analysis of the coal, the pure ash alone should weigh $\left(\text{Item } 22 \times \frac{\text{Item } 19}{100}\right)$, or $32{,}200 \times .0758 = 2440$ lb. The ash actually taken from the ash pit weighed 2870 lb. (Item 24); therefore it must have contained, Item 24 − $\left(\text{Item } 22 \times \frac{\text{Item } 19}{100}\right)$, or 2870 − (32,200 × .0758) = 2870 − 2440 = 430 lb. of combustible material, which is $\frac{430}{2870} = 15$ per cent of the refuse in the ash pit.

*Item* 26.—The combustible material burned on the grate is the total amount of dry coal fired, less the amount of ash and combustible material in the ash pit, the weight of dry coal being taken because the ashes are also dry, or Item 23 − Item 24 = 30,850 − 2870 = 27,980 lb. of combustible material actually burned.

*Item* 27.— = Item 23 ÷ Item 2
= 30,850 ÷ 20 = 1543.

*Item* 28.— = Item 27 ÷ Item 3
= 1543 ÷ 60 = 25.7

*Item* 29.— = Item 26 ÷ Item 2
= 27,980 ÷ 20 = 1399.

*Item* 30.— = Item 29 ÷ Item 3
= 1399 ÷ 60 = 23.3.

*Item* 35.—See Chapter VIII for method of calculating quality of steam from throttling calorimeter readings.

*Item* 38.—All of the moisture contained in the steam is still in the form of water and therefore should not be credited with the latent heat which would have been required to evaporate it; the moisture, however, has received enough heat to raise it to the boiling-point. The total amount of heat which is given to the feed water by the boiler is the heat in the dry steam plus the heat in the moisture which the steam contains. The heat contained in the dry steam is found by multiplying the total weight of feed water by the quality or $\text{Item } 37 \times \frac{\text{Item } 35}{100}$ and this quantity by the number of heat units given to 1 lb. of dry steam. The total heat contained in the *moisture* in the steam is found by multiplying the total weight of feed water by the percentage of moisture, stated as a decimal $\left(\frac{100 - \text{Item } 35}{100}\right)$ and multiplying this quantity by the heat added to the feed water inside the boiler, or the heat of the liquid ($h$) minus (Item 12 − 32°).

Thus the number of pounds of dry steam formed is

$$\text{Item } 37 \times \frac{\text{Item } 35}{100} = 250{,}500 \times .982 = 245{,}990 \text{ lb.}$$

The amount of heat given to each pound of dry steam by the boiler is

$$H-(t-32)=1183.9-(172-32)$$
$$=1183.9-140$$
$$=1043.9 \text{ B.t.u.}$$

in which $H$ is the total heat above 32° of 1 lb. of dry steam, and $t$ is the temperature of the feed water.

Therefore, the total heat given the dry steam by the boiler is

$$245{,}990 \times 1043.9=256{,}788{,}960 \text{ B.t.u.}$$

The per cent of moisture in the steam is

$$100-\text{Item } 35=$$
$$100-98.2=1.8 \text{ per cent}$$

The total weight of moisture contained in the steam is

$$\text{Item } 37 \times .018=$$
$$250{,}500 \times .018=4509 \text{ lb.}$$

The amount of heat given to 1 lb. of this moisture by the boiler is

$$h-(t-32)=305-140$$
$$=165 \text{ B.t.u.}$$

in which $h$ is the heat of the liquid above 32°.

Therefore, the total heat given the moisture by the boiler is

$$4509 \times 165=743{,}985 \text{ B.t.u.}$$

The total amount of heat given to the feed water by the boiler is the sum of the heat given to the dry steam and that given to the moisture or,

$$256{,}788{,}960+743{,}985=257{,}532{,}945$$

The weight of dry steam which this amount of heat would form is

$$257{,}532{,}945 \div \{H-(t-32)\}=$$
$$257{,}532{,}945 \div 1183.9-(172-32)$$
$$257{,}532{,}945 \div 1043.9=246{,}700 \text{ lb. (nearly)}$$

The result given is Item 38.

The above result may be obtained by the use of the following formula:

$$\text{Item } 38=W\left\{Q+M \times \frac{h-(t-32)}{h-(t-32)}\right\}$$

In which $W$ = weight of water fed to the boiler = Item 37

$$Q=\frac{\text{Item } 35}{100}$$

$$M=\frac{100-\text{Item } 35}{100}$$

$h$ = heat of the liquid of 1 lb. of steam above 32°

$H$ = total heat of 1 lb. of steam above 32°

Thus,

$$\text{Item } 38 = 250{,}500\left\{.982 + .018\frac{305-(172-32°)}{1183.9-(172-32)}\right\}$$

$$= 250{,}500\{.982 + (.018 \times .158)\}$$

$$= 250{,}500 \times .98{,}484 = 246{,}700 \text{ lb. (nearly)}$$

*Item* 39.—The factor of evaporation and its use has been explained in Chapter VIII. The factor of evaporation is always the quantity of heat supplied to the water in making one pound of dry steam divided by the latent heat of one pound of steam at 212° or 14.7 lb. per sq. in., which is 965.8. The heat supplied to the water in making 1 lb. of steam is equal to the total heat of 1 lb. of steam at the boiler pressure minus the quantity of heat already in the feed water when it enters the boiler,

or

$$\text{Factor of evaporation} = \frac{H-(t-32)}{965.8}$$

in which $t$ is the temperature of the feed water.

$$\frac{H-(t-32)}{965.8} = \frac{1183.9-(172-32)}{965.8} = 1.081$$

*Item* 40.—It is often desirable to compare the performance of two boilers which are generating steam under different pressures. In order to do this it is necessary to reduce the evaporation to a common pressure; in other words, to change the amount of water actually evaporated into the amount that would be evaporated at the common pressure, zero lb. per sq. in. by the gage, or atmospheric pressure. This is done by multiplying the actual number of pounds of dry steam generated by the factor of evaporation, or

Item 38 × Item 39

246,700 × 1.081 = 267,000.

*Item* 41.— Item 41 = Item 38 ÷ Item 2

= 246,700 ÷ 20 = 12,335.

*Item* 42.— Item 42 = Item 40 ÷ Item 2

= 267,000 ÷ 20 = 13,350.

*Item* 43.— Item 43 = Item 42 ÷ Item 4

= 13,350 ÷ 2500 = 5.34.

*Item* 44.— The horse-power of a boiler is the total equivalent evaporation per hour divided by 34.5

Item 44 = Item 42 ÷ 34.5 =

$13{,}350 \div 34.5 = 387.$

*Item* 45.—Item 45 = Item 4 ÷ number of square feet of heating surface alloted to each horse-power.

*Item* 46.—Item 46 = Item 44 ÷ Item 45
= 387 ÷ 250 = 154.8 per cent.

*Item* 46.—The items numbered from 47 to 52 inclusive aıe most useful in comparing the performance of boileıs. If the performance of two boilers are compared upon the basis of the number of pounds of water evaporated per pound of coal as fired, the amounts of ash and moisture in the coal used affect the results.

*Item* 47 = Item 37 ÷ Item 22
= 250,500 ÷ 32,200 = 7.78.

*Item* 48.—Item 47 is not suitable as a basis for comparing the performances of two boilers working under different pressures or generating steam of different qualities. Item 48 corrects for both of these things.

Item 48 = Item 40 ÷ Item 22
= 267,000 ÷ 32,200 = 8.29.

*Item* 49.—Corrects not only for the pressure and quality but also for the moisture in the coal. It is equal to

Item 49 = Item 40 ÷ Item 23
= 267,000 ÷ 30,850 = 8.65.

*Item* 50.—Corrects for the pressure and quality of the steam, for the ash and moisture in the coal and also for the amount of combustible material dropping through the grates. It is, therefore, a fair basis of comparison foı boilers alone, considered separately from their furnaces.

Item 50 = Item 40 ÷ Item 26
= 267,000 ÷ 27,780 = 9.61.

*Item* 51.— Item 51 = Item 50 × 965.8 ÷ Item 21
= 9.62 × 965.8 ÷ 13,360 = .695 = 69.5 per cent

*Item* 52.— Item 52 = Item 49 × 965.8 ÷ Item 20
= 8.65 × 965.8 ÷ 12,300 = .679 = 67.9 per cent

**278. Forms and Data.**—In the following pages are shown a set of convenient forms for recording the data taken duıing a boiler test. These forms are shown filled in with the data from a different boiler test and show the manner in which it may be recorded. On account of the small space in the blank form, the coal sheet does not show the time of firing nor the amount of coal fired each time, but simply the amount of coal delivered in front of the boiler each time. In carrying out a test it would be better to use several sheets of paper, ruled like the coal sheet, and record on them the amount of coal left in the wheelbarrow after each firing. Errors in the observations may then be detected.

The analysis of the coal used during this test was as follows:

| | |
|---|---|
| Fixed carbon | 54.10 per cent |
| Volatile matter | 24.21 per cent |
| Moisture | 12.19 per cent |
| Ash | 9.50 per cent |

Heating value per pound of dry coal, 13,530 B.t.u.

On account of the irregular times at which the furnaces are fired, the weights of coal cannot usually be taken at regular intervals, but this should be done whenever possible.

The amount of feed water used by the boiler will also vary from hour to hour. It should be weighed in equal portions, the weighing tanks being filled to a certain height and then emptied into the feed tank. If the water is weighed in equal portions, the time of weighing will ordinarily vary.

The readings for the calorimeter should be taken at regular intervals of about 20 minutes throughout the test, all the readings being taken at as near the same time as possible. In calculating the quality of steam from the calorimeter readings, it is not sufficient to take the average of the readings and calculate the quality from these average readings. The quality should be calculated separately from each set of readings, and the *average of the qualities* used in the report of the test. It is necessary to read the barometer only two or three times during a test as it varies but little during a day.

The readings of draft gages, stack temperature, and temperature of feed water should be taken every 20 minutes if possible. The flue gas should also be analyzed every 20 or 30 minutes, and the average of all the analyses recorded in the report of the test.

The following data is not shown in the data sheets and is given here in order to make the set of data complete.

Type of boiler = Scotch Marine
Kind of furnace = Morison Suspension
Duration of test = 10 hours
Grate surface = 40 sq. ft.
Water heating surface = 1470 sq. ft.
Builders' rated horse-power = 200

LOG OF BOILER TRIAL No. 2

Made at.....................

Date........................ By..............................

Boiler No .................. Fireman..........................

Coal Sheet

| Time | Coal delivered to scales, pounds | Coal on scales after each firing, pounds | Coal fired each time, pounds | Fuel | |
|---|---|---|---|---|---|
| 7:00 | 400 | 0 | 400 | Moist coal consumed, lb. | |
| 7:52 | 600 | 0 | 600 | Wood consumed, lb. | |
| 8:43 | 600 | 0 | 600 | Coal equivalent of wood = (wood × 4), lb. | |
| 9:41 | 600 | 0 | 600 | | |
| 10:30 | 600 | 0 | 600 | | |
| 11:20 | 800 | 0 | 800 | | |
| 12:15 | 800 | 0 | 800 | Description of fuel. | |
| 1:00 | 600 | 0 | 600 | Commercial name, *Washed No.* 4. | |
| 1:45 | 600 | 0 | 600 | Where mined, *Huron, Ill.* | |
| 2:36 | 600 | 0 | 600 | Size *No.* 4. | |
| 3:20 | 600 | 0 | 600 | Kind, *bituminous.* | |
| 4:00 | 600 | 0 | 600 | Appearance of coal. | |
| 4:45 | 600 | 0 | 600 | Record of cleaning fires. | |
| 5:50 | 460 | 0 | 460 | Time | Ash, lb. |
| | | | | 12:20 | 295 |
| | | | | 12:35 | 119 |
| | | | | 6:00 | 531 |
| | | | | Total Dry Ash, 945 lb. | |

LOG OF BOILER TRIAL No. 2

Made at. . . . . . . . . . . . . . . . . . . . . . . . . .

Date. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . By. . . . . . . . . . . . . . . . . . . . . . . . . . .

Boiler No. . . . . . . . . . . . . . . . . . . . . . . . . Fireman. . . . . . . . . . . . . . . . . . . . . .

Feed Water Sheet

| Time | Water delivered to feed tank, pounds | Temp. of water in tank | Time | Water delivered to feed tank, pounds | Temp. of water in tank | Remarks |
|---|---|---|---|---|---|---|
| 7:00 | 7855 | 196 | . . . . . . | . . . . . . . . . . . . | . . . . . . . . . . | *Test began at 7:00 A. M.; date, Mar. 26. Test closed at 6:00 P. M.; date, Mar. 26.* |
| 8:30 | 3169 | 197 | | | | |
| 9:00 | 3244 | 196 | | | | |
| 9:40 | 2567 | 196 | | | | |
| 10:00 | 5845 | 196 | | | | |
| 11:00 | 5638 | 198 | | | | |
| 12:01 | 6339 | 199 | | | | |
| 1:00 | 6449 | 197 | | | | |
| 2:03 | 9076 | 198 | | | | |
| 3:45 | 3312 | 200 | | | | |
| 4:03 | 3275 | 200 | | | | |
| 4:52 | 2600 | 195 | | | | |
| 5:04 | 4290 | 180 | | | | |
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LOG OF BOILER TRIAL No 2

Made at..........................

Date.............................. By..............................

Boiler No.......................... Fireman..........................

| Time | Pressures | | | Temperatures | | | | | Height of water in gage glass | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | Steam Gage | Draft gage | Barometer | Boiler room | External Air | Flue gas | Feed water | Steam | | |
| 7:00 | 115 | 1.2 | 29.2 | 86 | 15 | ..... | 196 | .... | ........ | *Test began at* 7:00 *A.M; date, Mar.* 26. *Test closed at* 6:00 *P.M.; date, Mar.* 26. |
| 8:00 | 113 | 1.8 | ..... | 84 | 16 | ..... | 197 | | | |
| 9:00 | 120 | 1.7 | ..... | 87 | 15 | 545 | 196 | | | |
| 10:00 | 110 | 1.6 | ..... | 86 | 17 | 572 | 196 | | | |
| 11:00 | 100 | 1.8 | ..... | 90 | 20 | 590 | 198 | | | |
| 12:00 | 108 | 1.8 | 29.1 | 91 | 19 | 626 | 199 | | | |
| 1:00 | 101 | 1.7 | ..... | 92 | 20 | 617 | 197 | | | |
| 2:00 | 112 | 1.6 | ..... | 92 | 21 | 550 | 198 | | | |
| 3:00 | 101 | 1.7 | 29.2 | 90 | 19 | 635 | 197 | | | |
| 4:00 | 100 | 1.6 | ..... | 90 | 19 | 671 | 200 | | | |
| 5:00 | 110 | 1.6 | ..... | 93 | 19 | 586 | 195 | | | |
| 6:00 | 109 | 1.4 | 29.2 | 90 | 16 | ..... | 180 | | | |
| | | | | | | | | | | |
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LOG OF BOILER TRIAL No. 2

Made at............................

Date.............................. By..............................

Boiler No.......................... Fireman..........................

| Time | Calorimeter | | | Draft, In. of water | | | Height of water in tank | Height of water in gage glass | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | Gage pressure | Calorimeter temperature, or steam discharge | Calorimeter pressure or water separated | Between damper and boiler | In furnace | In ash pit | | | |
| 7:00 | 115 | 276 | 1.50 | 1.2 | ..... | .20 | ....... | 5.5 | |
| 8:00 | 113 | 280 | 1.55 | 1.8 | ..... | .42 | ....... | 5.3 | |
| 9:00 | 120 | 281 | 1.55 | 1.7 | ..... | .40 | ....... | 5.8 | |
| 10:00 | 110 | 279 | 1.50 | 1.6 | ..... | .36 | ....... | 6.0 | |
| 11:00 | 100 | 277 | 1.50 | 1 8 | ..... | .40 | ....... | 5.4 | |
| 12:00 | 108 | 280 | 1.45 | 1.8 | ..... | .38 | ....... | 5.1 | |
| 1:00 | 101 | 276 | 1.45 | 1.7 | ..... | .40 | ....... | 5.7 | |
| 2:00 | 112 | 279 | 1.55 | 1.6 | ..... | .40 | ....... | 5.8 | |
| 3:00 | 101 | 274 | 1.40 | 1.7 | ..... | .32 | ....... | 5.5 | |
| 4:00 | 100 | 276 | 1.35 | 1.6 | ..... | .40 | ....... | 5.3 | |
| 5:00 | 110 | 280 | 1.50 | 1.6 | ..... | .40 | ....... | 5.2 | |
| 6:00 | 109 | 278 | 1.55 | 1.4 | ..... | .40 | ....... | 5.5 | |
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LOG OF BOILER TRIAL No. 2

Made at............................

Date............................ By...............................

Boiler No.......................... Fireman..........................

Flue Gas Sheet

| Time | $CO_2$ | $O_2$ | CO | Total | Remarks |
|---|---|---|---|---|---|
| 7:20 | 7.20 | 11.40 | 0.2 | | |
| 8:15 | 6.30 | 13.70 | 0.3 | | |
| 9:15 | 8.55 | 10.90 | 0.1 | | |
| 10:10 | 6.80 | 12.60 | 0.5 | | |
| 11:20 | 6.20 | 12.20 | 0.8 | | |
| 12:15 | 7.20 | 11.40 | 0.6 | | |
| 1:20 | 6.70 | 12.20 | 0.6 | | |
| 2:15 | 5.70 | 10.40 | 1.4 | | |
| 3.15 | 6.25 | 9.85 | 1.1 | | |
| 4:20 | 7.20 | 11.80 | 0.7 | | |
| 5:25 | 8.00 | 6.50 | 1.5 | | |
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