HOT WATER HEATING AND FITTING

Modern Hot Water Apparatus, the Methods of Their Construction and the Principles Involved

BY

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PREFACE.

The scarcity of data as to the theory and practice of warming buildings by hot-water circulation, induced me in the first edition of this book in 1889, to lay before the student and workman in this branch of mechanics as much of the information which I had acquired during more than twenty years' practical experience in the art of warming and ventilating buildings as was practicable in a book of this description.

The second edition was published in 1890 and the third edition in 1891. These were what are known as publishers editions, no material changes being made in the book, errors only being corrected where they were known to exist. In the present edition however, the entire book has been carefully revised and some new material has been added.

The wording and method of expressing and conveying ideas is not that usually adopted when addressing those who have received a scientific training. It is not, however, for professional readers that I have written, but for practical men who are unaccustomed to the abbreviated methods of the mathematician, which, though they express so much in a few brief sentences and symbols, are not suited to the wants of the average workman, or to one who has advanced himself to the position of foreman, superintendent or proprietor by passing successively through the lower branches of his calling.

In my intercourse with the mechanic, therefore, I endeavor to speak to him in terms which my familiarity with him in the workshop leads me to think he will not misunderstand; and I am aware from past experience that it is not well to leave much to be conjectured; hence also the occasional repetition of a problem in another and perhaps simpler manner than at first or the illustration of the second example of a simple subject by a sum in figures, or by graphic methods.

It is not necessary to explain to the educated engineer that absolute accuracy in scientific data is very rare, and that it would be folly to assume that all accepted formulæ are without error. It is, however, necessary to inform the mechanic that the accepted theoretical formulæ are in nearly all cases very close approximations to the truth, and that without them we would be working entirely in the dark; whereas, with them we are enabled to determine beforehand, to within a small percentage, one way or the other, what the results will be in actual practice, and that therefore he must look on them as correct for practical purposes.

The formulæ governing the flow of water in pipes herein given are the ordinarily accepted ones of the hydraulic engineer.

I desire to acknowledge the assistance I have received from my associate, Mr. Ralph C. Taggart, Ph. B., M.E., in the revision of the Fourth Edition of this work.

INTRODUCTION.

Before going into the details of the subject of warming buildings by hot-water circulation, I wish to call the attention of the designer of an apparatus to the fact, that it is of nearly as great importance to plan his work to secure an equal resistance to the flow of the water at all points of an apparatus as it is to have pipes of sufficient capacity to carry the amount of water necessary for a given duty. He has to provide not only pipes of sufficient diameter to carry a given quantity of water through the pipes of an apparatus, but he has to distribute it in proportion to the heating surface through all the branches of the system.

His *first* problem then is to determine the quantity of water to be moved in a given time, through the system as a whole; and the *second* is to secure its equal distribution.

The object of this book is to enable a designer to readily determine, not only the proper diameters and lengths of pipes for an equal distribution, but to determine the diameters and lengths for any stated duty or loss of temperature, and at the same time secure a practically equal resistance to the flow of the water through all the circuits of an apparatus.

For those who have not the time or inclination to study the subject thoroughly, tables and diagrams have been prepared summarizing the requirements for certain ordinary conditions of practice, whereby the diameters and lengths of pipes can be determined offhand for apparatus containing up to sixteen hundred square feet of heating surface.

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CHAPTER I.

THE CIRCULATION OF WATER.

Circulation of Water in Vessels, caused by the Addition or Subtraction of Heat—Heat the Primary Cause of Motion in Water and Gravitation the Negative Cause—Nomenclature of Circulation in the Pipes and Boiler of a Hot-Water Apparatus.

The growing demand for a better general knowledge of hot-water heating for buildings by architects, engineers, and the pipe-fitting trades in the United States induces me to give a description of American practice in hot-water heating.

In the United States many of the older Federal buildings are warmed by hot water, and a considerable number of buildings throughout the country have been warmed successfully by different special hot-water systems; but, as compared with the amount of steam-heating done, it is comparatively small, and the knowledge on the subject is limited and confined to a few who have made a specialty of it.

Before going into the question of methods employed for the different classes of buildings and their details, it is well, perhaps, to say a few words on the laws of hot-water circulation, that the reader may understand terms and technical applications as they appear and the more readily comprehend and reason by analogy when considering different classes of work, which however much they differ in appearance, are all controlled by a few common laws that must never be lost sight of in constructing a hot-water circulating apparatus; the chief one of which is that as each particle of water loses its heat by giving it off to the air, etc., through the walls of the pipes and heaters, it becomes heavier than the particles of water surrounding it and falls by the law of gravitation. displacing warmer particles than itself, which, by the interchange of position, rise above it, producing what is called circulation.

This takes place in all waters and in all liquids, without regard to mass or shape. If we have a glass or iron cube filled with warm water, say one foot square, or any convenient size, as shown in Fig. 1, with all sides but the lower one presented to the cooling action of the surrounding air, and radiating heat as well—which latter it will do, independently of the air—we find we will have currents in a downward direction on the four outer sides close to the glass, as shown by the waved arrows, while at the same time there will be noticed a current ascending at the center, as shown by the darts. This circulation will be noticed to go on in any vessel of water that is removed from its source of supply of heat as long as the water is warmer than the air.*

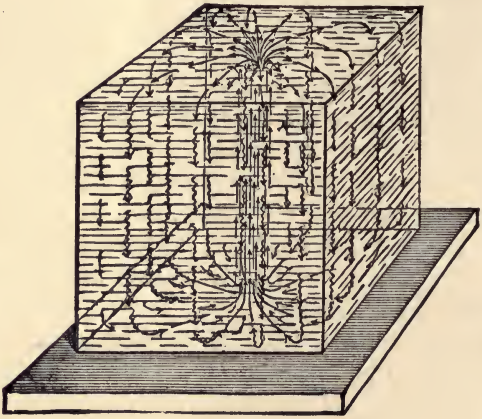

FIG. 1.

If, however, instead of standing on the table cooling, this cube was placed over a fire, as on a stove, so as to receive heat through its bottom, it would be found that the circulation or movement of the water would be in just the same direction as before, though possibly much stronger and faster; the only difference being in the *cause* that produces the circulation.

In the first case, the particles are cooled by contact with the sides of the cube, through which their heat was conducted away from the mass to warm the air on the outside, and in consequence of which they become smaller and more dense than

* When the temperature of the water is below 39° fahr., this statement is incorrect. This is explained at the beginning of Chap. 2.

their neighbors immediately behind and about them and which have not as yet come in contact with the outsides of the cube, and they sink, forcing an equal number of particles out of their way; and as the latter cannot escape from the cube they are forced to rise elsewhere within it, which, in the case of a cube exposed on four sides, must be near or at the centre.

In the second case, although the circulation is identical, in so far as appearances go, it is evidently the heat which expands the particles of water near the bottom, making them less dense than the water above. Heat, therefore, is the active cause of the circulation, for as fast as the colder particles come to the bottom of the vessel, they are expanded by the heat and hence tend to rise.

In the one case, then, the force of gravity is bringing down the particles as they cool, and in the other the force must be that of heat, or its mechanical equivalent, which overcomes gravity.

Throughout this book the reasoning as to the cause of circulation will be on the assumption that heat is the prime cause of all motion and that gravitation is negatively the cause of motion in water. Heat destroys the equilibrium of the particles of water and gravitation is ever on the alert and always active in restoring the equilibrium thus destroyed. Hence motion.

In considering the motion of water in the cube we saw how the loss of heat from the surface of the cube destroyed the equilibrium of the particles of the water, and they therefore descended. We also saw that an application of heat to the middle of the bottom produced a like result, by warming the particles near the centre, which gave them an upward movement; the particles at the side taking their place by gravitation.

If we now take a long cylinder or pipe filled with water, as shown in Fig. 2, in which the water is warmer than the air about it, the circulation will be found to go on just the same as in the cube when it was first laid on the table, and from the same cause—*i.e.*, the gravitation of the heavier particles between the lighter ones.

Again, if we take a long pipe and bend it into the simplest form of a closed circulating apparatus—say as shown in Fig. 3—we will still have local reversed and down currents in our *up* or flow-pipe close to the sides, as shown in the main flow-pipe at *a*. This is a factor to retard circulation not generally considered and still of too much importance to be entirely overlooked.

In a cube or short cylinder, or in a kettle on the fire, this circulation is shown at its best; and there is at that time no other, and it is equivalent to the main or primary circulation, such as goes on within a boiler. The circulation in a cube or short tube cooling on the table. as already shown, cannot properly be called a primary circulation, as it is not caused by an increase of heat, but by a loss of heat, and therefore might be

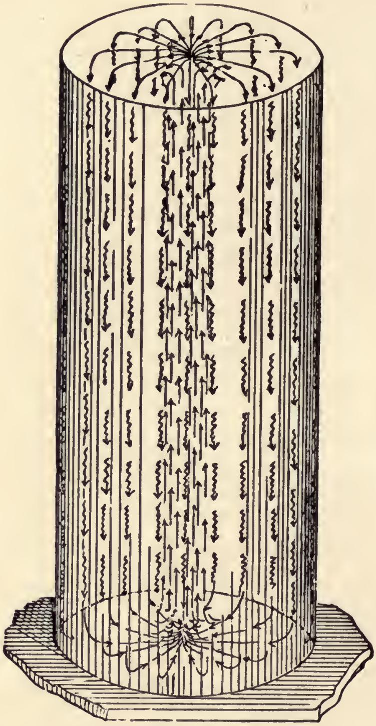

FIG. 2.

appropriately called a secondary circulation when contrasting it with a circulation caused by the addition of heat alone; but in considering the result and not the cause, and as the two causes are nearly always present in a warming apparatus, we must know this local circulation by the name of primary.

It is found in the boiler on the outer sides in the diagram (Fig. 3) at *b*, by the direction of the arrows.

If fire is now made under the boiler a general circulation is set up, which passes up the middle of the pipe, *a*, and over into the pipe, *c*, to return to the boiler again. Some of this water, however, which starts from the boiler, and which ordinarily is supposed to shoot right through the pipe, *a*, tries to return by the same pipe. Presumably, unless the pipe is very large in diameter for the work it has to perform, no considerable quantity of it returns into the boiler through the pipe it leaves, but, nevertheless, it starts this rolling motion at the surface of all ascend-

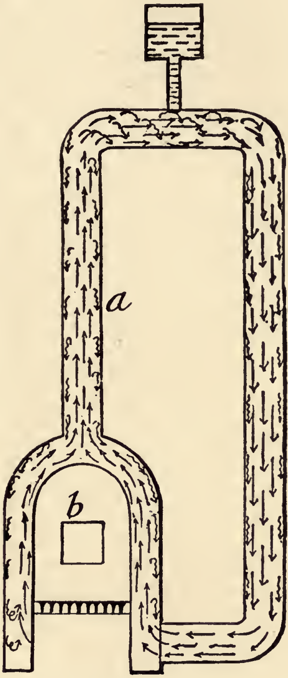

FIG. 3.

ing water-pipes, and forms a factor against the velocity and ease of flow, very similar to the resistance of friction, and this naturally increases the friction factor, as it establishes water-currents in opposite directions, giving a rolling motion to the particles and causing eddies against the wet side of the pipe.

This motion, at the surface of the pipe or cylinder, is sometimes called "molecular" circulation, which very well expresses the condition, but "local" circulation is probably the most comprehensive term for the fitter.

If the reader wishes to observe for himself the "local" circulation which goes on within hot-water pipes, let him take a small tin can for a boiler and make a simple circulation of glass tubing from its top, returning again to the side. He may then fill it with water and put in some very fine charcoal, when, upon applying heat to its bottom, the action of the water can be observed with advantage.

This local circulation always affects the general forward movement of the main current in an apparatus. We are unable, however, to determine the extra resistance to the flow in the upward pipes from this cause, but it is considerable, and is in a direct ratio to the outward surface of the pipe compared to its volume; being small when compared with the large diameter pipes, and causing no very practical drawback to their circulation, but comparatively great in the case of small pipes, so that a point can be reached by reducing diameter and increasing length where a local circulation would go on for a certain distance up the pipes, but the main circulation through the circuit would not take place, the pipes being warm to the touch for some distance of their length upward, and cold beyond, giving the general impression that the heat of the boiler has been conducted to that height by the iron of the pipe or by the passage of heat from contact of particles, not in motion; and while this may be so to a certain extent, it is more largely caused by local circulation in the lower end of the small pipe.

Local circulation goes on even in horizontal pipes, but in such cases cannot be said to affect the flow—certainly not to an appreciable extent.

The course of local circulation in a horizontal pipe would be from the top to the bottom side, with an upward or return current at the centre when the pipe is giving off heat. At the same time the forward motion would be going on by the force of the main circulation, giving particles of charcoal held in suspension the appearance of a screwing motion along each side of the pipe, the particles on one side of the pipe when looked down upon circling in one direction and those on the other side in a contrary direction.

In the downward pipe there may be said to be no local circulation. None is apparent, though some particles will be found to fall more rapidly than others; as in such case the main current and the local currents, if any, are in the same general direction. It is easy to understand how the water directly in contact with the surface of the pipe might fall a little faster than in the middle of such a pipe, it being a little colder, but this is not always observed to be so, as, in cases where the pipe observed is part of a main circuit, the water will be hurried along by the main current in the centre of the pipe faster than it will move against the sides, on account of friction. In the down pipes, however, both currents tend in the same direction, and the tendency of the surface current is to lessen friction or resistance to the main flow and need not be considered.

We will, therefore, for convenience, in these articles, call all currents not working or moving in the direction of the main current, local currents, and the currents induced within the boiler by the heat of the fire, primary currents, while the circulation through the main flow-pipes and back again through the main return-pipes will be known as the main current, or the main circuit; the circulations through all branches, coils, or radiators being known as branch circuits or branch currents.

CHAPTER II.

THE THEORY OF CIRCULATION OF WATER.

Consideration of the Question of Motion in the Pipes of a Hot-Water Apparatus as seen from Different Standpoints, though having the same Ultimate Bearing—Mr. Tredgold's Views—Mr. Hood's Views—Fixing the Cause of Motion in the Minds of Students.

I doubt whether it is worth while to consider very closely the philosophy of the question of the cause of circulation in hot-water apparatus. It is sufficient to say that hot water will ascend and cold water descend. This holds good, however, only in water at temperatures about 39° fahr., and therefore holds good for all warming apparatus; but, as a matter of fact, water colder than 39° fahr. will also ascend in a mass slightly warmer than itself, as may be seen in the brine-tank of a refrigerating or ice-making apparatus, where the intensely cold brine leaves the ammonia-pipes and flows upward instead of down, as might naturally be supposed by any one who has not carefully considered the matter.

T. Bramah, C.E., in an appendix to the "Principles of Warming and Ventilation," by Thomas Tredgold, C.E., published in 1836 in London, says: "The circulation of hot water when employed for the purpose of carrying and distributing heat through pipes or other vessels is produced by the unequal density of the fluid, arising from the difference of temperature in the ascending and descending columns of water connected with the heating reservoir and its velocity is governed by the height of the said columns." And to demonstrate more clearly the mechanical action of the moving force by which he considered the circulation is maintained, he inserts the accompanying diagram and reference previously employed by Mr. Tredgold in a letter to the Secretary of the Horticultural Society, and which was recorded in the transactions of that institution at the time. The passage reads as follows:

"If the vessel (Fig. 4), *A B*, and pipes be filled with water and heat applied to the vessel, *A*, the effect of heat will expand the water in the vessel, *A*, and the surface will rise to a higher level, *a d*, the former general level surface being *b b*. The density of the fluid in the vessel, *A*, will also decrease in consequence of its expansion, but as soon as the column, *c d*, above the centre of the pipe, is of greater weight than the column, *f e*, above that centre, motion will commence along the upper pipe from *A* to *B* and the change this motion produces in the equilibrium of the fluid will cause a corresponding motion in the lower pipe from *B* to *A*; and in short pipes the motion will be obviously continued till the temperature be nearly the same in both vessels, or if the water be made to boil in *A* it may be

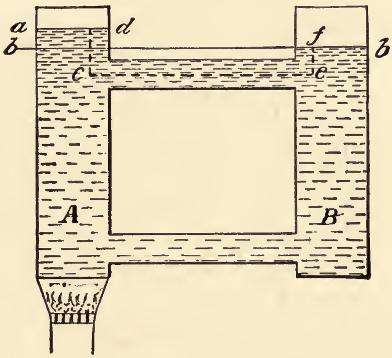

FIG. 4.

boiling hot in *B*, because ebullition in *A* will assist the motion."

Mr. Thos. Hood, in his "Treatise on Warming Buildings," takes exception to this, and says: "Now it is certain that this theory will not account for the circulation of the water under all circumstances and in every variety of form of the apparatus, and as the cause of motion must be the same in all cases, any explanation which will not apply universally must necessarily be erroneous."

To prove that Mr. Tredgold was wrong in his assumption, Mr. Hood constructed the diagram, Fig. 5, and said:

"Suppose the apparatus to be filled with cold water and the two stop-cocks to be closed, then, on applying heat to the vessel, *A*, the water it contains will expand in bulk and part of it will flow (run away) through the small waste-pipe, x, which is so placed as to prevent the water from rising higher in the vessel, A, than the top of the vessel, B." He then asserts that the water which remains in the vessel, A, after it has been heated and expanded and a portion of it has passed away through the overflow-pipe, x, as before stated, will be lighter than it was before warming or running off, but that its height remains the same, and then asks the reader to suppose the two cocks to be opened simultaneously and to assume (as assumed by himself) that the hot water in the boiler, A, will immediately flow through the upper cross-pipe to B, and that the water in B will correspondingly flow toward A through the lower pipe, evidently wanting the reader to agree with him that this flow takes place without the increased head (actual or potential)

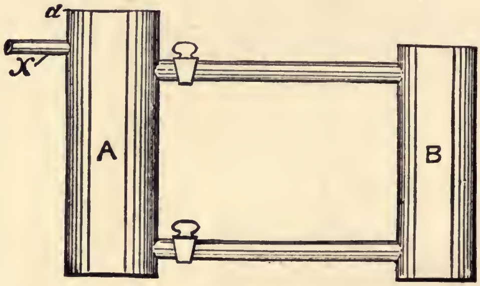

FIG. 5.

in the hot leg, arguing that we must find another explanation for the cause of motion, as the reason given by Tredgold "is insufficient to account for the effect in the simplest form of apparatus."

Mr. Tredgold's explanation of the manner in which the increased height of the warm leg caused the flow, is incomplete, but his meaning is apparent, and shows that he considered that there was just as much, or more, preponderance of pressure through the upper cross-pipe to B as there was through the lower pipe to A, and that he looked on heat as the cause of motion.

Mr. Hood goes on to explain that if heat be applied to the boiler, A, Fig. 5, an increase of the volume takes place, and that it becomes lighter, the heated particles rising through the colder ones, which later sink by their greater specific gravity, when they in turn become heated like the others (which, of course, is so far correct), and that then, when the water in *A* becomes lighter than that which is in the opposite vessel (*B*), the water in the lower horizontal pipe is pressed by the greater weight and moves toward *A*. A little reflection and consideration, however, will show that the pressure through the lower pipe toward *A* is no greater after the water in *A* is warmed than it was before, and if the top pipe is removed this becomes very apparent, as no water can pass from *A* to *B*, or *vice versa*, without going through the lower pipe; and one conversant with hydraulics knows this; as there are just as many particles in one vessel as the other, and every particle weighs the same whether it is expanded by heat or not. Mr. Hood, on the other hand, in his treatise, is endeavoring to prove that the motion of the water is caused solely by a force of gravitation in the cold pipe instead of by the force of heat imparted to the water in the warm pipe, and uses some apparently forcible arguments to sustain his theory.

From the practical side of this subject it may appear unnecessary to argue this question, and it would be were it not that it will be a means of fixing the cause of motion in the water in the minds of some who have not considered it, and may, presumably, throw some light on the question of the difference between the Tredgold theorists and those who follow Mr. Hood, and it goes to show that there is really no practical difference between the two men, the fact being simply that they view the question from different standpoints, and that Mr. Hood undoubtedly mistook the effect for the cause, as he by that means more readily explained some of the problems that at first appear to be unexplainable by Mr. Tredgold's views as he interpreted them.

If we return to Mr. Hood's diagram, Fig. 5, and follow what takes place to the point of getting ready to open the "two cocks simultaneously," we will find that some water has run from the pipe, x, and that both cold and hot pipes stand at the same level, though not in hydrostatic equilibrium, as some of the hot column has been drawn away through the pipe, x.

Mr. Hood then asks us to open the two cocks together. We do so, and that the water circulates or moves we know from experience. But Mr. Hood must assume for himself, and asks us to assume also, that it circulates without a rise of head in the hot pipe.

This, of course, we cannot agree with if we stop one moment and consider that the hydrostatic equilibrium must first be established the moment the cocks are opened, and that we cannott consider the question of a thermo-dynamic circulation to commence until some of the cold and heavy column *B* runs into *A* through the bottom pipe to establish the balance that was destroyed by running some of the water out at the pipe, *x*; and it is at the commencement of this first movement Mr. Hood assumes the circulation commences. The first movement of the water commences then, but it is only a hydraulic movement,

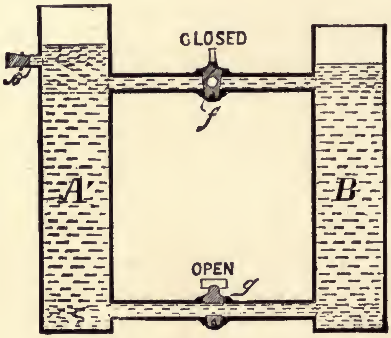

Fig. 6.

which ends the moment the columns are in hydrostatic equilibrium, and it is at this time the thermo-dynamic current commences that afterwards goes on to keep up the motion of the water in the pipes.

In the experimental apparatus, that is not receiving heat, we are apt to consider gravitation only as the cause of motion; but we must look further and consider that heat is being added to the up-leg of the syphon in as great or even greater quantity than the cold one is giving it off.

Surely we cannot assume that the water in *B* had anything to do with lifting and discharging some of the water of *A* through *x* while the lower pipe was closed, and when the said lower pipe is opened, the upper one being closed; the pressure and current through the lower pipe goes only so far as to establish the balance again; the warm column going to a somewhat higher level because of its lessened weight—not as high as before, as some of it was run to waste—but relatively as much above the top of the cold column as it was before, and it is then the heat circulation starts and goes on, by the water in the higher level flowing toward the lower one.

Let the reader make a diagram or a model for himself like Fig. 6, and plug or cork the pipe, *x*, and open the lower cock alone (as in Fig. 6) and see what takes place. He will find that the water in *A*, being lighter than in *B* (for a given measure of it), will rise again higher than the water in *B* until they balance in weight. Let him then open the upper cock, closing

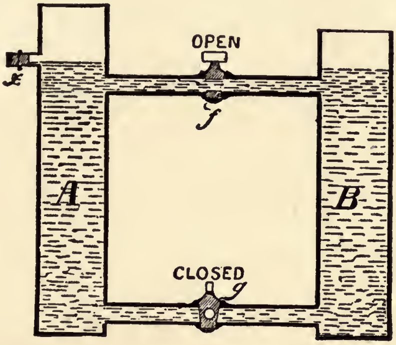

Fig. 7.

the bottom one (as shown in Fig. 7), and this head flows through the upper pipe into *B*, though certainly not pushed there by the weight in *B*, as *the lower cock is closed*, but by the excess of head in *A*, above a passage through which it may run off either into *B* or into an outside vessel, as I will endeavor to show by the diagrams, Figs. 8 and 9.

Heat is applied to the boiler, *A*, Fig. 8; the lower cross-pipe being closed. Some of the power of the heat goes to warm the water, and some of the heat is converted into motion, and raises a quantity of the water in the boiler, *A*, from the normal common level water-line, *C*, to the level, *D*, or line of equilibrium. It is in raising this water the *work* is done which causes motion, and it is the fall of this water again to its normal level which maintains the circulation.

If we let this water run over into *B*, as we may do by opening the cock in the upper pipe, an equal weight of cold water from the bottom of *B* will run into *A* if the lower pipe is open; but

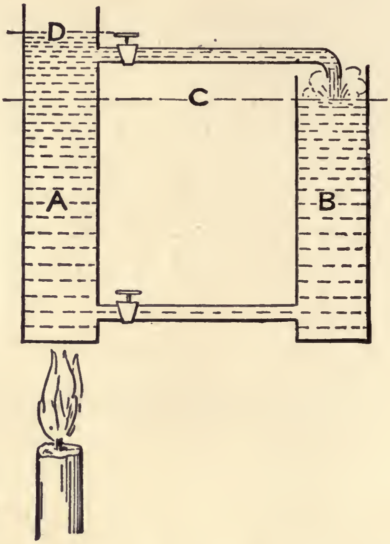

FIG. 8.

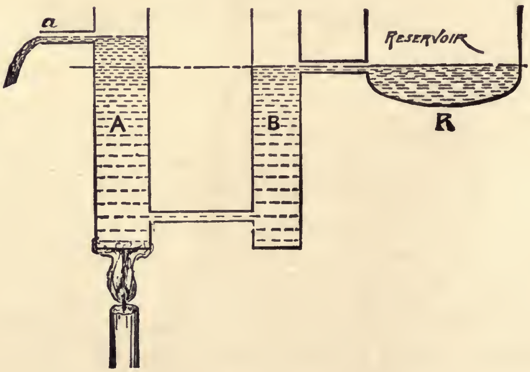

FIG. 9.

if it is not open, this water, which has run through the upper pipe, will stay above the normal level, *C*, in the chamber, *B*, and it is the fall of this water to the normal level, and not any power below it, that maintains circulation. This may be made plainer by Fig. 9. Water flows at a constant level from a reservoir, *R*, to the chamber, *B*, thence through the bottom pipe to the chamber or boiler, *A*, where it is warmed, expanded, and lifted until it flows through the small pipe, *a*, at a much higher level than the surface of the reservoir, *R*. The question now is, was it the weight in *B* or the heat applied to *A* that caused the motion and elevation of water.

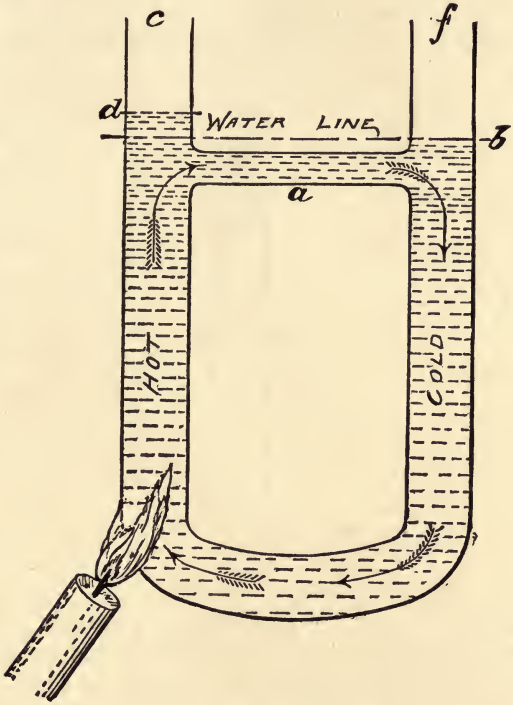

FIG. 10.

If we take an apparatus like Fig. 8, but with the cocks removed from the cross-pipes, and apply heat to the bottom at *A*, the water will rise in the latter until it runs over into *B*; and as long as heat is maintained the water will flow; and the water elevated might be just as well run into another vessel as into *B*, and it would so run until a quantity equal to the increment by expansion runs off.

Of course, when the pipes are open, to allow the water to move around the circuit, this rise is very small, and in an apparently closed apparatus it is said it cannot exist, and this is adduced to try to prove Mr. Tredgold's assumption entirely erroneous; but a little thought will dispel this, as all apparatus must have an expansion-chamber, and it matters little whether it is on *A* or *B*, for when it is on the latter, and *A* is a cylinder closed on top, with the cock in the bottom pipe closed, the excess by expansion simply flows through the upper pipe and rises in *B* to flow through the lower pipe when the latter is opened.

If we make Fig. 10 we have the simplest form of a water-

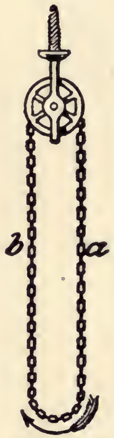

FIG. 11.

circulating apparatus. A slight rise actually takes place at *d*, even with the largest pipe at *a*. If the pipe at *a* is small the water at *d* will stand higher than when the pipe is large, and the head (*d*) will increase until it overcomes the friction in the small pipe (*a*), and this head is the *friction head*, the equivalent of the resistance to the flow of the water in an apparatus.

In the consideration of circulation for our purpose, it makes no great difference if we suppose the cold leg to be pushing the water up within the warm leg of the apparatus. It matters little from the practical side which way we consider it. We are only obliged to consider the difference of power between the rising column and the falling column of water for equal perpendicular heights; and whether this power is the elevation of water in one pipe, due to expansion, or a downward force in the other, it matters little to the fitter, as long as the result is obtained.

Any force that will tend to destroy the equilibrium among the particles of a body of water will result in motion. It is usual to attribute the flow to the force of gravity alone. Certainly, if the force of gravitation did not exist, there could be no circulation or return of the current, but, on the other hand, if the work was not done by the heat in lifting the water, gravitation alone could not produce motion. The addition or the loss of heat destroys the equilibrium and gravitation always tends to restore it.

We may liken the whole matter to a chain over a pulley, as shown in Fig. 11. If we add weight at one side at *a*, it comes down at that side and goes up at the other as shown by the arrow. If we lift it at *b* it still goes on in the same direction whether we pull down at *a* or not, and if we lift and pull together it simply goes the faster in the same direction. The lifting power is figurative of the force of expansion from the boiler (heat), and the pull or weighing down is likened to the force or gravity, when the latter becomes possible to assert itself by the loss of heat from the water, or relatively by the addition of heat to the opposite leg of the apparatus.

CHAPTER III.

THE PRINCIPLES DETERMINING THE FLOW OF WATER IN PIPES.

To Find the Flow of Water in the Pipes of an Apparatus — Simple Formula Expressing the Law which Governs a Body Falling by Terrestrial Gravitation—Diagram Showing the Curve of the Coefficients of the Expansion of Water—Diagram Showing the Velocity of Flow of Water in Feet per Second when the Height from which it Falls is Known—The Use of the Diagrams in Estimating Flow through an Apparatus.

We will next consider how to calculate or find the rapidity of motion in the mass of water, or its velocity through the pipes of an apparatus. Let us take a tube, say twelve feet long, as shown in Fig. 12, and fill it with water at 40° fahr.—what would ordinarily be called cold water—until it just reaches the 10-foot level at *a*; in other words, we have a column of water just ten feet high at mean temperature within the tube. If we now apply heat to the bottom of the tube and expand the water until it boils, or until the whole mass of water is warmed to 212° fahr., we will find by measurement that the column that was just ten feet high when it had a temperature of 40° fahr. is now $10' + 4.8''$ high, or at *b* in the tube, having increased just .04 of its length (Dalton) by being warmed from 40° to 212° fahr.

Let us now consider two such tubes arranged side by side as in Fig. 13. These two tubes are to be connected at the bottom with a cross tube and furnished with inter- and overflow connections. If we pour in water at *d*, so that the column of water in *A* remains $10' - 4.8''$, while it is 10 ft. in *B* (or so that the difference in level *a b* is 4.8″) we will find that, with friction neglected, the velocity of the water through the pipes *A* and *B* will be 5.06 feet per second of time or 303 feet per min. This is the velocity a piece of lead would attain as it reached *a* if it fell from *b* to *a*, a distance of 4.8 inches.

In other words, if we maintain a head of water in *A* equal to the height, *a b*, the water will flow through the pipe, *A*, to the cross-pipe, through that pipe to *B*, and overflow at *c*, with a lineal velocity of a little over five feet per second, assuming the pipes are of equal diameter throughout, friction not considered.

This will be the greatest theoretical velocity possible in the pipes of an appatarus for a *ten*-foot column, under the greatest ranges of temperature and density due to the pressure of our atmosphere at sea level.

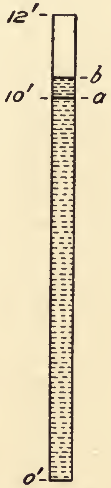

Fig. 12.

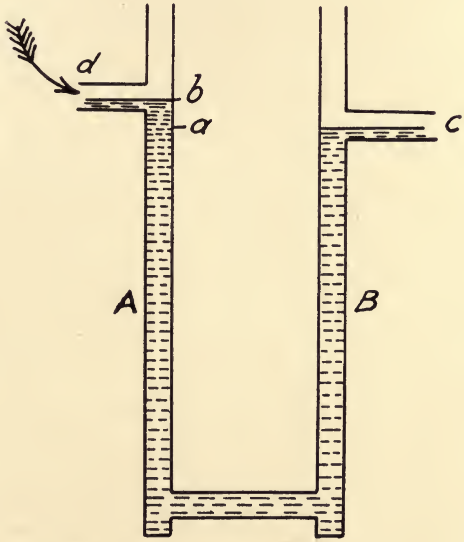

Fig. 13.

If our column is twenty (20) feet high the expansion of the water will be just double for the same range of temperature, and the fall will be 9.6 inches, but the velocity is not doubled by any means, and it will be found to be only 7.15 feet per second, as I will endeavor to show.

The fall of water in pipes follows the same law as the fall of a weight in a vacuum. Where a weight falls through the air it meets resistance, and when water falls in a pipe it meets resistance by friction, etc., but we will not consider the resistance here.

The simplest formula to express the law which governs the velocity of a body falling by terrestrial gravitation is

$$V = \sqrt{H} \times 8,$$

in which H = the height fallen from or the distance fallen through in feet, and V = the velocity in feet per second.

If we therefore apply this rule to a body falling 9.6 inches—in other words, .8 of a foot—we will find the velocity to be 7.15 feet per second, or 429 feet per minute, and the same is true of the water falling from the same height.

It will be noticed, therefore, that although the distance through which the water had to fall was *doubled* the velocity was not increased *one-half*, for the simple reason that the velocity increases only as the square root of the height from which the water falls.

If we go on, therefore, and see what the velocity will be for a 100-foot column (which is ten times the height of the first column), the ranges of temperature remaining the same (40° to 212°) and the distance fallen from four feet, we will find by applying the rule, that the *square root* 4 = 2 and that $2 \times 8 = 16$ feet per second, or 960 feet per minute, which is very little over three times the speed it would attain when falling from only one-tenth of the height.

The velocity last mentioned, however, will never be attained in the pipes of an ordinary heating apparatus, as there cannot be in ordinary practice anything like 170° fahr. between the temperatures of the flow and return pipes, even should there be a building 100 feet high warmed with hot water, and it is therefore instanced here simply to fix in the mind of the fitter the fact that the increase of velocity of flow is *small* compared to the increase of height of the apparatus, and that comparatively shallow or low apparatus, with an apparently small difference between the temperatures of the water in flow and return pipes, will be found to have a velocity of flow surprisingly good, if the pipes are only sufficient in diameter to avoid retarding the flow materially and are properly aligned and fitted.

The diagram, Fig. 14, I have constructed to show the expansion of water according to Dalton—from *mean temperature* to 212° of the scale of Fahrenheit's thermometer; in other words, to show the expansion of water from the temperature at which its bulk is smallest and its density greatest to its greatest bulk and least density, under the pressure of our atmosphere at sea-level, and which covers all the ranges of temperature and bulk ever likely to take place in an open or low-pressure circulation. It will be noticed the base line is laid off into divisions of 10° fahr. (excepting the first, which is 12°) from 40° to 212°, and that the perpendicular line of figures, which represent inches, is the expansion or increase of length of a *ten-foot column* of water when warmed from 40° fahr., and that the ordinates of the curve show the coefficients of the expansions of water irrespective of volume.

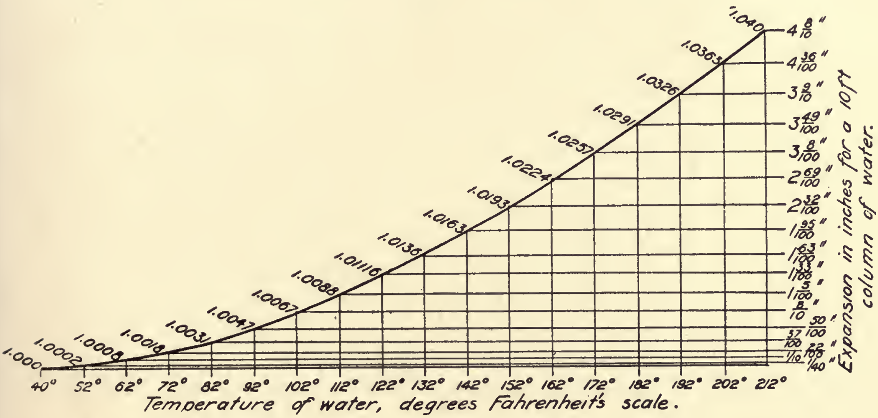

FIG. 14.—Curve of the Coefficients of the Expansion of Water.

The diagram, Fig. 15, has been constructed to show the velocity of the flow of water in feet per second when the height from which it falls is known. The lower, or base, and horizontal lines are divided into *feet* from 0′ to 8′, as probably covering the greatest range of velocities found in heating apparatus, while the vertical lines represent in inches the expansion that will be found to take place in a column of water. It is intended that these two diagrams (Figs. 14 and 15) be used together.

For instance, let us assume we have an apparatus ten feet high, such as we might find where only one floor of a building was warmed. Let us assume now that the water goes up in a flow-pipe at a temperature of 182° fahr. and returns at 162° fahr. What, then, should be the greatest possible velocity of the water through the rising flow-pipe? Let us return to diagram, Fig. 14, and see what the column in inches reads for a temperature of 182°. We will find it to be 3.49 inches. Now see what it is for a column of 162°, and we find it 2.69, the dif-

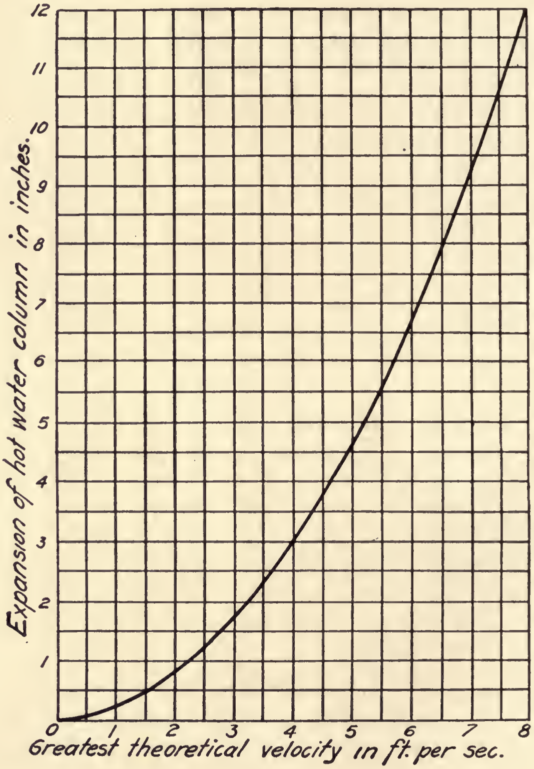

FIG. 15.

ference being .8 of an inch. If we now turn to diagram Fig. 15, and approximate .8 of an inch on the vertical scale of inches, (commencing at the top) we will find that a horizontal line drawn with our pencil so as to start at .8 of an inch will cross the curve line just where the two-foot velocity line crosses it, showing that for a fall of a little over ¾ of an inch we have a velocity of flow in our pipe of two feet per second. Let us take another example of the same, the better to understand the use of the diagrams.

Suppose we have an apparatus fifteen feet high, as shown in Fig. 16 and we have to find the measurement of the difference of weight or power that keeps up the circulation in this apparatus. Heretofore we have spoken of the height from which the water falls, but it may appear to the beginner that the water cannot fall in an apparatus of this kind, as it is practically

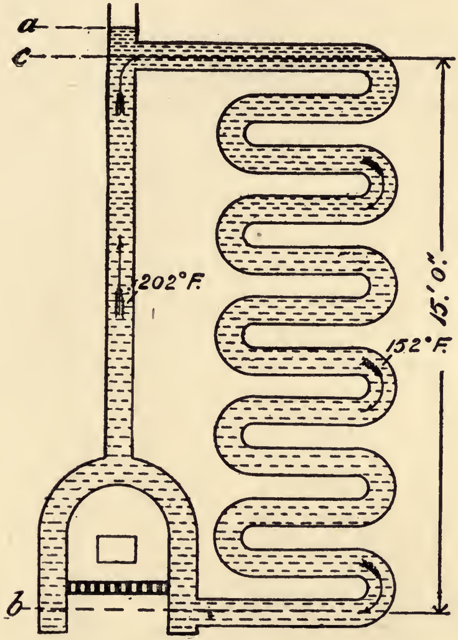

Fig. 16.

closed, and that there is, therefore, something to be explained, that the theory of a falling body may harmonize with the water rushing through the pipes of such an apparatus.

Practically there is a hydrostatic head or its equivalent. It may be likened to the increased weight of the cold leg of the syphon or the lessened weight of the warm leg. In the case of an apparatus as in Fig. 16 one may readily think he sees where the head comes in play in producing circulation, as the distance, *a c*, readily appears to be due to the expansion of the column, *c b*, but in Fig. 17 it is not apparent at all. Nevertheless, to consider the question of velocity in pipes, we are bound either to consider the fall of the water in the hot column from *a* to *c* (Fig. 16), or the fall of the cold column from *c* to *e* (Fig. 17), which latter is the measure between the columns, *a b* and *c d*, for equal weights. It, therefore, matters nothing to us practically whether we consider the height, *a c* (Fig. 16), or the height, *c e* (Fig. 17), as the measure of the flow, as the result will be practically the same in either case.

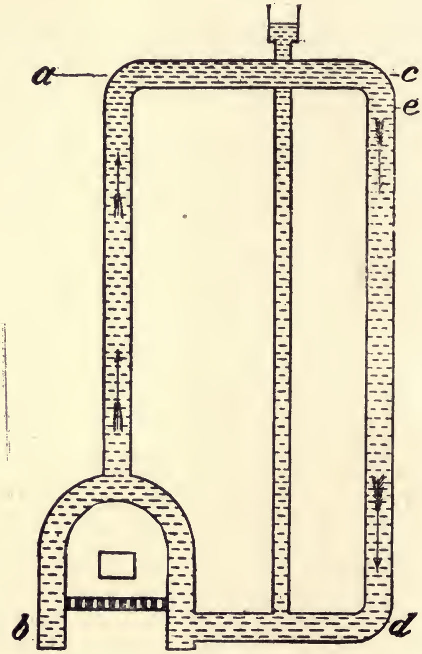

Fig. 17.

Our diagram, Fig. 14, was made on the increase of height of a column of water due to expansion and not on the decrease due to contraction; therefore we will speak of the head which produces circulation the same as we would of the total head from a reservoir that produces the discharge through apertures or pipes and on which the velocity of efflux or movement depends.

We will return to our example, Fig. 16, to familiarize ourselves with the use of the diagrams. The height, $c\,b$, is fifteen feet and the expansion of the water is that due to the rise of temperature between 152° and 202° fahr. For a 10-foot column, as per diagram, Fig. 14, we find it to be $4.36' - 2.32'' = 2.04''$, which is the rise for a 10-foot column at 202° fahr. over one at 152° fahr. But as our present column (Fig. 16) is fifteen feet, we have

$$\frac{2.04'' \times 15'}{10'} = 3.06''$$

as the increase for the 15-foot column.

If we now turn to diagram, Fig. 15, and approximate 3.06 on the inch column at the left, we will find whereat a pencil line run horizontally will cross the curve. From this point if we drop a vertical line we will find it bisects the base line at 4.04—as near as we can approximate—giving us the greatest possible theoretical velocity in this case as 4.04 feet per second.

The velocities already spoken of are the theoretical ones, no allowance being made for friction, and they can very nearly be obtained through a short, smooth, taper nipple or nozzle when measured at its point of smallest diameter.

CHAPTER IV.

THE ENTRY OF WATER INTO PIPES.

Easy Entry of Water into Pipes, etc.—Proper Shaped Points of Entry or Vena-Contracta—Table of Quantities of Water in U. S. Gallons that will pass through a Short Pipe Two Diameters Long after being Led to it through a Vena-Contracta or Easy Point of Entry.

According to accepted authorities on hydraulics, the efflux through a circular aperture in a thin plate is only .615 of the theoretical flow, on account of the convergence of the current at a short distance outside the plate. We, however, have nothing to do with such conditions, unless it should be to roughly calculate the time a vessel would take to become empty through a plug-hole, and which would be out of place here.

When an aperture is through a considerable thickness or through a short parallel tube projecting outwards, whose length is not less than twice its diameter, the discharge has been found to be greater than when it is through a plate, and although a contraction of the water takes place it is less than in the former case, reducing the water passed to a little over .8 of the total theoretical quantity due to the head and aperture. This loss is due to the entry of the water into the pipe, there being a reduction or contraction of the water by convergence of its particles which reduces the area of the stream for a short distance within the pipe, and as the velocity at this reduced area is the theoretical one, it stands to reason the amount of water passed is proportional only to the area of the contraction compared to the area of the pipe.

The loss, therefore, due to the entry into the common form of pipe must be taken as two-tenths of the whole quantity that would be ordinarily supposed to pass, and must be considered separately from the loss due to friction in a long pipe, and must be added thereto, and also to the loss for bends, elbows, etc., when the latter is known, as will be explained later.

When a pipe enters or passes in through the side of a reservoir or boiler for a short distance the loss caused to the flow of water by entry is even greater than with a pipe flush with the inside of the tank or boiler, and this loss has been found

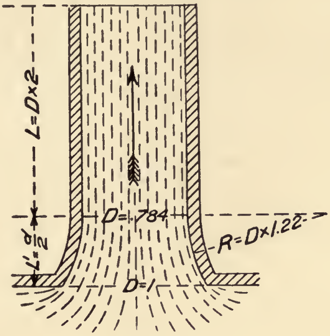

FIG. 18.

by experiment to be over .3 of the whole, decreasing the flow of the water one-eighth over a pipe that is flush; and for this reason pipes should never be carried through the side of a

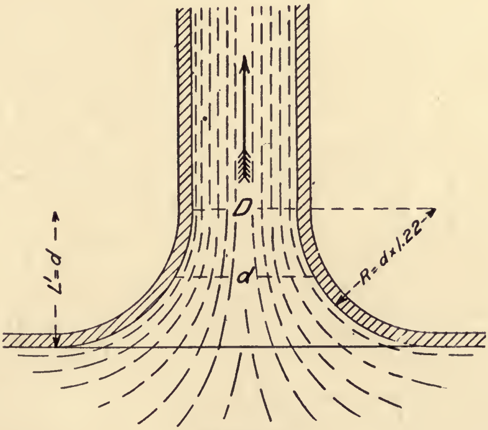

FIG. 19.

boiler or through a junction or fitting so as to make a projection; unless the obstruction to the flow is no objection, or that there is some object of greater importance to be obtained.

When the water leaves the side or top of a boiler through a

TABLE I.—TABLE OF TOTAL THEORETICAL FLOW OF WATER THROUGH SHORT PIPES UNDER RANGES OF DIFFERENCE OF PRESSURE IN HEATING APPARATUS.

D^2 Diameter of pipe in inches	Head of Water in Inches. ¼	½	1	2	3	4	5	6	7	8	9	10	11	12
	U. S. Gallons per minute.													
1..........1	2.9	4.06	5.8	8.18	10.0	11.57	12.95	14.17	15.32	16.37	17.37	18.3	19.15	20.
1.5625....1¼	4.5	6.33	9.04	12.76	15.6	18.07	20.2	22.14	23.89	25.55	27.09	28.54	29.87	31.25
2.25......1½	6.5	9.10	13.0	18.4	22.5	26.03	29.13	31.88	34.47	36.83	39.08	41.17	43.10	45.
4.........2	11.6	16.24	23.2	32.72	40.	46.28	51.80	56.68	61.28	65.48	69.48	73.2	76.6	80.
6.25......2½	18.12	25.37	36.25	51.12	62.5	72.31	80.93	88.56	95.75	102.31	108.56	114.37	119.69	125.
9.........3	26.1	36.54	52.2	73.62	90.00	104.13	116.55	127.53	137.88	147.33	156.33	164.7	172.35	180.0
16.........4	46.4	64.96	92.8	130.88	160.00	185.12	207.20	226.72	245.12	261.92	277.92	292.84	306.4	320.0
25.........5	72.5	101.5	145.	204.5	250.0	289.2	323.75	354.2	383.	409.2	434.2	457.5	478.7	500.
36.........6	104.4	146.16	208.8	294.48	360.0	416.52	466.20	510.12	551.52	589.32	625.32	658.8	689.40	720.0
49.........7	142.1	199.00	284.2	400.82	490.0	566.93	634.55	694.33	750.68	802.13	851.13	896.7	938.35	980.0
64.........8	185.6	259.84	371.2	523.52	640.0	740.48	828.80	906.88	980.48	1047.68	1111.68	1171.2	1225.6	1280.
81.........9	234.9	328.86	469.8	662.58	810.	937.17	1048.92	1147.77	1240.9	1325.97	1406.97	1482.3	1551.15	1620.0
100........10	290.0	406.00	580.00	818.	1000.	1157.	1295.	1417.0	1532.	1637.	1737.	1830.	1915.	2000.
121........11	350.9	491.26	701.8	989.8	1210.	1400.	1566.9	1714.57	1853.7	1980.8	2101.8	2214.3	2317.15	2420.
144........12	417.6	584.6	835.2	1177.92	1440.	1666.08	1864.80	2040.48	2206.08	2357.28	2501.28	2635.2	2757.60	2880.
Velocity in feet per second...	1.16	1.624	2.32	3.275	4.01	4.628	5.18	5.67	6.13	6.55	6.95	7.32	7.66	8.03

tapered circular nozzle, the loss by entry is less than when the pipe is parallel at the commencement. When this nozzle or truncated cone has a length of half its greatest (or base) diameter, and its smallest diameter .784 of its base, the flow of water will be augmented as it passes the smaller end, until it approaches to within less than .05 of the theoretical flow; and if the curve of the side of the cone is 1.22 of the diameter of the pipe, as shown in Fig. 18, the loss will be reduced to about

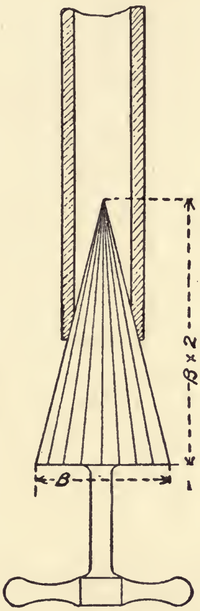

Fig. 20.

.025 of the theoretical, or a quantity almost too small to take into consideration in ordinary calculations.

If the smallest diameter of the cone, therefore, forms the area of the flow-pipe the loss of flow by entry is reduced to a minimum, and Fig. 18 gives probably the best practical proportions for points of entry into pipes or departure from boilers or large fittings, and is the proper form and shape for boiler outlets; and it also could be used to advantage whenever it became necessary to use enlargements or contractions of a pipe, as abruptness in the contractions affect the flow detrimentally by increasing friction, and for that reason, even with the best form of contracted vein, a coefficient of .05 should be allowed for entry in close calculations, even with the best form of vein considered.

Fig. 19 shows the *vena-contracta* carried to the extreme. It makes a trumpet-shaped point of entry, which looks well and symmetrical, but withal little, if any, more water will pass into it under the same pressure than will into a vein similar to the one shown in Fig. 18; and this fact should be enough to impress on us the advantage derived by having the ends of all wrought-iron pipe, or in fact any pipe for hot-water apparatus, reamed to a thin edge with a triangular or conical reamer whose length is just twice its base, as shown in Fig. 20. In thick pipes, or ones of small diameter that are relatively thick, enough can be taken from them in this way to almost give the best form of *vena-contracta*, and it will be of immense advantage for elbows and all fittings, not excepting couplings.

The accompanying Table, No. 1, gives the greatest theoretical quantity of water in U. S. gallons that will pass through a short tube whose length is about two diameters (as shown in Fig. 18), provided the water is led to it through a contracted vein (termed *vena-contracta*) as there shown.

The table is calculated by the simple formula,

$$G = \frac{V \times d^2}{.4}$$

in which G is the quantity in U. S. gallons, d^2 the square of the diameter of the pipe in inches, and .4 the part of a minute required for the passage of one U. S. gallon, with a velocity of one foot per second through a 1-inch diameter round pipe.*

* For British gallons the division .5 is to be used instead of .4, both of which are close enough for our purpose.

CHAPTER V.

THE PASSAGE OF WATER THROUGH SHORT PIPES.

Passage of Water through Pipes—Common Parallel-Shaped Point of Entry to Pipes—Table of Quantities of Water in U. S. Gallons that will Pass through a Common Nipple Two Diameters Long.

Fig. 21 shows the common parallel-shaped point of entry found in ordinary practice. The water, in entering such a pipe, contracts to about .9 of the diameter at *d*, a short distance within the pipe. This lessens the quantity of water that would pass the pipe under a proper shaped point of entry to .81 of the theoretical quantity, for the reason before explained;

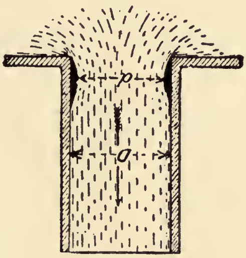

FIG. 21.

as the velocity at its greatest contraction is that due to the pressure only. This leaves it, then, that the velocity in the pipe beyond the contraction depends on the number of gallons that pass the contraction, and as this is but .81 of the whole, both the velocity beyond the contraction and the quantity will be correspondingly reduced to a little over .8 of the theoretical, or what can be obtained by Table No. 1, when the proper shaped point of entry is used. It is commonly taken as .8, however, and on this basis the Table, No. II, has been calculated.

Table No. II gives the head of water required for entry into the various sized parallel pipes with square ends from one to twelve inches inclusive for the different quantities of

TABLE II.—HEADS OF WATER REQUIRED FOR ENTRY INTO VARIOUS SIZED PARALLEL PIPES WITH SQUARE EDGES FOR NUMBER OF U. S. GALLONS GIVEN IN BODY OF TABLE.

Diameter of pipe in inches	Head of Water Required in Inches.													
	¼	½	1	2	3	4	5	6	7	8	9	10	11	12
	U. S. Gallons per minute.													
1	2.3	3.22	4.6	6.54	8.0	9.25	10.36	11.33	12.25	13.1	13.89	14.64	15.32	16.00
1¼	3.6	5.04	7.2	10.2	12.5	14.4	16.16	17.6	19.11	20.4	21.66	22.83	23.89	25.00
1½	5.1	7.3	10.4	14.72	18.00	20.8	23.3	25.50	27.57	29.46	31.26	33.00	34.58	36.00
2	9.2	13.	18.6	26.17	32.00	37.00	41.44	45.34	49.02	52.38	55.58	58.56	61.28	64.00
2½	14.5	20.30	29.0	40.9	50.0	57.84	64.80	70.84	76.6	81.84	86.76	91.50	95.75	100.00
3	20.8	29.19	41.7	58.9	72.00	83.2	93.24	102.	110.3	117.86	125.06	131.76	137.88	144.00
4	37.1	51.94	74.2	104.8	128.	148.1	165.76	181.36	196.1	209.53	222.30	234.27	245.12	256.
5	58.0	81.20	116.	163.6	200.0	231.36	258.96	283.2	306.4	327.36	347.36	366.00	382.96	400.00
6	83.5	116.9	167.	235.6	288.0	333.21	372.96	408.1	441.2	471.45	500.25	527.04	551.52	576.00
7	113.6	159.21	227.3	320.6	392.0	453.5	507.60	555.44	600.5	641.70	680.9	717.36	750.64	784.00
8	148.6	208.00	297.	418.8	512.0	592.4	663.00	725.5	784.4	838.16	889.36	936.96	980.48	1024.00
9	187.9	263.00	375.8	530.0	648.0	749.7	839.2	918.24	992.7	1060.77	1125.6	1185.84	1240.92	1296.00
10	232.0	324.80	464.	654.4	800.0	925.6	1036.0	1133.6	1225.6	1309.6	1389.6	1464.0	1532.	1600.
11	280.7	393.	561.4	791.8	968.	1120.	1253.5	1371.65	1483.	1584.6	1681.4	1771.4	1853.7	1936.
12	334.2	467.7	668.2	942.4	1152.	1332.8	1491.84	1632.4	1764.8	1885.7	2001.	2108.1	2206.0	2304.0

This table is found by taking .8 of the theoretical quantity of water, as given in Table I, and is correct enough for ordinary purposes.

water in U. S. gallons given in the body of the table, for pressures varying from ½ to 12 inches of water-head. In other words, it gives the quantity of water that will pass through a short nipple, under the given pressures, with square ends, and does not include the head required for friction of longer pipes. The use of these tables will become obvious as we proceed.

In reality the commercial pipe standards are somewhat larger than the actual diameter, but this is not taken into consideration in the tables, as the ends of pipes are seldom carefully reamed; the general practice being to cut them with a wheel-cutter, which gives them some contraction. So, for this reason, the nominal size of the pipe is taken as d^2; therefore the tables are for nominal dimensions of fairly clean standard pipe and not for actual sizes, which are a little larger in all cases, except for 2½ and 8 inch pipe, which happen to be a little under the nominal size, if they are made of standard thickness.

When the end, therefore, of a pipe as it leaves a boiler is square and parallel and no regard paid to a proper form of point of easy entry, then eight-tenths only of the Table, No. I, is to be taken as the number of U. S. gallons that will pass through a short, fairly smooth nipple, the power to move the remainder being consumed in entry; in other words, instead of getting ten gallons through a short inch pipe or nipple in a minute of time, with a 3-inch head of water as per Table No. I, only eight gallons would be found to pass, as given in Table No. II, and so on through the whole table; the remainder that might be expected to flow under such head being consumed in the effort of getting the particles of water into the pipe, overcoming the eddies and giving them direction.

If we divide the heads in Table No. II into that which is consumed by entry and into that which remains to move the water, it will give us about one-third of the total head for entry and two-thirds for the movement of the water. These amounts remain constants for the quantities of water given and for the size of pipes given, no matter how much greater the head at our disposal may be. To make this plainer we may say that so long as only thirty-two gallons of water enters a 2-inch pipe in a minute, regardless of what the total head may be capable of producing, about one-third of the 3-inch head in the Table (No. II) is the amount that is consumed by entry.

CHAPTER VI.

THE FRICTION OF WATER IN STRAIGHT PIPES.

The Loss to the Flow by Friction in Long Pipes—Table of Friction Loss in Inches for 10-Foot Lengths of Pipe for Various Diameters—How to Find Loss of Head for Other Lengths, Etc.

In long pipes the friction of the water against the insides of the pipes as it passes must be considered. The insides of the pipes are then often called the "rubbing" sides, or surfaces. In short smooth pipes, under small head or pressures, the loss by friction is not very great when compared to the whole, but in long pipes, passing large quantities of water, it is considerable, as it increases in a ratio (about) directly as the increase of length of the pipes and as the square of the velocity of the water through the pipes.

The loss to the flow by friction in pipes of four inches and upwards, under pressures and velocities such as are used in cast-iron water-mains, is well established and known to hydraulic engineers; many eminent mathematicians having considered the subject and formulated rules which some of our more recent investigators have verified or corrected, and which, in the hands of some of our hydraulic engineers, give results surprisingly accurate.

For small tubes, however, under very small heads of water, and such as can be found in heating apparatus, the tables are not so accurate. Prony's formula is considered by Thomas Box as probably the most correct for small pressures and small diameter pipes. For my practice I depend much on the tables of G. A. Ellis, C.E., of Boston.

He has constructed a table for friction in small diameter pipes of various sizes from existing tables, reduced to pounds pressures for U. S. gallons and 100 feet length of pipes. With his kind permission I have reduced and interpolated such parts of his table (No. 5 in his book) as, in my judgment, would be likely to be of use to a hot-water engineer, to pressures represented by *inches of water-head* instead of pounds, and for a length of 10 feet, instead of 100 feet as in his table.

This table is No. III, and shows the approximate friction loss in inches of water-head as consumed in the straight pipes of an apparatus for each ten feet of their length for the different number of U. S. gallons of water given in the first column.

For instance, should the difference of temperature between the flow and return pipe of any part of an apparatus appear to warrant a flow of 10 U. S. gallons of water per minute in a 2-inch pipe, .280 inch of the head will be consumed in each ten feet of the pipe in overcoming resistance to the water, and it will be lost as power. If the pipe is twenty feet long, twice as much of the total head—or .560 of an inch—will be consumed by friction, as in the case just cited; but if five feet of pipe is used, half only of the .280 inch of water-head will be consumed, or .140 of an inch.

The loss of head by friction in very short pipes compared to the loss of head by entry is small, but as the pipes become longer the friction loss increases about as the length of the pipe, whereas the loss by entry remains the same, so that a point is soon reached where the loss by friction is greater than the loss by entry. This point may be roughly placed at between 50 and 60 diameters of the straight tube.

Let it be borne in mind, therefore, that in a short tube the loss of head by entry may be a large percentage of the whole loss, but that in a long tube it may be comparatively small; the loss by friction alone becoming great enough to use up the greater part of the whole head at our disposal.

With our subject, however, the loss by friction of straight pipes will be generally comparatively small, with small velocities and large diameters, as an inspection of the Table, No. III, will show, but it also shows how rapidly it increases as we attempt to use small diameter pipes and try to get a given quantity of water through them by an increase of pressure.

Our table, therefore, may be likened to a table of resistances, and it can be used to determine approximately the comparative size of flow-pipes for an apparatus in which the resistance is to be nearly alike. For instance, it will be noticed that when one gallon of water passes through 10 feet of 1-inch

TABLE III.—FRICTION LOSS IN INCHES OF WATER-HEAD FOR EACH 10 FEET LENGTH OF DIFFERENT SIZE CLEAN IRON PIPES; DISCHARGING GIVEN QUANTITIES OF WATER PER MINUTE.

U. S. gals. passed per min.	Friction loss in inches of water-head for each ten feet of length. Size of pipe—inside diameter.															
	¾"	1"	1¼"	1½"	2"	2½"	3"	4"	6"	8"	10"	12"	14"	16"	18"	20"
1	.4	.1	.033	.019	.003											
2	1.6	.4	.132	.052	.012											
3	3.6	.9	.297	.117	.028	.01										
4	6.4	1.6	.528	.208	.05											
5	8.91	2.26	.837	.324	.075	.02	.01									
10	35.1	8.53	2.835	1.269	.280	0.10	.04	.01								
15	85.6	18.84	6.426	2.619	.550	0.17	.091									
20		33.21	10.99	4.482	1.144	.400	.160	.04								
25			17.28	7.074	1.773	.567	.27	.061	.009							
30			24.7	10.128	2.457	.815	.41	.09								
40				17.61	4.32	1.275	.60	.16								
50				27.	6.558	2.187	.945	0.243	.035							
75					14.364	4.86	1.998	0.510								
100						8.64	3.537	.891	.135							
125						13.203	5.373	1.336	.200							
150						18.9	7.695	1.863	0.270							
200							13.554	3.294	.459							
250								5.103	.702	0.189	.081	.027				
300								7.182	.999	0.243	.108	.036				
500									2.592	0.675	.243	.108	.045			
750									5.967	1.431	.486	.210	.090			
1000										2.538	.864	.351	.1674	.0972	.054	
2000											3.321	1.323	.6318	.3321	.1097	
3000												2.997	1.390	.720	.4000	

pipe in a minute the resistance is about one-tenth of an inch of water-head, and that nearly two gallons will pass through the same length of 1¼-inch pipe with the same resistance, three gallons through one 1½-inch pipe, five gallons through a 2-inch, 30 gallons through a 4-inch, 300 gallons through a 10-inch, and so on through the table; all giving a resistance of only one-tenth of an inch of water or thereabout.

It stands to reason, therefore, that the 10-inch pipe will pass 300 gallons with so small a loss of head that 60 *two*-inch pipes may flow into it, each passing five gallons and the resistance in all will be alike; or they may all take supply from it as they would in the flow-pipe of an apparatus. Of course, if the pipes are all doubled in length, the resistance is doubled also, but what I wish to call attention to in the table is, that lines of equal resistance may be traced approximately through it for pipes of about the same length, though for different diameters, and that hereafter in proportioning the size of pipes for apparatus this fact may be made use of.

CHAPTER VII.

THE FRICTION OF WATER IN ELBOWS, VALVES, ETC.

Loss of Head or Pressure by the Friction and Resistance of Elbows —The Division of the Total Resistance into its Elementary Parts—Great Loss by Short Radius Common Elbows— Saving by Long Radius Elbows—Saving by Smooth Elbows—Resistance of Return-Bends—Resistance Caused by Couplings—Resistance Caused by Globe, Angle and Gate Valves.

The loss of head in an elbow or bend should be divided into three parts when we intend to make a study of the subject: (1) That due to change of direction of the water alone; (2) that due to friction alone, the same as in any pipe; and (3) that due to eddies caused by enlargements or contractions of the currents, such as exist when common screwed elbows are used, that have pipes within them with square ends forming sharp shoulders against the passage of the current.

The *first* applies to all bends whose radius is less than five times the diameter of the pipe; but when the radius is five times or greater, with smooth bends, the loss of head for change of direction becomes so small that it may not be considered, as it practically becomes nothing.

The *second* (friction against the sides) applies to all bends, and, in fact, to all pipes, etc., without regard to shape, and it must always be considered as equal to the head consumed by the same length of straight pipe of the same diameter and character.

The *third* applies only to cases where the diameter of the bend or elbow is larger than the diameter of the pipe and has shoulders and threads, and it is greatest with square-ended pipes and least with pipes whose point of entry is easy, with the edges cut to a knife-edge and the angle of the side about as shown by Fig. 24, and it does not exist at all in smooth bends of equal diameter throughout.

The *second* and *third* quantities above mentioned also apply to straight-screwed couplings or sockets and tees, and in them has about the same value as in elbows; but couplings being straight, of course there can be no loss for change of direction.

The loss of head for change of direction alone in elbows differs with the angle. Weisbach's formula is the one most used, but it is difficult of application by practical men, and was presumably founded on the loss of head in fairly smooth bends in large water-pipe. If we had special fittings for hot-water work, somewhat like the Durham Company's special fittings for wrought-iron soil and waste pipes, in which the square ends of the pipes are screwed against shoulders in the fittings, or nearly so, and with the diameter of the elbow or tee no greater than the pipe, then we could, with considerable accuracy, determine the loss of head by a bend or elbow, as we would have little more than change of direction and friction to consider; but with our present common elbows and tees, reasonable approximations only can be formed.

The late Robert Briggs was of the opinion that a common elbow (90 degrees), with a radius of about three-fourths the diameter of the pipe, would use as much of the head for change of direction as a pipe of the same nominal diameter thirty-eight diameters in length would use in friction while passing the same quantities of water or other fluid.

Deductions from the tables of Mr. Thomas Box also seem to confirm this, for what he calls " quick bends," or ones whose radii are about $1\frac{1}{2}$ diameters of the pipe (or double the radii assumed by Mr. Briggs), gives a resistance of about $\frac{1}{4}$ only (for change of direction) of what Mr. Briggs finds, and as this very nearly represents the ratio in which the resistance should decrease as the radii increased, we may reasonably assume that our common elbow will not use more head for change of direction than would be used by friction in 38 diameters long of the same pipe, and that this is the maximum. When the bend has a change of direction of 45 degrees, or only one-half of 90, then the loss per change of direction is only half.

It might be well to mention here, that, although the loss for change of direction in two smooth 45-degree bends only equals the loss in one 90-degree elbow, the total loss in two ordinary 45-degree elbows is much greater than in the one of 90 degrees, on account of the extra nipple, double the number of the enlargements and contractions of the currents and the extra number of square ends of the pipes, and that a much greater loss does ensue from the nippling of two 45-degree elbows together than will follow with one common elbow of 90 degrees.

The *second* division of the loss of head by elbows relates to friction only, and in that case the length of the bend through its centre line is taken and treated as so much straight pipe only.

The third division of the head lost by elbows is, as before stated, on account of the enlargement of the current when it enters the elbow and its subsequent contraction again to enter the pipe as it flows along, making a new point of entry.

There appears to be no question but that we should consider the action of the water in an enlarged bend nearly the same as when it leaves the boiler, and that a fresh point of entry, with its attendant loss, occurs each time. With favorable points of entry this third division of the head that is lost or consumed may be very much reduced, but with square ends there is as much of the head lost each time as is equivalent to three-tenths of the heads given in Table II; and this with very low pressures such as is to be found in hot-water apparatus, is too considerable to be neglected.

On the subject of entry, Mr. Briggs considered that as much head was used at entry as was used by 58 diameters of the pipe, and about the same deduction may be drawn from a study of Mr. Box's tables for small diameter pipes.

From all this, therefore, if we are led to take the extreme view of all the conditions, we are then bound to consider that a short common elbow uses as much head as 38 diameters of the pipe for change of direction alone, and that for entry, with ordinarily fitted square-ended pipes, we must add 58 diameters more, and it points to the fact that the total loss of head from all causes in a common elbow must be about equal to the loss from friction in 100 diameters long of the same pipe; at which rate a 2-inch elbow will consume as much head as 200 inches, or $16\frac{2}{3}$ feet, of 2-inch pipe passing equal quantities of water.

This, of course, is the extreme view of it, and the rule may not hold true with large diameter pipes, as relatively they are not as thick as small ones at the ends, nor are the enlargements of the elbows relatively as great, though, presumably, we should apply it to all pipes smaller than four inches with common elbows.

With such diameter pipes and elbows as we ordinarily have to deal with in a heating apparatus, however, if we accept this as correct, we will be probably on the safe side and may have some little to spare when the radii of our elbows are no less than the three-quarters the diameter of the pipe (say a common elbow).

As the radius increases, however, the resistance decreases, so that in an elbow of 5 diameters radius, but otherwise a common screwed elbow, we have only the resistance to the

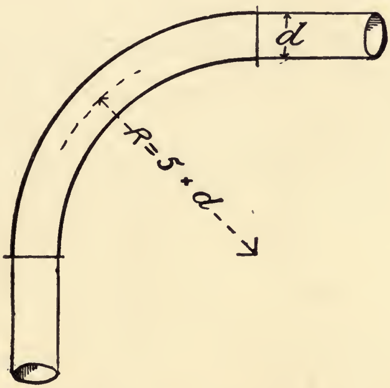

Fig. 22.—Least Radius that will Consume no Head for Change of Direction.

entry of the water into the pipe, plus the loss by friction, to consider, which reduces the head consumed to be equal that lost by a straight pipe 62 diameters long.

If, on the other hand, we have a short common elbow, we will have: (1) a resistance equal to 38 diameters of the pipe for change of direction; and (2) if we take the trouble to ream the pipe ends carefully the resistance to entry may be reduced very much below the value of 58 diameters given to it by Mr. Briggs, so much so that in thick pipes it may become practically nothing, and probably reduce the *total* resistance to considerably less than a straight pipe 50 diameters long will give; as a perfect shaped point of entry would reduce it to 38 diameters

—plus something for friction, which even in a common elbow is less than four diameters of pipe will cause. Should the elbow be a long bend, however, as shown in Fig. 22, then the first factor (for change of direction) is reduced to practically nothing, and the second is done away with altogether, so that friction alone remains and the resistance then is 7.8, or the length of the bend in diameters of the pipe, which reduces it to the same value as so much straight pipe.

To make this more comprehensive, I introduce several diagrams of elbows and pipe, giving each part its value in *diameters*, and by diameters I mean the amount of head that would be consumed by a straight pipe one diameter long.

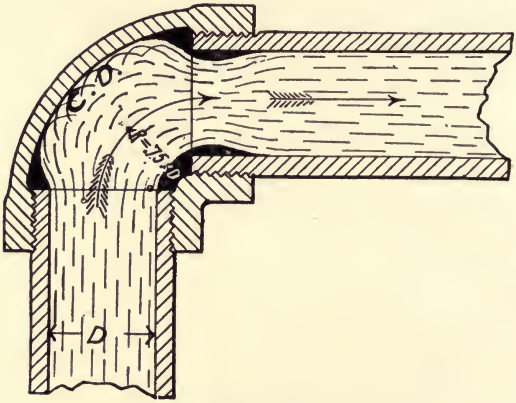

Fig. 23.

Let Fig. 23 be a common elbow with a radius of three-quarters the diameter of the pipe, with square-ended pipes entering it as shown. Then we will have 38 diameters for change of direction $(C\,D)+58$ diameters for entry $(E)+4$ diameters for friction = 100 diameters, as the value of an elbow joining pipes as in Fig. 23.

Let Fig. 24 be a common elbow, with a radius of three-quarters of the diameter of the pipe—same as in Fig. 23—but with the ends of pipes entering it carefully reamed to an easy entry with a reamer, as shown; then we will have for a change of direction $(C\,D)$ 38 diameters + nothing (or nominally nothing) for entry $(E)+4$ diameters for friction = 42 diameters. If the pipe is not thick enough to ream until it gives the proper depth of an easy entry, why then, we must use our judgment and add something to the 42 diameters, and as the roughness of some uncovered threads in the fittings will always play some part in adding to the resistance, we may, perhaps, be justified in calling the value of Fig. 24 as a whole, 50 diameters.

Let us now consider Fig. 25. It is a fairly long diameter elbow, the radius being $1\frac{1}{2}$ diameters of the pipe, and into it we screw a pipe the same as that shown in Fig. 23, by the dotted lines at the edges. Incidentally it is explained elsewhere that to double the radius of a bend is the means also of lessening the head required for change of direction to about one-quarter

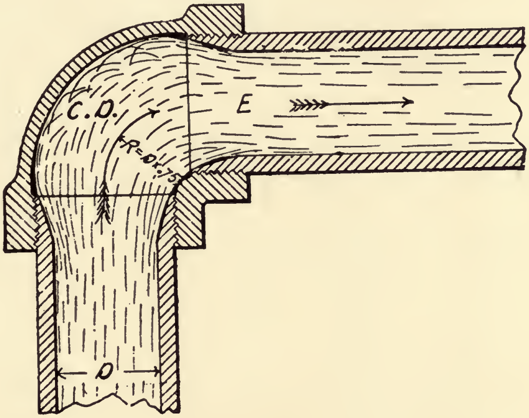

FIG. 24.

what it would be for the shorter radius—in other words, the head required decreases somewhat faster than the inverse of the square of the radius—therefore, for change of direction in Fig. 25, we have, say, $\frac{38}{4} = 9\frac{1}{2}$ diameters, plus *no* diameter for entry, plus 5 diameters for friction (the elbow being longer than before) = $14\frac{1}{2}$ diameters, and if we add 8 diameters (as we did in Fig. 23, for the same reasons as there given), we will bring the value up to $22\frac{1}{2}$ diameters. If we go further and lengthen the radius of elbow to 5 diameters, $C D$ becomes nothing, E, 8, as before, and F, 7.8. The total then is 15.8.

If we make one more diagram (Fig. 26) with the elbow and pipe the same diameter throughout, the radius of the elbow being $1\frac{1}{2}$ diameters, then we have CD $(= 9\frac{1}{2}) + E$ $(= 0.)$ $+ F$ $(= 5.0)$ = total, $14\frac{1}{2}$; and if this elbow is further drawn out, so as to equal 5 diameters radius, then we have CD $(= 0.)$ $+ E$ $(= 0.) + F$ $(= 7.8)$ = total 7.8.

These are approximations that I have reason to believe are not far wrong, and, though perhaps not absolutely correct, give the practical men or mechanic *some definite idea of what the resistance of an elbow really amounts to*, and show how greatly it can be lessened and made almost nothing by proper radii of elbows and easy points of entry.

With a return-bend, the loss for change of direction is just

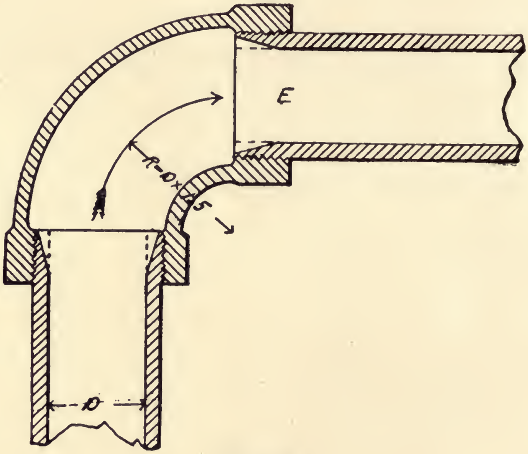

FIG. 25.

double what it would be for a 90-degree elbow. The loss for entry will be no greater, but the same for similar fittings and ends, while the loss for friction will be about doubled, as the bend is about twice as long as an elbow.

The shortest elbow or bend must have a radius of one-half its diameter, and if the back of it is round, the loss of head for such an elbow is about sixteen times as great as it would be in a bend of two diameters, and four times as great as in one of one diameter. So that the advantage to be obtained, by lengthening the radii of common fittings for hot-water work ever so little, is obvious.

Therefore, if we consider the total loss of a common elbow as equal to that caused by 100 diameters of a pipe—being made up of 38 for change of direction, 58 for entry, and the remainder for friction—the resistance of a common close return bend will be equal to about 76 diameters for change of direction, 58 for entry into a square-ended pipe, and, say, 8 for friction = 142 diameters.

If the radius of the bend is doubled, the 76 for change of direction becomes about 19. If an easy entry is made the 58 drops very rapidly, say to 8 again, and friction is increased slightly on account of the increase of length, giving the value, say, of 40—a most decided gain.

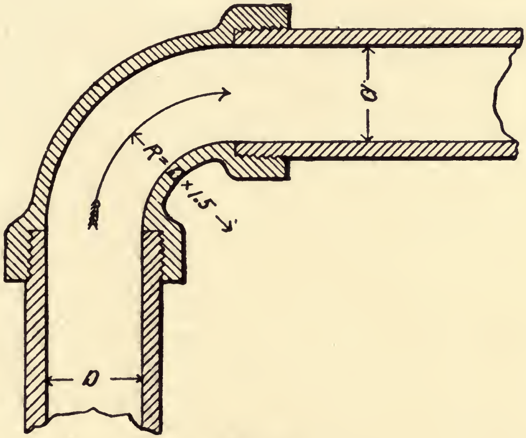

FIG. 26.

In box-coils for hot-water work it is probable that return bends of greater radii than one diameter cannot be used, but by care their resistance value may be reduced to equal that of 50 diameters of the same pipe. So that in an inch-box coil four feet long the length of pipe and the bend can be made to have equal values, whereas, by neglect, the resistance in the bend may be increased to three times as much as the resistance of the pipe.

It might be well to remark here that a common screwed coupling connecting two square-ended pipes of small diameters together has a resistance equal to about 60 diameters of the pipe it connects, and that by carefully reaming the edges of the pipe as shown in Fig. 24, this can be reduced to practically nothing, or without doubt to a resistance of less than ten diameters.

All other fittings and valves cause resistance to the flow of the water. The resistance of a common globe-valve is probably little short of that caused by three common elbows, and in my judgment a common angle-valve will use as much head as two elbows. Straightway or gate valves, therefore, should be used in preference to globe or angle valves, but even they cause considerable resistance on account of the shoulders of disks and seats, etc. The butterfly valves, therefore, are the ones that cause less resistance, and as absolute tightness is not required as a general thing, they should be used in flow and return pipes in preference to any others. I do not wish to create the impression, however, that ordinary gate or angle valves are not suitable for radiators, for with reasonable diameter inlets and outlets they are satisfactory, and I cite the above simply for comparison and to show what may be gained by attention to details.

CHAPTER VIII.

SOME APPLICATIONS OF THE LAWS OF HYDRAULICS.

Flow of Water through Mains of an Apparatus—(1) To find the total head when the quantity of water to be passed and the size and length of pipe is given—(2) To find the quantity of water that will pass in U. S. gallons when we know the total head at our disposal and the length and the diameter of our pipe—(3) To find the diameter a pipe should be for a given discharge, under equal heads, with another pipe, whose length, diameter and discharge are known—(4) To find the discharge by pipes of different diameters, the head and length being the same.

1. To find the total head when the quantity of water to be passed and the size and length of pipe, are given.

From the foregoing tables and what has been said about friction and resistance in pipes and fittings it is not a very difficult matter to determine the amount of head required for any particular set of mains, when the quantity of water passing and the size and length of the pipes are known, as we have simply to refer to the tables.

Say we have a line of straight and level 4-inch pipe, 100 feet long (no provision made for easy entry), passing 50 gallons of water per minute, from the side of a tank or boiler, what will be the total head required? By Table III the head for *friction* of 4-inch pipe passing 50 gallons of water is .243 of an inch for 10 feet of length, and for 100 feet it is $.243 \times 10 = 2.43$ inches. Then by Table II it will be found that half an inch of water-head will be required to move 51.94 gallons of water through a 4-inch pipe without considering the head for friction. This gives us a total of 2.43 inches for friction, *plus* .5 of an inch for velocity $= 2.93$ as the total head necessary to move 50 gallons of water through a 4-inch pipe 100 feet long in a minute. In other and fewer words, the head for friction is directly as the length of the pipe in 10-foot lengths (according to the tables here given), and the head for velocity is a constant, irrespective of length.

If we now put one common elbow into this pipe, such as shown in Fig. 23, we will proceed as in the example given above, but instead of considering the length of the pipe as 100 feet, we will consider it 100 feet + 100 diameters for elbow; which will be 400 inches, or 33.3 feet, making the resistance equal to what it would be in feet 133.3 of straight pipe. Then we will have $\frac{133.3'}{10'} \times .243'' + .5'' = 3.74''$ total head required.

If we had five elbows in a run of 100 feet of pipe, then our problem would be, 100′ of 4″ pipe + 500 diameters (or 166.5) = 266.5′. Then, $\frac{266.5'}{10'} \times .243'' + .5'' = 6.97$ as the total head required for passing 50 U. S. gallons per minute. Of course, when the elbows are better than the common, as explained under "Loss of Head by Elbows or Bends," then fewer diameters must be considered and added as the value of the elbows.

By the above simple means we can always determine the amount of head necessary to produce a certain result in pipes that have been already run or set up. In other words, should we go into a building that had been already piped, or should we have the plans of a job before us, with the lengths and sizes marked, and wished to know if the diameters of the pipes were ample or not for a given velocity and quantity, we would proceed as above and determine the total head required as per plan; when it would be manifest whether the pipes were greater or less than they should be, knowing the greatest head at our disposal, which can be obtained by the aid of the diagram Figs. 14 and 15, pages 21 and 22.

2. To find the quantity of water that will pass in U. S. gallons when we know the total head at our disposal and the length and the diameter of our pipe.

This is one of the most important points to a designer of hot-water apparatus. Where the total head at our disposal is known we are at a loss to know how much of the head is required to overcome the friction and how much is left to produce motion in the water. This does not admit of a direct solution, but we can take advantage of the fact that the discharge by any pipe or series of pipes and fittings is proportional to the square root of their heads (and that *conversely* the head is proportional to the square of the discharge), and therefore all we have to do is to assume a discharge for our pipe, and after having found the head necessary for the assumed discharge (as in 1, pages 47 and 48) apply the above rule thus:

$$\text{Assumed discharge} \times \text{by square root of required head} \div \text{by square root of assumed head.}$$

Thus, say we want to find the number of U. S. gallons that will pass through a 4-inch pipe 100 feet long under *one* inch of total head; we will commence by assuming, say, 50 gallons, and already by (1) we have found that 50 gallons required a total head of 2.93 inches of water, which we will take now as our assumed head; therefore we have quantity looked for =

$$\frac{50 \text{ gallons} \times \sqrt{1''}}{\sqrt{2.93}},$$

which is equal to

$$\frac{50 \times 1}{1.70} = 29.4 \text{ U. S. gallons}$$

as the quantity that will pass under one inch of total head through a 4-inch pipe 100 feet long.*

Having now found the quantity of water that will pass through 100 feet of 4-inch pipe under a *one-inch* head, it is important, also, that we should be able to establish the diameter of a pipe of the same length and under the same head that will discharge some other desirable or fixed quantity of water.

First we found the total head for an assumed quantity, the *length* and *diameter* being known (1). Then we found the actual quantity that would pass through the same pipe under the smaller head of one inch (2), and now we want to establish a new diameter—the length remaining the same—that will pass, say, 50 gallons, as at first assumed (1), but to pass it with only *one inch of head* (2).

* Those who do not wish to work out the square roots of numbers can find tables in Trautwine's or Haswell's Pocket-Books that give the desired information.

This can be done by taking advantage of the fact *that the diameters of pipes vary directly as the fifth root of the square of their discharges*, head and length remaining the same; in other words, the diameters of pipes are proportional to the $\sqrt[2.5]{\text{discharge.}}$*

Thus our third problem :

3. To find the diameter a pipe should be for a given discharge, under equal heads, with another pipe whose length, diameter, and discharge are known.

In our last problem (2) we found that 29.4 U. S. gallons would pass through 100 feet of 4-inch straight pipe under a total head of one inch. Let us now see how large a pipe of the same length it will take to pass 50 U. S. gallons under one inch total head.

The sum, according to the rule given, resolves itself into a simple proportion, thus:

The fifth root of the square of 29.4 gallons	:	a diameter of 4 inches	: :	the fifth root of the square of 50 gallons	:	× inches

= the new diameter in inches.

Or the following simple formula:

$$\frac{\sqrt[2.5]{\underset{50.0}{\text{gallons.}}} \underset{\times 4}{\text{inches.}}}{\sqrt[2.5]{\underset{29.4}{\text{gallons.}}}} = 4.9 \text{ inches,}$$

the new diameter.

It probably is not plain to many very practical men how this answer is obtained, so we will endeavor to go over it in a simpler manner still.

When the discharges from pipes are in the ratios of 1, 2, 3, 4, 5, 6, etc., the diameters will be in the ratio of 1., 1.32, 1.55, 1.74+1.90+, 2.05–, etc.

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* As it is a difficult thing to extract the fifth root of a number, and as practical men rarely wish to go into abstract calculations, I will refer them to Trautwine's Engineering Pocket-Book, where they will find tables of *fifth roots and fifth powers* that will obviate tedious calculations and, presumably, avoid clerical errors.

These ratios of the diameters may be picked out of Trautwine's Tables of Fifth Roots and Fifth Powers by squaring the discharges and substituting the answers thus found for the "Power" in the tables; opposite to which is the Number or Root that is the ratio of the diameter.

In our case, then, we have 29.4 and 50 gallons respectively that we must first square, and then find the fifth root of the respective squares. To get the fifth root of the square of either of these numbers will take us far beyond the limit of the tables of reference cited heretofore, but we may (without much error) use some common divisor, such as 10, and reduce the discharges to 3 and 5 respectively and then proceed as above.

Thus, 3 squared = 9, the fifth root of which is 1.55.

Then, $5^2 = 25$. the fifth root of which is 1.9.

Then, 1.55 : 4 : : 1.9 : X″
1.9
―――
1.55)7.60(4.9 inches.
6.20
―――
1.400
1.395
―――
5

Thus the diameter sought is very nearly five inches, and as there is no 4.9-inch merchantable pipe, the nearest practical size larger (5-inch) should be used.

4. To find the discharge by pipes of different diameter, the head and length being the same.

This is necessary for the engineer when he has found the capacity of one set of pipes and wishes to know the capacity of another set, either larger or smaller in diameter but with the same head and length.

The rule for this is, that the discharges from pipes of equal lengths and heads is in the ratio of the 2.5 power of the diameter or the converse of the foregoing (3). The symbol "2.5 power" means the square root of the fifth power of a number as here written.

For the reason given before to practical men, a table of the 2.5 powers of numbers can be used much more readily than to attempt to find the root and raise it to the fifth power, therefore I again refer the reader to Trautwine's tables in this matter, and, by a study of the same, it will show that with the diameters in the ratio 1, 2, 3, 4, 5, 6, etc., the ratio of discharge will be 1., 5.65, 15,59. 32., 55.9, 88.18, and so on.

Let us, then, proceed to find the discharge by 100 feet of 6-inch pipe under a 1-inch head; the discharge by a 4-inch pipe of the same length and head being 29.4 gallons. This is simple proportion again, so long as we have the ratio the discharge bears to the diameter, and this can be taken from the tables of the " Square Root of Fifth Powers " before mentioned, or the above ratios may be used as far as they go. Thus:

2.5 power of known diameter	:	known discharge	: :	2.5 power of required diameter	:	(×) discharge =

(in this case) $4\frac{5}{2}$: 29.4 gallons : : $6\frac{5}{2}$: (×). Then substituting the ratio for the diameters we have

```
Ratio. Gallons.   Ratio.
 32  :  29.4  : : 88.18 : ×
        88.18
        -----
 32)2592.49(81.01+gallons
    256.
    ----
      32
      32
      --
      49
      32
      --
      17
```

or about 81 U. S. gallons that will pass through a 6-inch pipe 100 feet long under one inch of head.

CHAPTER IX.*

THE METHOD OF DETERMINING RADIATING SURFACE.

How to Compute Radiating Surfaces—Experiments of Tredgold on Warming Surfaces.

Before we can proceed to construct and settle the proper sizes for the mains and other pipes of a hot-water apparatus, we have first to determine the size of the radiators or coils that we must use, and the quantity and temperature of the water that we must pass through them.

To keep a room warm by artificial means, we must add as much heat to its walls and the air enclosed within them, through the medium of our radiators or coils, as is given off from the same room by the glass of its windows, its walls, the air admitted and extracted for ventilation, as well as the cooling done by accidental causes, such as leaky windows, doors, etc. In well-built houses the latter (or accidental) factors become small. In poorly-built ones they are often large, and in frame or wooden houses they are, as a general thing, greater than in brick houses.

To find the amount of radiator surface necessary to counteract the effect of windows and walls, it is necessary for us to have a good conception of the amount of heat lost through the windows and walls. It is also necessary to know how much heat will pass from the water inside our pipes to the air of the room for given surface of the pipe—say one square foot.

Heat from a room or building is lost by radiation, conduction, and convection. From a philosophical point of view, it would be desirable for us to know how the sum total of the heat lost is divided between these three methods of transmis-

* Before applying the rules in the foregoing chapter to the question of determining the size of flow pipes, etc., for ordinary conditions of practice, it is necessary that the reader should become acquainted with the subject of the loss of heat from the radiators, so as to determine the amount of water to be passed through them in an hour or any other given time; hence the introduction of chapters IX and X at this part of the book.

sion, but for our purpose it is only necessary to know what the total amount is and how to find it—at least approximately.

At low temperatures, or such as we are likely to have to deal with in hot water and air questions, the heat given off by radiation is less than that given off by convection and other causes. Above 400° fahr. the heat given off by radiation alone becomes greater, but with this we have nothing to do at the present time, though when speaking of boilers hereafter it may be well to say something about it as bearing on their design.

Mr. Thomas Tredgold, C.E., in his work on "Warming and Ventilation," the third edition of which appeared in 1836, (after his death), while speaking of the laws of cooling, says: "If the surface giving off heat be different at different times" (having different temperatures only, he undoubtedly means), "the heat given off in a given portion of time will be directly as the excess of temperature of the surface of the body giving off the heat in gaseous media, or in any fluid that is kept in motion."

This would be according to Sir Isaac Newton's theory of the law of cooling; and though later investigators (Petit, Dulong, and others) have demonstrated that this is not absolutely true for even low temperatures, and that at very high temperatures it is erroneous, we have, nevertheless, Dalton and Leslie as authority for the fact that, for differences of temperature between *mean temperatures* (40° fahr.), and 212° fahr., it is correct enough for any ordinary purpose.

If we accept this, the quantity of heat given off will be directly as the surface and the difference of temperature between it and the media it is giving heat to. This, however, holds true only of surfaces of a like description against which the air can come in contact and rub freely at all points, such as flat windows, flat walls, and flat or vertical radiators; and by flat is meant surfaces that the air can come freely in contact with either as it rises or falls—one whose vertical plane is straight.

We are not far wrong, presumably, when we contrast for comparison the flat surface of a sheet-iron heater with the glass of a window while taking the difference of temperature into consideration, and it was this I did when I adopted the empirical rule given on page 373 of "Steam-Heating for Buildings" which reads: "Divide the difference in temperature between that at which the room is to be kept and the coldest outside atmosphere by the difference between the temperature of the steam-pipes and that at which you wish to keep the room, and the product will be the square feet or fraction thereof of plate or pipe surface to each square foot of glass (or its equivalent in wall surface)."

According to this rule if we desire to keep a room at 70° fahr. when it is zero outside, with the temperature of the radiating surface 212° fahr., we have:

$$\frac{\begin{array}{c}\text{Difference between temperature of}\\ \text{room and outside temperature,}\\ 70^\circ \text{ fahr.}\end{array}}{\begin{array}{c}\text{Difference between steam-pipes}\\ \text{and air of room.}\\ 142^\circ \text{ fahr.}\end{array}} = .493 \text{ sq. ft.}$$

or, say, one-half a square foot of plate surface.

Now, use has confirmed this rule as sufficiently near for practical purposes, with ordinary good radiators, either in vertical or horizontal coil form, when the length of the vertical pipe or loop is not greater than 30 inches, and with horizontal coils of 1-inch pipe not higher than eight in number.

This, of course, is only an approximate rule for use in direct radiation alone, and, with a liberal addition of from one-quarter to one-half to provide for air admitted accidentally, has always proved sufficient in low-pressure steam-heating.

Of course, the value of the walls, in addition to windows, as cooling surface must not be overlooked, and though we have only spoken here of glass, each 7 to 12 square feet of wall surface, according to its nature, will have a cooling power equal to a square foot of glass, and must be considered the same.

The above is the first and simplest way of finding direct radiating surface for rooms. The example taken, however, was for radiator surface at a temperature of 212°. This is too high a temperature for low pressure hot-water practice, and the writer, in his own practice, in designing for hot-water apparatus, prefers to make his figures on the basis that the water in the coils or heaters of the apparatus has a temperature of 140° fahr., and that the outside temperature is 30°, or just below freezing point. As the temperature outside goes down, it is then possible to increase the temperature of the water in the radiators or coils by keeping a stronger fire in the boiler. This gives us:

1. Temperature of air of room, 70° fahr.—temperature outside, 30° fahr. = 40° fahr.

2. Temperature of coils of heating surface, 140° fahr.—temperature of air of room, 70° fahr. = 70° fahr.

3. 40° ÷ 70° = .571 as the part of a square foot of heating surface at 140° fahr. that will counteract the cooling done by one square foot of glass or its equivalent, under average circumstances, when the outside air is 30° fahr.

Of course, to make this a scientific equation, the relative velocities of air-currents would have to be taken into consideration, which would bring wind velocities into the question; that would so complicate matters—and that unnecessarily—that no attempt will be made to do so, as, with a hot-water apparatus under increased wind velocities, we have the same means of increasing the efficiency of our surface as we do under a lowering of temperature—namely, the increase of temperature of our water within the limits of our initial coil temperature (say 140° fahr.), and our maximum 212° fahr. or the steam-making point under our atmosphere; which gives us a reasonable range of temperatures that is sufficient to carry us down to a temperature of about 10° below zero outside.

The following columns show approximately the increase of temperature of the surface to the decrease in outside temperatures, increased wind velocities not considered:

Temperature of surface	Temperature outside	Ratio of heating surface in square feet to a square foot of glass
140° fahr.	30° fahr.	.571
157° fahr.	20° fahr.	.57
175° fahr.	10° fahr.	.57
192° fahr.	0° fahr.	.57
210° fahr.	10° below.	.57

This gives us the same ratio of hot-water surface as we would have of steam surface figured for the same conditions, and there is no good reason why we should use more surface for hot water than we should for steam, the surfaces having the same temperature. In "Steam Heating for Buildings," the ratio is .49, because it was assumed the temperature outside was zero fahr. and the temperature of the pipe 212° fahr.; but here the calculations are based on the assumption that the air outside is 10° below zero, so that for low temperatures in the coils the surface may prove a little more efficient.

To this ratio of .57 of a square foot of pipe or plate surface to one of glass, or its equivalent of wall surface, from one-quarter to one-half more should be provided for warming air accidentally admitted and for loss of heat by sources other than the walls and windows, and the addition must depend on the character of the building and the judgment and experience of the designer.

Roughly, then, for hot water, a building will require a ratio of plate or pipe surface of from .70 to .85 to one of glass at the temperatures given in the first column in the table to maintain them at 70° fahr. by direct radiation when the air outside is of the temperatures given in the second column.

Mr. Thomas Tredgold, early in the present century, considered the question of loss of heat from heated surfaces in a very thorough manner, and, later, he was followed by Mr. Charles Hood on the same subject, both having the same object in view—namely, to find the value of radiating surfaces for warming buildings.

Mr. Tredgold found that 2.19 pounds of water cooled from 180° to 150° fahr. in a vertical tin cylinder in 46 minutes, the exposed sides of which were 79 square inches, when the temperature of the room was maintained at $55\frac{1}{2}$° fahr. during the trial. This gave a mean difference between the air of the room and the surface of the cylinder of 109.5° fahr.

From this we have 2.19 pounds of water cooled 30° fahr. by $\frac{79}{144}$ of a square foot of surface in 46 minutes of time, which is equivalent to 65.7 B.t.u. for the time, or 85.7 B.t.u. for an hour of time, and 156.21 B.t.u. as what would be given off by one entire square foot of the same surface (tin cylinder) in an hour of time. This total heat, for a square foot of surface, for an hour of time, then, divided by the *mean* difference of temperature (109.5° fahr.) between the air and the surface of the cylinder equals 1.42 B.t.u.; the amount given off per square foot of surface per degree difference of temperature.

His *second* experiment was with a glass cylinder that held 2.125 pounds of water and had a surface of 71 square inches. It cooled from 180° to 150° fahr. in $31\frac{1}{2}$ minutes in a temperature of $56\frac{1}{2}°$ fahr., which, by the same method of reasoning as we used before, gives 2.269 heat-units per hour per square foot of surface per degree (fahr.) difference.

His *third* experiment was with a sheet-iron cylinder—the surface being that of new sheet iron unpainted—whose surface was 76.7 square inches, holding 2.14 pounds of water and cooled from 180° to 150° fahr. in 29 minutes, the temperature of the air of the room being 57° fahr. By the same reasoning and method of calculation used in the foregoing examples we can find that the sheet-iron gave off 2.309 heat-units per hour per square foot of surface per degree difference of temperature.

These cylinders were as nearly alike as they could be obtained in form and size, and one cover fitted all. They were suspended by cotton threads, so little or no heat could be lost by conduction or contact, and the sides and bottoms were exposed to the action of the air, etc. The top was covered by about one inch in thickness of alternate folds of cotton and flannel, so that the loss of heat by this direction was very small.

A few days later when the experiments were repeated the iron cylinder had become rusted. This, Mr. Tredgold says, increased its efficiency in the proportion of 156 and 180; the rusted cylinder having the latter value when as a new one it had the former. The experiments with the tin are of no value to us except to show that bright surfaces have a less value than dull or slightly roughened ones. Experiments with brass, etc., by other experimentors confirm this. The relative values of glass and iron, however, are of some value to us as showing how nearly they agree; the iron being the better of the two, even when new and bright, and increasing in value as it becomes rusty.

It would be well to remark here that, probably, when surfaces become dusty, which they will in practical heating, they may deteriorate somewhat, and that it would be well to assume that what they may increase in efficiency by rusting will be fully offset by accumulations of dust, etc.

The form of Mr. Tredgold's cylinders—short, vertical ones—are, presumably, the best that can be devised for giving off heat. The same cylinders in a horizontal position would probably be found to be a little less efficient, and if they were to be increased in height, say two or three times, though used in a vertical position, it is only reasonable to suppose they would do less duty, for the very simple reason that the air in contact with the upper parts would have been warmed somewhat by the lower part as it passes upward, and, therefore, is not capable of extracting as much heat. The same holds good for horizontal cylinders or pipes when placed one above the other; each successive one, counting from the bottom upward, does less work than the one next below it.

According to the above relative values, therefore, of glass and iron, the empirical rule given above for finding heating surfaces by the window area, etc., is not without some scientific pretence, as the loss of heat through the glass of a window can rarely, if at all, be greater than through the iron of the heaters for equal difference in temperatures or for proportional differences.*

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* I do not draw the same deductions from Mr. Tredgold's experiments that he does himself, and, therefore, did not give his figures here, but substituted my own in the manner just shown; the summary of the matter being that the heat lost through glass would be 2.269 B.t.u., when that lost through iron would be 2.309 B.t.u.

CHAPTER X.

EXPERIMENTS IN RADIATION AND COOLING.

Experiments of Hood on Warming Surfaces—Cooling Effect of Window Glass—Experiment with Coils—Mr. Barrus' Experiments with Steam Radiators and Their Probable Bearing on Hot-Water Surfaces—Value of Average Vertical Radiator Surface.

To go further with this subject, I will refer to experiments of Mr. Hood made more recently than Mr. Tredgold's, as he was not satisfied with the latter's deductions, and made experiments for himself. In his work on "Warming and Ventilation" he tells us that "to ascertain the velocity of cooling for a surface of cast iron, a pipe 30 inches long and $2\frac{1}{2}$ inches internal diameter and three inches diameter externally was used. The ends of the pipe were closed by corks, which entered the pipe $1\frac{1}{2}$ inches at each end, and the bulb of the thermometer was inserted into the water about three inches from one end. * * * The exposed surface of the pipe (including the surface exposed by the thickness of the metal at the ends) was 287.177 square inches. The quantity of water contained in it was 132.534 cubic inches, and the equivalent to be added to this for the specific heat of the pipe was 39.341 cubic inches, making the estimated quantity of water 171.875 cubic inches." The temperature of the room in which the observations were conducted was 67° fahr.

This pipe was presumably used on its side in the horizontal position (though this is not stated), and represented no doubt a section of an ordinary 3-inch cast-iron heating-pipe used at that time for green-house heating, etc.

He informs us the rates of cooling were tried with different states of the surface: *First*, when in the usual state of cast-iron pipes covered with protoxide of iron (fine rust); *second*, black varnished; and *third*, with the varnish removed and two coats of white-lead paint substituted. He observed that the rusty surface cooled from 152° to 150° fahr., or 2 degrees, in 2.5 minutes and that it cooled from 152° to 140° fahr., or 12 degrees, in 15 minutes. This is at the rate of the whole quantity of water, or its equivalent, cooling one degree in 1.25 minutes.

He took observations every *two* degrees fall of the thermometer, which gave slightly varying results as to the rate of cooling. This variation may be due to errors in reading the scales or in errors in the thermometers, and a close study of the table of his experiments go to confirm the belief that for all practical purposes of house-warming the rate of cooling is very nearly directly as the difference of temperature between pipe or plate surface and the surrounding air.

With the black surface of the pipe black-varnished he found that to cool from 152° to 150° fahr. (2 degrees) it took 2.266 minutes, and that to cool from 152° to 140° fahr. (12 degrees) it took 14.533 minutes; or, in other words, cooled an average of one degree in 1.21 minutes. If we take the average of six experiments (1.23 minutes), progressing by two degrees, and correct the time observed on cooling the first two degrees by it, we have 2.42 minutes, instead of 2.266 minutes. This shows that the black-varnished surface is slightly more efficient than the rusty one—a little over three per cent.*

With the pipe with two coats of white-lead paint, the efficiency was less than with either of the others, but not as great as usually considered.

The cylinder cooled from 152° to 150° fahr. (2 degrees) in (observed time) 2.316 minutes, and it cooled to 140° fahr., or 12 degrees, in 15.366 minutes; or, in other words, it cooled one degree in 1.28 minutes average.

Mr. Hood's summary of the matter is that 100 feet of varnished pipe, 103¼ feet of plain pipe, and 105¾ feet of white-painted pipe have the same values as heating surface. He does not, however, give us the values of these surfaces in B.t.u. per square foot per degree difference any more than Mr. Tredgold does, and as this will be very important to us hereafter when we desire to ascertain the quantity of water that must pass through a heater at a given time, to maintain some constant

* In comparing these statements with Mr. Hood's table, note that the time here is given in minutes and decimals of a minute, while in the table it is given in minutes and seconds.

temperature, we will have to calculate it for ourselves by the same method of reasoning which we used in the case of the latter's experiments.

The surface of the experimental piece of pipe is given as 287.177 square inches, which is two square feet lacking less than one square inch, and therefore we will call it two square feet. The quantity of water actually contained in it was 132.534 cubic inches, and the equivalent in cubic inches of water that was to be added for the specific heat of the iron of the pipe, 39.341 cubic inches; making the estimated value of the water and its envelope equal to 171.875 inches of water.

The water was cooled from 152° to 140° fahr. in each experiment, and therefore had a *mean* temperature of 146° fahr. The weight of a cubic inch of water at this temperature is 248 grains; therefore we have

$$\frac{171.875 \text{ cu. in.} \times 248 \text{ grs.}}{7{,}000 \text{ grs. (1 lb.)}} = 6.089 \text{ lbs. of water.}$$

This water was cooled 12 degrees in the various times, which gives us $6.089 \times 12 = 73.068$ heat-units as the total heat given off in each case from two square feet of heating surface, or 36.534 heat-units per square foot.

The air of the room was 67° fahr.; consequently the difference of temperature—or, in other words, the excess of temperature of the surface over the air—was 79 degrees.

The time for cooling the rusty cylinder was 15 minutes, or one quarter of an hour; therefore we have:

$$\frac{36.534 \times 4}{79° \text{ fahr.}} = 1.849 \text{ heat-units}$$

per square foot per hour per degree difference. For the varnished surface it is 1.909 heat-units, and for the white-painted surface 1.805 heat-units.

To ascertain the effect of glass windows to cool the air of a room, Mr. Hood made experiments with a glass vessel as nearly as possible of the same thickness as ordinary window-glass. The temperature of the room was 65° fahr., and the surface of the vessel was 34.296 square inches, and it contained 9.794 cubic inches of water, including the equivalent for the specific heat of glass. He does not tell us the form of the vessel, which would be very important to know, but, presumably, it was rectangular, or at least had perpendicular sides, and, being small, represented an average effect in cooling; so that the deductions obtained are, presumably, fully equal to average conditions.

The average rate of cooling from 150° tc 110° fahr. was found to be 1.176 degrees when the *mean* excess of temperature of surface was 65° fahr. above the temperature of the air, and the time 34 minutes.

The total quantity of water, or its equivalent, is found to weigh .3482 pound at a temperature of 130° (its mean temperature). This cooled 40° fahr. = 13.93 B.t.u. for 34.296 square inches, or 58.48 B.t.u. for a square foot for 34 minutes, or 103.2 heat-units for an hour; divided by the mean difference in temperature $= \frac{103.2}{65°} = 1.59$ heat-units per square foot per hour per degree difference of temperature.

Mr. Hood's deductions from his experiment is to the effect, that each square foot of window-glass will cool in a minute of time 1.279 cubic feet of air as many degrees as the inside air is warmer than the external in a comparatively still atmosphere, but that when windows are exposed to the action of winds further experiments are necessary.

It is evident the cooling of air through glass, etc., depends on both the velocity of the air inside and outside taken together.

Nearly all the heat that is lost by air of rooms to cooler air through glass is lost by convection. The air inside the glass falls by loss of heat and increase of weight and follows the laws of a falling body. The velocity of air outside is due to wind-pressure and the angle at which it strikes the glass. Quadrupling the velocity of the outer air, however, does not quadruple the loss of heat through the glass, for the reason that the air inside will not fall in the same ratio, but in a ratio about as the square root of the increase of outside velocity, so that the loss of heat through glass cannot be accurately established for a given difference of temperature and a certain velocity of the wind outside; an approximation, however, can be made to the loss of heat for other velocities and temperatures. Unfortunately, we have no very accurate data on the cooling effect of windows for the guidance of heating engineers, though on the warming effect of radiator surfaces there is not such a scarcity of information.

As this book is on warming by hot water, I would like to give some data on the values of hot water surfaces used in common practice in this country. For the present, however, I shall content myself with an experiment with a common box coil that is similar in many respects to a radiator set for direct radiation.

While making experiment on indirect coils I boxed one at the sides and ends and left the top and bottom open, so the air ascends vertically. Presumably, slightly better results would be obtained if the heater was open at the sides as well as top and bottom, but of this there is some doubt.

The coil was of *one*-inch pipe, 6 pipes wide, 10 pipes high and 36 inches long between bends; the total surface of pipes, bends, and headers being 74 square feet. A difference of about 110 degrees was maintained between the air of the room and surface of the pipes during the time of trial. By measuring the increase of temperature of the air and its quantity, etc., after passing the coil, the amount of heat found corresponded to 1.343 B.t.u. per square foot of surface per hour given off for each *one* degree fahr. the air was warmer than the coil. The coil-box was then closed in at the top until the outlet for air was 12 x 16 inches without apparently diminishing the flow of air, the better to use the anemometer, and the result obtained was practically the same. This is somewhat smaller than the result obtained by Mr. Hood, as given for the 3-inch horizontal pipe. We would naturally expect, however, that the coil would do the less work, because ten pipes in the box coil stand one above the other. The difference may have been lessened by an air acceleration due to the boxing in of the coil.

It may also be that an error existed in the use of the anemometer and that it recorded more air than actually passed, which is possible by taking the centre of the current; the rubbing sides of the box and pipe causing a slower velocity there than was measured where the anemometer could be used. It is not safe, however, to give a box-coil ten pipes high, used for direct radiation, a higher value than 1.343, and, presumably, 1.25 B.t.u. is high enough.

Mr. George H. Barrus, of Boston, in experiments with a Walworth vertical wrought-iron pipe radiator for steam, found that under average conditions of use, with eight pounds of steam, in an atmosphere of about 51° fahr., that the B.t.u. given off per actual square foot of surface was 394.4. If we assume the surface of the iron to be 235° fahr. (the temperature of the steam), we have $235° - 51° = 184°$ difference. Then

$$\frac{394.4}{184°} = 2.143 \text{ B.t.u.}$$

This is somewhat less than Mr. Tredgold's experiments give for a short vertical cylinder, but it is what would be expected, as the pipes used were thirty inches long, and in a cluster two inches wide, screwed into a base.

He also experimented with a Nason radiator of ordinary height, two pipes wide by 24 pipes long. The total number of B.t.u. per square foot of surface given off was 347.6; the pressure of the steam was eight pounds, and the temperature of the air of the room 65° fahr. Assuming the temperature of the pipe to surface to be 235° fahr. then the difference between air and heating surface is 170° fahr., which gives us $\frac{347.6 \text{ h. u.}}{170°}$ $= 2.045$ B.t.u. per hour per square foot per degree difference.

Mr. Barrus' method of measuring the heat was to receive the water of condensation carefully and to ascertain its weight, then compute the heat according to the latent heat of steam. The nearness of the results thus obtained by vertical radiators of different makes, and at different times in different buildings, by the same methods, adds value to the data and establishes the fact, when taken with other investigations, that a tube of a vertical radiator will give off heat equal to about two heat-units per square foot per hour per degree difference.

An experiment made by the writer in 1884 on a 2 x 7 Bundy steam-radiator, for his own information, and before the Bundy patterns were altered to have an actual surface equal to their commercial rating, gave the following results: Actual surface, 38 square feet; water condensed for one hour was 12.843 pounds, when the pressure of steam was maintained between 1 and 1½ pounds; temperature of air of room at floor commencement of experiment, 52°; at 5 feet high on side wall, 58°; temperature of air of room at floor at end of experiment, 57½°; and at 5 feet high, 64°. The temperature of the air as it was found at the floor was, presumably, the temperature at which it first came in contact with the heater, but, as in the other cases, the temperature of the room only was noted—without informing us further—we will in this case take the mean of the temperature given, which is 57.9° fahr., and, presumably, near enough for our purpose, which is not to compare rival heaters, but to establish the condensation or cooling for ordinary conditions of use.

Taking the temperature of the steam (one pound), therefore, at 215° fahr., and the latent heat of its vaporization at 962 heat-units per pound, we will have: difference of temperature between steam (or pipe), 157.1° fahr., and total heat of 12.843 pounds of steam, 12,355 B.t.u., or 325.1 B.t.u. per actual square foot of surface, equaling 2.07 B.t.u. per square foot of surface per hour per degree of difference between steam and air.

It is possible that should these radiators be transposed as to the buildings they were tested in, the results would slightly differ, as the effect of the passage of heat by radiation alone from or to the radiator cannot be estimated, as it will depend on the surrounding walls, etc. For instance, one experiment being made in a cellar and another on an upper floor of a building, it is reasonable to assume it will affect the results, and the question of humidity may also come in as a factor for or against a radiator. Draughts of air, also, will materially alter results, and the effect of an open hatchway, machinery in motion, or down draughts from windows, etc., will all tend to throw some uncertainty into the matter, so that unless positions, etc., are transposed and the water of condensation measured in the same manner and similar apparatus, it would be difficult to determine positively which of the above radiators gives the highest result per actual square foot of surface. Such remarkable uniformity, however, by different makers appears to establish beyond a doubt that 2 heat-units per square foot of surface per degree difference of temperature between surface and air may be taken as the basis of loss of heat from vertical radiators whether they are for hot water or steam.

This, of course, is the maximum, and it is for radiators of plain, smooth surface, say not over three feet in height, that are not covered up with screens or slabs, but used in the most practical manner and not too close to the walls. It should be borne in mind, also, that these radiators were only two pipes wide and represented more than the average, and that radiators of three or four pipes wide should not be expected to give quite as good results.

It is very probable, taking all the styles and kinds of radiators and coils known to the writer, that the minimum condensation or cooling may be placed at 1.25 B.t.u. and the maximum at 2 B.t.u. Between these points it must be left to the judgment and experience of the fitter to select when the character of the radiator or coil is known.

CHAPTER XI.

THE QUANTITY OF WATER REQUIRED BY RADIATORS.

How to Find the Amount of Water that Should Pass through a Radiator to do a Certain Duty—How to Determine the Size of Inlet and Outlet to Hot-Water Radiators—A Reasonable Loss of Temperature to the Water while Passing through a Radiator—The Quantity of Water that Should Pass through a Radiator for a Loss of Temperature of 10 *Degrees fahr.—The Diameter and Resistance of Radiator Connections—The Diameters of Pipes for a Loss of* 20 *Degrees fahr.—The Diameters of Pipes for a Loss of* 30 *Degrees fahr.*

The object of the last article was to fix in the mind of the reader the average quantity of heat given off per square foot of ordinary heating surface when placed within a room and used as a direct radiator, and to give him a knowledge of the experiments and *data* on which it is based.

A summary of the matter, therefore, points to the fact that the best vertical tube radiators will do duty a little in excess of two heat units per square foot of surface per hour for each degree the radiator is warmer than the air, and that the poorest form of coil or radiator, as ordinarily made, if exposed to the free action of the air, will not go under 1.25 B.t.u. This, remember, is for direct radiation only, with natural currents of air, or such movements of the air as are produced by the heat of the radiator.

Knowing, then, the heat given off by a radiator for a unit of surface, our next step is to determine the total amount of water that should pass through in a given time to do a certain duty, and from this determine the size of inlet and outlet equal to that duty.

Let us assume we have a radiator of 100 square feet in a room with the air at 70° fahr., and that the water enters at 210° and flows out of it at 200° fahr. This is equal to a loss of 10 degrees, making the mean temperature of the water in the radiator

$$\left(\frac{210+200}{2}\right) = 205°.$$

We have then the difference between the water (205° fahr.), and the air of the room (70° fahr.), or 135 degrees, which, multiplied by B.t.u. and by 100 square feet. gives us 27,000 units of heat that is given off by the radiator in an hour, or the equivalent of 27,000 pounds of water cooled one degree.

It is not our object, however, to pass the water so rapidly that it will cool but *one* degree between the inlet and outlet, as we would therefore have to pass 3,375 gallons of water through the radiator in an hour, which would call for radiator connections so enormously above practicable sizes—with heads of water to be obtained in ordinary hot-water practice—that we must content ourselves with a difference or loss of temperature between inlet and outlet of, say, 10 degrees. Therefore, we divide 3,375 gallons by 10 and find that instead of passing 3,375 gallons with a loss of one degree we pass 337.5 gallons with a loss of ten degrees.

This is for an hour of time, and consequently 5.625 gallons will be the amount to pass in a minute, and if we turn to Table II, page 32, we will find that a common one-inch nipple under one inch of water head is not sufficient to pass it, as its capacity is but 4.6 U. S. gallons per minute, and that in practice we would have to take the 1¼-inch nipple, whose capacity is 7.2 U. S. gallons.

In ordinary apparatus, however, the connections to radiators are always longer than nipples, and we have also to take into consideration not only the increased length of connections but the effect of elbows or other fittings and valves on the flow of the water.

From a rising line to a radiator and back again to a return riser, or the ordinary connection through a floor from a main underneath, it is certainly not safe to place the average length of the two connections when taken together at less than ten feet, and to this should be added from four to six elbow turns and one valve. We have, therefore, to find, not the size nipple that will pass 5.625 gallons of water, but the size pipes of ordinary lengths with their turns and valve for an average condition of practice.

This brings us to a point where the rules given in Chapter VIII will be of service to us. In the above case we have (1) determined the quantity of water that must be passed through the radiator to be 5.625 U. S. gallons per minute; (2) the diameter of the pipe we are at liberty to assume as being 1¼ inches, and (3) the length is fixed at ten feet, with six common elbows, square-ended pipes and angle-valves.

According to Chapter VII, we must, for friction, add to the length of the pipe, in determining its resistance, 100 diameters for each common elbow, and for an angle-valve something like 200 diameters, so that the ten feet of 1¼-inch pipe becomes 10 feet + 800 diameters (83.3 feet) = 93.3 feet; or, in other words, the resistance of the connections to the flow of the water—though only ten feet long—is equal to the resistance of 93.3 of straight pipe.

By Table III we find the friction for ten feet of 1¼-inch pipe passing five gallons of water—or the nearest to our quantity—to be .837 inches of head, and by interpolation we may establish the friction head for 5.625 gallons to be about 1 inch, and consequently it will be $1 \times 9.33 = 9.33$ inches for our connections as a whole. This, remember, is only the head to overcome friction, and to it must be added the velocity head as found by Table I, and which will be seen to be under ½ of an inch though above ¼ of an inch, and which it is as well to take as the former, so the error will be in favor of the diameter of the pipe. This will make the total head, therefore, 9.83 inches.

This head is considerably more than we are likely to obtain in ordinary practice in low-pressure apparatus. It is about equal to the head obtained in an apparatus when the water is cooled from 212° to 152° fahr., whose height would be forty feet. In designing for the *maximum-sized flow-pipe*, we should consider an apparatus whose height would not exceed 10 feet, and if we require that the water of the apparatus shall not cool more than 10 degrees, or say from 210° to 200° fahr., the total effective head at our disposal will be but .44 inches, as will be seen by diagram, Fig. 14.

For this head, therefore, .44 inches, we have to find a new diameter. With a head of 9.83 inches, a 1¼ pipe was ample, but with a head of .44 a greater diameter is necessary. The rule for this is: When *quantity and length* are to remain constant the diameters will vary *inversely* as the fifth root of the heads. The above heads, therefore, are in the ratio of 1 and 22.34, and the inverse ratio of their fifth roots is 1.86 and 1, so that the $1\frac{1}{4}$-inch pipe must be enlarged to

$$\frac{1.25'' \times 1.86}{1} = 2.325 \text{ inches}$$

as the new diameter.

It is not necessary, however, to make our pipes as large as will be required by a 10 degree drop in temperature. It is necessary, therefore, to find what the size of the pipes will become with a greater drop in temperature. The rule for this is that when the length of the pipes is constant and when the head varies inversely as the quantity of water (due to the change in temperature), the quantity of water the pipes will pass will vary directly as the $\frac{5}{3}$ power (cube root of the fifth power) of the diameters.*

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* The mathematical explanation is as follows:

Let h = 1st head
h' = 2d head
w = 1st quantity of water
w' = 2d quantity of water
k = constant
d = 1st diameter
d' = 2d diameter.

Then

$$h = \frac{w^2}{d^5} k \qquad (1)$$

$$h' = \frac{(w')^2}{(d')^5} k \qquad (2)$$

$$\frac{h}{h'} = \frac{w'}{w} \qquad (3)$$

$$h' = \frac{w}{w'} h. \qquad (4)$$

Substituting the value of h' in (2),

$$\frac{w}{w'} h = \frac{(w')^2}{(d')^5} k. \qquad (5)$$

If we decide that a 20 degree drop in temperature is the maximum that should be allowed, the quantity of water will be diminished one-half, as compared with that required for a 10 degree drop in temperature.

The fifth root of the cube of $\frac{1}{2}$ is .66. The 2.325 inch pipe required for a 10 degree drop in temperature with 100 square feet of surface may therefore be reduced to $(.66 \times 2.325 = 1.54)$ a 1.54 inch pipe for a 20 degree drop in temperature.

For a 30 degree drop in temperature the quantity of water will be diminished to one third of that required for a 10 degree drop in temperature.

The fifth root of the cube of $\frac{1}{3}$ is .517. The 2.325 inch pipe required for a 10 degree drop in temperature may therefore be reduced to $(.517 \times 2.325 = 1.2)$ a 1.2 inch pipe for a 30 degree drop in temperature.

Throughout these papers, for practical reasons, nearly all small differences or errors of calculation are in the favor of the diameter of the pipe. The reason should be obvious, but fearing it would not be understood by all, I will say I wish to err on the side of safety, if at all, and therefore as practical men may not assume new conditions, but accept the size and condition above given as a maximum, and therefore a standard for all conditions, I will say that from my own practice I am of the opinion a $1\frac{1}{2}$ pipe will do a little better than 20 degrees, which, no doubt, is partly accounted for by the fact of the commercial pipe being larger than its nominal diameter.

In ordinary practice radiators should be tapped for the maximum duty by the maker, and therefore if the steam-fitter uses smaller diameter pipes, he does it at his own risk.

Dividing (1) by (5)

$$\frac{w'}{w} = \frac{w^2 \, (d')^5}{(w')^2 \, d^5} \tag{6}$$

$$\frac{(w')^3}{w^3} = \frac{(d')^5}{d^5} \tag{7}$$

$$\frac{w'}{w} = \left(\frac{d'}{d}\right)^{\frac{5}{3}} \tag{8}$$

Q. E. D.

Fortunately, in hot-water heating, a small diameter of supply pipe does not entirely destroy the value of a heater. The heater or radiator, however, depreciates in value as the quantity of water passing through it decreases. This is why two heaters of the same size in rooms of equal dimensions frequently give results extremely different. The pipe to the poor heater is either smaller in diameter than the other or very long (though of the same diameter) and the water perhaps travels only one-quarter as fast, and the result is that one radiator circulates so rapidly that the loss of heat is only 20 degrees, while the loss in the other may be forty degrees or more, corresponding to a difference of at least 30° between the average temperatures of the two radiators.

Should we settle the diameter for the inlet and outlet of a 100 square-foot radiator, therefore, at 1½ inches, we shall be obliged, by the rule that the quantity varies as the square root of the fifth power of the diameter, other things remaining the same, to use a 1¼-inch pipe for a radiator of 63 square feet, a 1-inch pipe for one of 36 square feet, and a ¾-inch pipe for one of 18 square feet.

There are, however, many commercial sizes of radiators between those mentioned, while in the matter of the diameter of pipes we are confined to the standard sizes of commercial pipe and have none between those mentioned; we are therefore compelled, if we are to keep up the standard, or rather not go below the standard of a 1½-inch pipe for a 100-pipe radiator, to use.

¾	-inch pipe	for	18	square feet	or under.			
1	"	"	36	"	"	down to	19	square feet.
1¼	"	"	63	"	"	"	37	"
1½	"	"	100	"	"	"	64	"

These diameters for radiators of the sizes given in the second column will circulate the water with a loss of about 20 degrees while passing through radiators, when set one story above the boiler, with average length of connections.

Of course, when a radiator of forty square feet has a 1¼-pipe, or one of 68 or 70 square feet has a connection of 1½ inches (as it would have under the above schedule of sizes of pipe, etc.), the results would be somewhat better than 20 degrees—in other words, the amount of cooling would be less.

If, however, we are not satisfied with so small a difference as 20 degrees, and require that the difference shall be about 30 degrees, then we may take the size of a 1.2-inch pipe as our standard for 100 square feet of surface, and we will have sizes as follows, for inlet and outlet of radiator:

¾	-inch pipe	for	31	square feet	or under.			
1	"	"	62	"	"	down to	32	square feet.
1¼	"	"	110	"	"	"	63	"
1½	"	"	175	"	"	"	111	"

It is important in this connection that a person, in determining the sizes of the pipes in a hot-water heating apparatus, should fully realize that there will certainly be trouble with the circulation, unless the resistances of all branches are properly equalized. With larger pipe sizes this danger is not eliminated, but smaller differences will cause less trouble, when larger pipes are used.

CHAPTER XII.

DIAMETERS OF RADIATOR CONNECTIONS.

Table of the Diameter of Short Pipes or Connections for a Loss of Temperature of 20 and 30 Degrees while the Water is Passing through the Radiator—The Greater Resistance and Necessary Increase of Diameter Caused by Greater Lengths.

Under the foregoing schedule of sizes—owing to the fact that we have no intermediate commercial sizes of pipe—we would be compelled to use a 1½-inch pipe for a 111 square foot radiator. This, of course, would be unnecessary and would result in two radiators (a 111 square foot and a 110 square foot) of almost the same size, giving very different results. Therefore, for this schedule and the one that precedes it for a difference of 20 degrees, it is better that we should interpolate and form averages in each case—thus: For differences of 20 degrees let the sizes be:

TABLE IV.

¾	-inch pipe,		24 square feet or under.		
1	"	"	25 to 40 square feet.		
1¼	"	"	41 to 70	"	"
1½	"	"	71 to 100	"	"

For differences of thirty degrees:

¾	-inch pipe,		35 square feet and under.		
1	"	"	36 to 69 square feet.		
1¼	"	"	70 to 119	"	"
1½	"	"	120 to 175	"	"

These diameters, it must be remembered, are for ordinary lengths of connections with three common elbows in each connection and one valve in one of the connections—usually the inlet.

Taken together the connections have a resistance equal to about 93.3 feet of straight pipe, or at least of pipes with long easy bends and no elbows. It may be that 100 feet of straight pipe will give a resistance no greater than has been allowed for these connections, for reasons before explained, and therefore each additional fifty feet, without elbows, that the radiator is removed horizontally from the place of supply, will add to the resistance an amount equal to that allowed for one connection and correspondingly decrease the quantity of water that will pass through the radiator.

The resistance already considered is for a set of average connections, say from the head of a boiler or from ample mains, the total resistance head being between .88 and 1.32 inches for the greater and lesser diameter pipes respectively.

We must, for practical reasons, in such a complex matter as the flow of water through small pipes with many turns, etc., confine ourselves to some general method of reasoning. I have, therefore, calculated it so that the resistance of a pair of ordinary radiator connections is shown to be about equal to the resistance of 100 ft. of straight pipe. This, of course, would be equal to the extra resistance caused by the moving of a radiator away from the boiler or mains a distance of 50 ft. without extra bends or changes in pipe sizes.*

When we double the length of the radiator connection, we double the resistance, and under the rule, that when quantity and diameter are constant the head is directly and simply as the length, we will have lengths in the ratio of 1, 2, 3 and 4; and head in the same ratio—1, 2, 3 and 4.

The total head at our disposal is always fixed by the height of the radiator above the boiler; or, more properly speaking, by the relative densities of the two columns of water. Therefore, when we increase the length—without the height—we are either compelled to do with a smaller quantity of water or use a larger diameter of pipe.

We will assume the diameter of the connection to be unchanged, however, for the present, at least, or until such time as we find we cannot get sufficient water through it for our purpose: when as it is in our power to change it, we may do so after proving it is not ample for our purpose, or rather, when we have found how great a loss we will sustain if we retain it.

For the present, therefore, as we are only to consider the effect on the quantity of water passed, and therefore on the value of the radiator when we double or otherwise increase

* The resistance of coupling is not considered. If the ends of the pipes are carefully reamed, however, this will be very small.

the length of the radiator pipe, we must consider the diameter as *constant*, which in our case means that it is the size of the short radiator connection as before established. (Table IV.)

By the rule, that when *head* and *diameter* are constant, the discharge or quantity passed will vary *inversely* as the square root of the length, we have: for lengths in the ratio of 1., 2., 3., 4., etc., the quantities of water passed will be in the ratio of 1; $\frac{1}{1.41}$; $\frac{1}{1.73}$ and $\frac{1}{2}$, etc.*

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* Since a change in the quantity of water passing through any one radiator will effect its cooling, the assumption that the head is a constant, should at times be modified. When the return water from one radiator mingles with the return water from other radiators, before dropping to the level of the boiler return inlet, the head may remain practically a constant, notwithstanding the additional cooling of the water in the one radiator. If, however, the return pipe from a radiator or a group of radiators drops independently to the level of the boiler return inlet, any additional cooling within this radiator or group of radiators will tend to quicken the circulation through this radiator or group of radiators exclusively. We may therefore have the condition that, when the diameter is a constant and when the head varies inversely as the quantity of water passed, the quantity of water passed will vary inversely as the cube root of the length.

The mathematical explanation is as follows:

Let h = 1st head
h' = 2d head
w = 1st quantity of water
w' = 2d quantity of water
l = 1st length
l' = 2d length

(1) $h = w^2 l k$

(2) $h' = (w')^2 l' k$

(3) $\frac{h}{h'} = \frac{w'}{w}$.

Dividing (1) by (2) we have

(4) $\frac{h}{h'} = \frac{w^2 l}{(w')^2 l'}$.

Equating the values of h/h' in equations (3) and (4) we have

(5) $\frac{w^2 l}{(w')^2 l'} = \frac{w'}{w}$,

or

$$\frac{w}{w'} = \sqrt[3]{\frac{l'}{l}}.$$

Q. E. D.

In our case we are at liberty to assume any quantity passed through the pipe. Say it is 10 gallons that passes through the ordinary connection, whose length is 1, with a resistance equal to 100 feet of straight pipe. If we, however, add 50 feet to the length of each of the two connections they become 2., and the quantity then will decrease in the same ratio that 1 is less than 1.41. Thus,

$$\frac{10\times 1}{1.41} = 7.09,$$

or, say, 7.1 gallons will pass through when the length is doubled, instead of the 10 gallons as at first; or in that ratio for any other quantity of gallons.

If we make the line 100 feet long (200 feet in the circuit) then it is equivalent to three times the length of the ordinary connection, and the sum is

$$\frac{10\times 1}{1.73} = 5.78 \text{ gallons};$$

and if we add 50 feet more, or four times the resistance to the length of the line (100 feet to the circuit), it makes

$$\frac{10\times 1}{2} = 5 \text{ gallons},$$

or just half the quantity that will go through the short connections.

This points to the fact that we can run connections (flow and return) 150 feet (300 feet circuit), giving them four times the resistance (if we are careful and ream the ends in the couplings) before we reduce the quantity of water passed to half what it would be with short connections, and consequently increase the cooling of the water to double; so that the amount of water that will cool 20 degrees with a short connection will cool 40 degrees with connections 150 feet long with bends.

If, however, instead of losing 20 degrees extra by the long connection we are desirous of delivering an equal quantity of water at the greater distance, then we must vary the diameter of the pipe, as before intimated that we could.

In this new case, then, we have *head* and *length* constant and require a new diameter for a stated quantity, knowing what some other diameter will do under the same head and length, as we have just shown.

Our problem now is: that instead of passing five gallons through connections each the equivalent of 200 feet in length (150 feet, plus short connections), or four times the resistance of an ordinary connection, we require a new diameter that will pass ten gallons.

Where *head* and *length* are constant the diameter varies directly as the fifth root of the square of the discharge; thus for discharges in the ratio of 1, 2, 3 and 4 the diameters will be in the ratio of 1., 1.32, 1.55, and 1.74, etc. Our discharges are in the ratio of 1 and 2 (five and ten gallons), consequently our diameters will be in the ratio of 1 and 1.32. Therefore, if our connections for a radiator of 100 square feet are 1½-inch, the pipes to supply the same quantity of water to it 150 feet off, plus elbows, etc., without increasing the head, will be

$$\frac{1.5 \times 1.32}{1} = 1.98 \text{ inches.}$$

According to this, therefore, if our radiator openings are of the size shown in the first column at the inlet and outlet, they will have to be enlarged to pipes of the diameter shown in the second column if they are 150 feet distant *horizontally* from the mains or boiler, thus:

Short connections	Connection 150′ long	Which in practice would probably have to resolve themselves into—	Radiator, square feet
¾	1.	1″	
1	1.32	1¼″	
1¼	1.64	1½″	
1½	1.98	2″	
2	2.64	2½″	

To get the full benefit of the enlarged diameter circuit, the inlet and outlet of the radiator must be the full size of the pipes which it is found necessary to run to it, and consequently hot-water radiators should have ample inlets and outlets that can be pushed to a smaller diameter, if the circuit is short and it does not require a pipe as great as the inlet. All the benefits of the large diameter pipe, however, are not lost should the inlet to the radiator be a size smaller than the circuit, and no one must fall into the error of using a pipe as small as the inlet for that reason. In fact it is a reason for using a larger pipe, so as to get the water to the contracted point with the least resistance.

CHAPTER XIII.

PIPE SIZES.

The Decrease in Diameter of Pipes as the Building Grows Higher —Tables V and VI of the Diameters of Flow and Return Pipes for Various Conditions of Length and Height.

We have now to consider the effect on the sizes or diameters of pipes as the building grows higher. The foregoing was all on the supposition that the head at our disposal was that equivalent to one story of a house. Let us assume, however, we have another story, or 10 feet more in height, so that part of our pipes run horizontally and part of them the height of two stories, or about twenty feet. This will double the head under which we have been working so far, so that now our head will be about 1.76 inches. For our present purpose it matters not what it was in the first case, and it may be called the head for one story here, being doubled for the second story, being trebled for the third story, and so on as the apparatus grows higher in the building.

The rule for this is: That when gallons (or quantity) is to remain *constant*, and the length is constant, the diameter will vary inversely as the fifth root of the head. Thus for heads in the ratio of 1, 2, 3, and 4, the diameters will be as $1 : \frac{1}{1.15} : \frac{1}{1.25} : \frac{1}{1.32}$ or as $1; \frac{87}{100}; \frac{80}{100}; \frac{757}{1000}$, so that in the case of a connection 150 feet long, if it runs two stories high instead of one, we have, taking the case of the two-inch pipe, again

$$\frac{2' \times 1}{1.15} = 1.74',$$

or a $1\frac{3}{4}$-inch pipe, if we had such a size.

In the case of the third story it would be 1.6, and of the fourth, 1.5 inches. In other words, if it is necessary to run pipes of the diameters in the first column given below to radiators 150 feet away on the first floor, the sizes given in the remaining columns are for each successive story; the pipes remaining the same length.

1	2	3	4	Stories in Height
¾″	¾″	¾″	¾″	Note.—As no pipe smaller than ¾ inch should be used in an apparatus, the ¾ diameter is given throughout.
1	.87	.8	.757	
1¼	1.1	1.0	.947	
1½	1.3	1.2	1.1	
2	1.75	1.6	1.5	
2½	2.17	2.0	1.89	

It must be remembered that the first column in this table corresponds to the last column in the preceding table, and that, therefore, the first column here is not the radiator connection, but the nearest commercial diameter for 150 feet horizontal. This table, therefore, forms the reduction for rising lines that are not branched separate rising lines), without reference to length. In other words, if we were to run from the head of a boiler, or from properly designed mains, straight upwards to separate radiators, this table shows the comparative size of pipe for each story averaging ten feet of rise.

The fitter must use his own judgment in selecting commercial sizes of pipe to correspond with tables. For instance, in the case of a first-story radiator with a 1¼-inch pipe to it, he should use a 1¼-inch also to the second story, as there is no 1.1-inch pipe, but in the case of the third and fourth stories his results will be more uniform if he uses an inch pipe in both cases, and so on; bearing in mind that it is better to overrun in the size than be under when circumstances will permit the former.

The following tables are summaries of the sizes of pipes for different radiators under different conditions of temperature, distance, and height, according to the rules, etc., just given.

The third column is for the radiator connections and is given in commercial sizes. The remaining columns are the actual sizes of the diameters in inches, taking the first column as the basis of calculation.

It must be understood that many, if not all, of the rules here given for the flow of water, etc., are not absolutely correct, but they give close approximations to the truth, and for practical purposes we may accept them. By applying these rules to new conditions we may extend the following tables (Nos. V and VI) indefinitely. The tables V and VI, as far as they go, however, are just suited to hot-water apparatus that have many mains or rather circuits starting from the head of a boiler and running to the different sections of a house; usually from *four* to *six* such lines being used for private houses, though in some large buildings in Canada twenty or more such circuits are not unusual where the practice is to connect two or more boilers with a large header—both top and bottom—taking the flow-pipe from the upper one and entering the lower one with the return pipes.

TABLE V.—SIZE OF FLOW AND RETURN PIPE FOR A DIFFERENCE OF 20 DEGREES FOR LENGTH AND CONDITIONS GIVEN.

Actual size of radiator in square feet for size of pipe connection in 3d column.	Size of radiator, average range interpolated to suit practice.	Size of connection, first story (commercial).	Size of connection, 150 ft., first floor (actual).	Size of connection, second story, 150 feet (actual).	Size of connection, third story, 150 feet.	Size of connection, fourth story, 150 feet.	Size of riser, if run to second floor, less than 50 feet.	Size of riser, if run to third floor, less than 50 feet.	Size of riser, if run to third floor, less than 50 feet.
18	24 sq. feet or under	¾"	1.	.87	.8	.757	.75	......	......
36	24 to 40 square feet	1	1.32	1.15	1.05	1.0	.87	.80	.757
63	40 to 70 " "	1¼	1.64	1.426	1.31	1.25	1.1	1.0	.947
100	70 to 100 " "	1½	1.98	1.72	1.584	1.5	1.3	1.2	1.1
198	100 to 198 " "	2	2.64	2.3	2.1	2.0	1.74	1.6	1.5

Elsewhere in this work will be found an illustration of this kind of fitting. The Tables V and VI, therefore, are for this class of work and give the diameters of circuits for different conditions covering all that is in the small tables that are not numbered.

In using the tables judgment must be exercised in selecting a commercial size of pipe, as the sizes given are not, as will be noticed, "commercial," except in the third column.

For instance, the size given for 75 square feet of surface on a second story (difference 20 degrees), 150 feet away, is 1.72. If there are many more elbows than six in the whole circuit, it is better to make it two inches than 1½ inches, for reasons that are obvious, although with the latter size pipe it would not be a failure, as by the table for thirty degrees difference, it will be noticed, a pipe 1.42-inch diameter will do for 70 square feet. What would follow if the smaller size is used, would be a greater difference of temperature of the water, which, of course, would not be desirable in good work. If, on the other hand, the radiator was 45 or 50 square feet, then the 1½-inch pipe would be ample, provided there are not too many elbows introduced into it.

Table VI.—Size of Flow and Return Pipe for a Difference of 30 Degrees for Length and Conditions Given.

Actual size radiator in sq. feet for pipe connections in third column.	Size of radiator, average range interpolated to suit practice.	Size of connection, first story (commercial).	Size of connections, 150′ dist., first floor (actual).	Size of connection, second story, 150 feet.	Size of connection, third story, 150 feet.	Size of connection, fourth story, 150 feet.	Size for riser, if run to second floor, under 50 feet.	Size of riser, if run to third floor, under 50 feet.	Size of riser, if run to third floor, under 50 feet.
31	35 sq. feet or under	¾″	1	.87	.8	.757	.75	....	......
62	35 to 70 square feet	1 ″	1.32	1.15	1.05	1.0	.87	.8	.75
110	70 to 120 " "	1¼″	1.64	1.426	1.31	1.25	1.1	1.0	.947
175	120 to 185 " "	1½″	1.98	1.72	1.58	1.5	1.3	1.2	1.1
345	185 to 350 " "	2 ″	2.64	2.3	2.1	2.0	1.74	1.6	1.5
1	2	3	4	5	6	7	8	9	10

The first columns of the tables show the actual square feet of radiator surface suitable to the diameters. The second columns give the safe ranges for variation of sizes above or below the actual size. By comparing the actual size of radiator, therefore, and the range of sizes, any one of intelligence should be able to judge as to whether it would be safe or not to use diameters smaller than those given in the remaining columns.

The table for a difference of 30 degrees also forms a guide to determining minimum diameters for average duty of 20 degrees. In other words, if a diameter is selected for a certain size heater, smaller than that given in the 20-degree table, and it proves as small as the diameter given in the 30-degree table for a heater of about the same size, it should be rejected as causing too slow a circulation. For instance, suppose the radiator to be 70 square feet, then under the 20-degree table it will call for 1.72 inches diameter, while under the 30-degree table a diameter of 1.42 inches is required. It is reasonable to suppose this heater would give satisfactory results (about 20 degrees difference) with a 1½-inch pipe, as 63 square feet would only call for 1.42 inches diameter by the 20-degree table.

There are two points to which I wish to call special attention. The first is that when we allow a large drop in temperature within a radiator, the average temperature of the water within the radiator is lowered and we should allow for an increase in the radiating surface.

The second point to which I wish to call attention is one which has caused many failures in the circulation of hot water heating plants. What I wish to point out is that trouble is often likely to occur in the circulation, particularly of first floor radiators, when the common return pipe from a number of radiators is carried back to the boiler near the ceiling of the basement.

If the first floor radiator connections are somewhat small as compared with the risers to the upper floors, the second and third floor radiators will circulate much more rapidly than the first floor radiators. When some of the radiators circulate rapidly, the difference in temperature between the water in the flow and return pipes is correspondingly reduced. If now the difference in temperature in the water in the flow and return mains is brought to a very small amount, the circulation through any individual radiator is practically dependent upon its own cooling and its elevation above the mains. Second floor radiators are situated far enough above the mains so that they are not usually the first to suffer. First floor radiators on the other hand, may be only a few feet above the mains and are apt to show a sluggish circulation. What I recommend is that the main return pipe be run near the basement floor and that the return pipes from all first floor radiators be connected independently to it. In case this cannot be done and it is necessary to connect the return pipes from first floor radiators directly into the common return pipe at the basement ceiling, the resistances in the various circuits should be carefully figured. Practically, we will find that with our common return pipe run overhead, the connection to first floor radiators may often be increased with advantage at least one size over that shown by the tables. It is better also to use the pipe sizes for the 20 degree drop in temperature rather than the 30 degree drop in temperature; and if we wish to have the best results from a hot water heating apparatus, I would often recommend the use of the pipe sizes shown by the tables for a 15 degree drop in temperature.

CHAPTER XIV.

DIAGRAMS OF PIPE SIZES.

Diagrams Giving the Diameter of Flow and Return Pipes in Inches when the Radiator Surface and Length of Pipe Circuits are Known—Exercise Illustrating the Use of the Diagrams—Skeleton Diagram of the Pipes of a Building.

The rules relating to the flow of water in pipes are very confusing to any one who has not the time to thoroughly consider and familiarize himself with them. For this reason, although I have tried to make myself understood, some readers may be still unable to find any practical good in the rules and examples I have given. I have, therefore, constructed six diagrams, Figs. 27, 28, 29, 30, 31, and 32, based on the ordinary rules of hydraulics, which give the diameters of pipes for hot-water apparatus up to 1,600 square feet of surface, or what I consider sufficient for private dwellings.

Diagrams, Figs. 27, 28 and 29, show the diameters of rising lines for the different stories of a house, on the supposition that the stories are an average of 10 feet in height. Fig. 27 is worked out for a loss of 15 degrees in the temperature of the water between flow and return-pipe, Fig. 28 for a loss of 20 degrees, and Fig. 29 for a loss of 30 degrees.

The horizontal lines show the number of square feet of surface the pipe is to supply water for, and the vertical lines indicate diameter of pipe in inches; while the ordinates of the curved lines, where they bisect the horizontal lines, indicate the required diameters by the vertical lines.

The curved line, *a*, indicates the diameters for the first stories, *b* for the second, *c* for the third, and so on; or they stand for heights, about 10, 20 and 30 feet, etc., when the stories are greater or less.

The diagrams, Figs. 30, 31, and 32, show the diameters of the main lines for lengths, varying from 100 to 1,000 feet, These lengths are the lengths of the circuits, so that 1,000 feet means 500 feet through the flow-pipe, and as many more backwards through the return-pipe to the boiler.

The horizontal lines show square feet of heating surface up

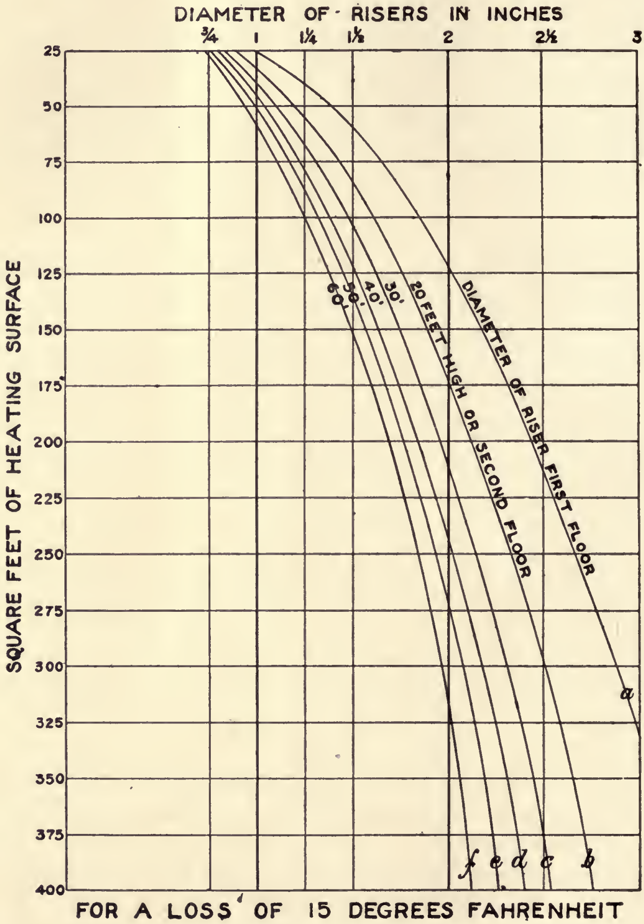


Fig. 27.

to 1,600, and the vertical lines the diameters of pipes, while the ordinates of the curved lines indicate the diameter for the surface opposite to them, or the surfaces for the diameters above them.

To illustrate the use of the diagrams in finding the diameters of the pipes of the different parts of an apparatus, we should construct a skeleton diagram of the pipes of a house

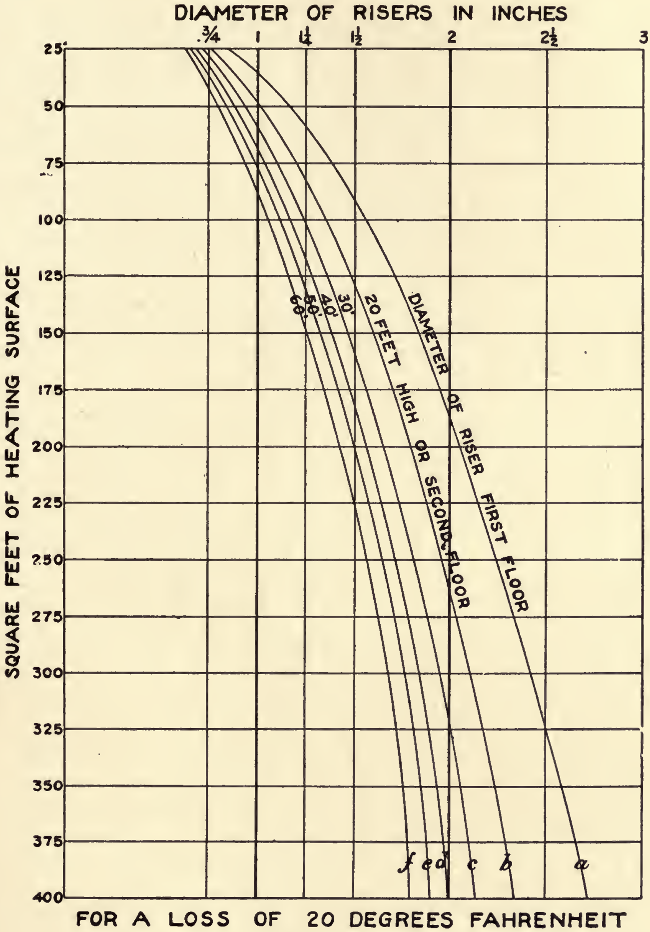


Fig. 28.

or building in the manner so well known to heating engineers and shown in Fig. 33.

The distance from the datum, or the level at which the returns enter the boiler, to the radiators on the first floor is assumed to be ten feet, and each succeeding floor of the building is assumed to be ten feet higher than the one below it. The length of the horizontal pipes are marked in feet, and to those who are not accustomed to these diagrams, I will explain that all diagonal pipes, as well as the ones shown in the horizontal

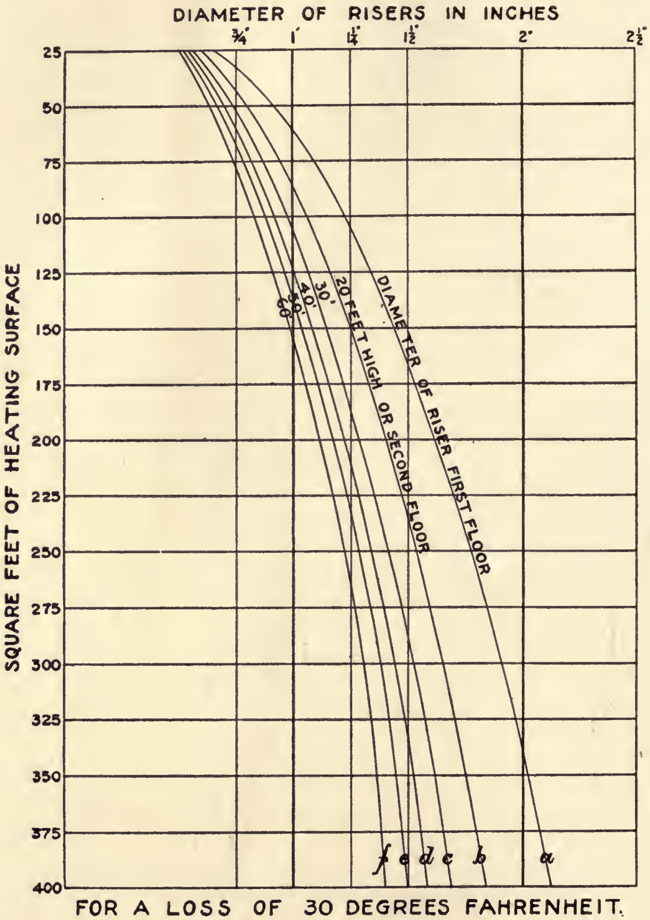


Fig. 29.

position, are to be considered as horizontal; the diagonal pipes as shown being horizontal branches at right angles to the mains. The vertical pipes in the diagram are rising lines, and the diagonal branches are radiator connections.

The numerals, 1, 2, 3, etc. (Fig. 33), shown at the branches of the risers indicate the floor the radiator is on. The figures shown at the opposite side followed by the sign for square feet thus |__|, indicate the size of the radiator in square feet. The

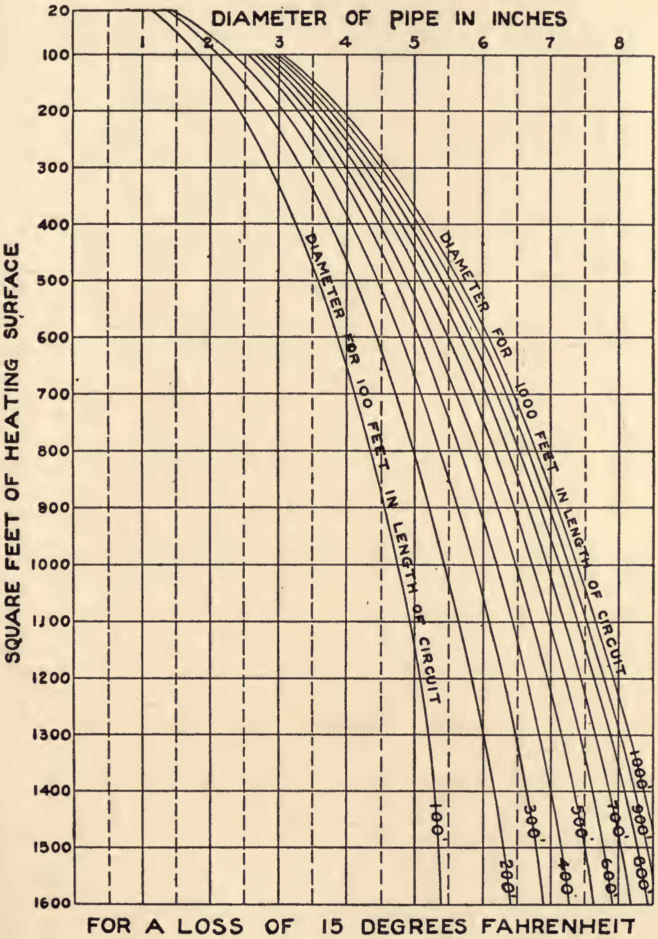


FIG. 30.

rising lines are further numbered from the left to the right, as No. 1, No. 2, No. 3, etc., for convenient reference.

To use the diagrams the engineer constructs a diagram suitable to the building, for which he is designing an apparatus, and it will be found of advantage to trace it over the ground plans of the building, letting the rising lines then run in a diagonal direction as the branches can be shown in their proper position on the plan.

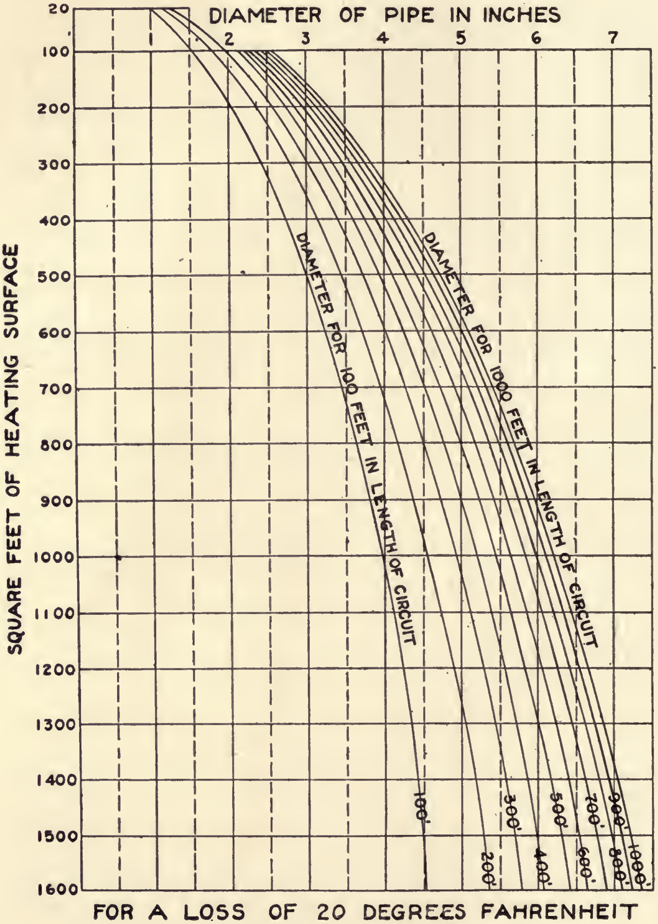


Fig. 31.

To find the diameters the designer will commence with the head of the rising line furthest from his boiler in any direction, and note the radiating surface and the floor number. In the case of our diagram we take riser No. 5, as it is the end of the line or circuit on the right of the boiler. We note it calls for 75 square feet of surface on the third floor, and as we are going to determine sizes for a loss of 20 degrees, we turn to Fig. 28, and find that 75 square feet of surface on the third floor

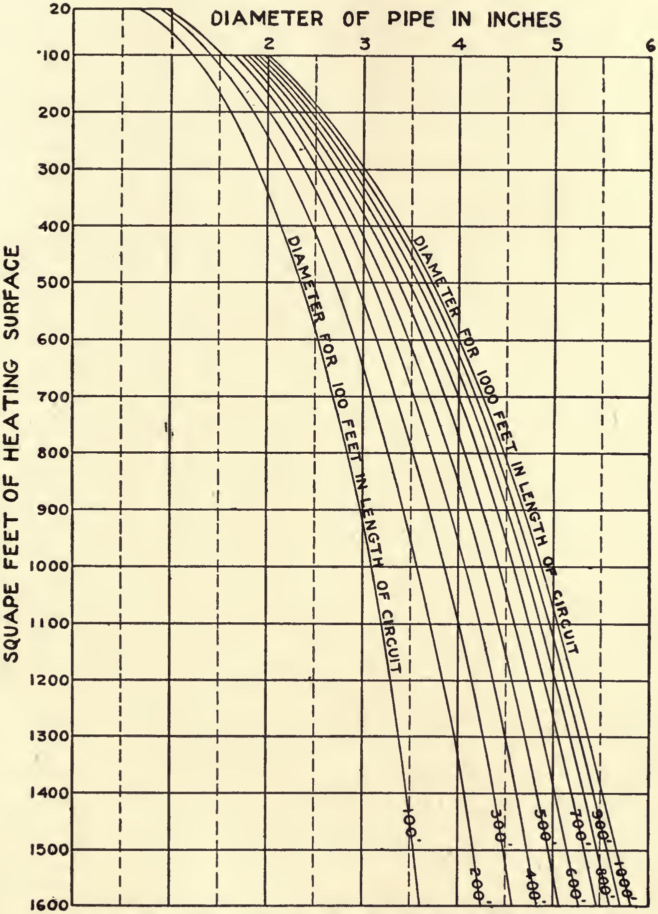


Fig. 32.

calls for a pipe a little larger than 1 inch, as will be seen by noticing that the line, *c*, for the third floor crosses the horizontal line opposite 75 square feet at a point a little beyond the 1 inch line. As it is nearer to 1 inch than it is to 1¼ inches, and as 1 inch "commercial" is a little larger than 1 inch actual, and as it is also necessary to take the averages into consideration as shown in the second column of Table VI, the 1-inch pipe is ample; its use probably causing a loss of 22 degrees in that particular heater.

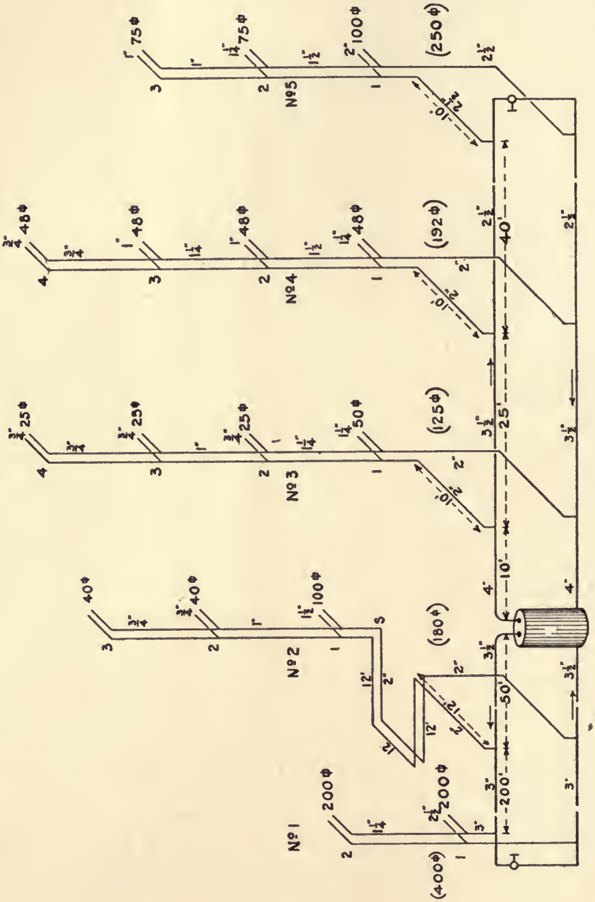


FIG. 33.

We then come to the second floor on the same rising line and find a heater of 75 square feet also. As the pipes to this point must be ample for taking care of all above it as well as the immediate radiator, we have to add the 75 square feet on the third floor to the 75 square feet on the second floor and proceed to pick out the diameter for 150 square feet on the curved line, *b*, Fig. 28.

We see that the diagram calls for a pipe only slightly larger than 1½ inches. A 1½-inch pipe will, therefore, do very well in this case. The connections to the second floor radiator should be picked out on the line, *b*, for 75 square feet of surface. It will be noted that this gives us a size a little smaller than 1¼ inches. We will therefore mark the connections to this radiator 1¼ inches.

Coming to the first floor, we have to provide a pipe for 100 sq. ft. + 75 sq. ft. + 75 sq. ft. = 250 sq. ft. The size is found on the curved line, *a*, opposite 250, Fig. 28, and is somewhat less than a 2½-inch pipe. In the present instance there are six common elbows between the first floor and the main. The branches are ten feet and with the pipe that goes through the floor the circuit may be taken as 25 feet of 2½-inch straight pipe plus 600 diameters (or 125 feet for six elbows) = 150 feet of circuit so far as resistance is concerned. To this 150 feet should be added 150 feet, which is double the distance to the boiler, giving us about 300 feet of circuit, so far as resistance is concerned. The diameter of the 2½-inch pipe already found was for a 100 foot circuit. By referring to Fig. 31 we see that the diameter of the pipe for 250 square feet and for a circuit of 300 feet is a little larger than 2½ inches. A 2½-inch pipe will, however, be sufficient.

The size of the first floor radiator connections on rising line No. 5 should of course be figured for a 300-foot circuit. In other words, we should bear in mind that all first floor heads are figured as causing the flow from the boiler to the first floor radiators, and the circuit between the radiator and the boiler should be considered in figuring first floor radiator connections. We see from Fig. 31 that 100 square feet on a 300-foot circuit will require a pipe a little smaller than two inches. We will use, therefore, a 2-inch pipe.

Rising line No. 4 is for average size radiators and they are of the same size throughout (48 square feet). The upper radiator on the fourth story will require at least a ¾-inch pipe, as seen by the curved line, *d*, diagram Fig. 28. The pipe to the third story will be 1¼ inches, as seen by the line, *c*, and the pipe to the second story is very near the 1½-inch line. The radiator connection on the third floor is near the 1-inch line, and on the second floor we may also use 1-inch radiator connections.

In figuring the size of the mains between rising line Nos. 4 and 5 we must remember that we figured the length of the circuit between the boiler and the first floor radiator on riser No. 5 as 300 feet. The first floor head is expended within this circuit and of course equal parts of the head should be expended within equal lengths of the circuit. The part of the 300-foot circuit from the boiler up to where riser No. 4 branches off is 70 feet, and the part beyond this point is 230 feet. $\frac{230}{300}$ of the first floor head is therefore expended beyond the point at which riser No. 4 branches from the main. An equal head should therefore be expended in riser No. 4 beyond this same point; or in other words $\frac{230}{300}$ of the first floor head should be expended in riser No. 4 between the point at which the riser leaves the main and the first floor radiator.

If we figure the length of the circuit between the main and the first floor radiator on riser No. 4 as 125 feet, we have $\frac{230}{300}$ of the first floor head to be expended in a circuit of 125 feet. This of course is the same as expending the first floor head in a circuit of $\frac{300}{230} \times 125 = 163$ feet. Fig. 31 shows the size for 192 square feet for a 163-foot circuit as a little larger than a 2-inch pipe. The size of the radiator connection for a 48-square foot, first floor radiator on a 163-foot circuit is shown as 1¼ inches. We will therefore use 2-inch connections to the riser and 1¼-inch connections to the first floor radiator.

On rising line No. 5 we have 250 square feet of surface, while on rising line No. 4 we have 192 square feet of surface. These amounts taken together form part of the data by which to find the diameter of the 25-foot lengths between risers No. 3 and 4. In addition to the number of square feet of surface we must take into consideration the length of the circuit of which this forms a part and in which the first floor head causes the flow, viz., the distance of the circuit from the boiler to the first floor radiator on riser No. 5. This was previously fixed as 300 feet.

By reference to the diagram Fig. 31, we see that 442 square feet of surface with a circuit 300 feet in length requires a 3½-inch pipe.

The sizes for rising line No. 3 are obtained from Fig. 28 in the same manner as for the other rising lines.

The length of the circuit from the mains to the first floor radiator on rising line No. 3 may be taken as 125 feet. The part of the circuit from the boiler to the first floor radiator on rising line No. 5 which lies beyond the connection to rising line No. 3 is $\frac{28}{30}$. The part of the first floor head which is to be spent between the mains and the first floor radiator on riser No. 3 is therefore $\frac{28}{30}$ of the whole. This will make the connections to rising line No. 3 figure as for a circuit length of $\frac{30}{28} \times 125 = 134$ feet. This gives us a size between 1½ and 2 inches. As this rising line has generally been sized a little larger than called for by the diagram we will use a 2-inch connection in order to insure a sufficient quantity of water for the first floor radiator. Diagram, Fig. 31, calls for 1¼-inch pipe for 50 square feet of surface with a circuit of 134 feet. We will, therefore, use 1¼-inch radiator connections for the first floor radiator on riser No. 3.

If the return main should be carried back overhead, it might be well to reduce somewhat the sizes of the pipes in riser No. 3 rather than make them larger than called for by the diagram. This rising line is the nearest to the boiler and if the return main is near the ceiling of the basement, it is objectionable to have this rising line circulate much more rapidly than the rising line beyond this point. If the return main runs near the floor of the basement there is not the same objection to a somewhat more rapid circulation in this rising line.

The mains from the boiler to riser No. 3 are to be figured for 567 square feet and for a circuit length of 300 feet. Our diagram shows that a 4-inch pipe is the size required.

The sizes, which we have fixed for the pipes on the right hand side of the diagram (Fig. 33), are no larger than good practice would call for. It is possible, however, to so arrange our pipes that we will secure a different drop in temperature than that which we will have with the pipe sizes which we have just determined. I will, therefore, ask the reader to select with me the diameters for the pipes on the left hand side of the boiler, where the loss in temperature is to be about 30 degrees.

It may appear to many that these further examples in the use of the diagrams are unnecessary. My apology, however, to those who grasp the matter quickly, is that these papers are for practical men, who desire to see the matter in as many of its bearings as possible.

The pipes on the left hand side of the boiler are long and the radiators on them are large, and in riser No. 2 there are a number of extra elbows, caused by the piping going around a light shaft elevator passage, bank vault or some other obstruction to its direct course. We will commence at the head of riser No. 1 and pick out its diameter for 200 square feet on the second story for a loss of 30 degrees. On diagram Fig. 29 we find it to be about half-way between 1¼ and 1½ inches. We have now to use our judgment as to whether we will use a 1¼-inch pipe or a 1½ inch pipe. The answer to this question is readily found from the diagram, as well as the answer to the question. What would be the additional loss of temperature if we used the smaller pipe (1¼ inch pipe)? To find the additional loss in this case let us follow the curved line, *b* (Fig. 29), until it crosses the 1¼-inch line. Opposite this point in the column of square feet of heating surface we find 150 square feet, indicating that a 1¼-inch pipe will supply that number of square feet of heating surface on the second story, or in other words, that it will carry the water for 150 square feet to this point, instead of for 200 square feet, under the conditions we first required. Our problem now is, that if 150 square feet cools a given measure of water 30 degrees, what will 200 square feet cool it? In this case the answer is $\frac{30 \times 200}{150} = 40$ degrees, which will be the loss of temperature if we use the 1¼-inch pipe. This is on the assumption that no additional head is secured by the greater drop in temperature. As this is not strictly true, and the flow will be quickened, the drop in temperature will be reduced slightly below 40 degrees. We will assume that this drop in temperature is not too much and we will use a 1¼-inch pipe.

This brings us to the first floor, at which point we must provide for $200 + 200 = 400$ square feet. This calls for a pipe a little larger than 2 inches (Fig. 29).

This diameter is for a circuit of 100 feet (50 feet flow and 50 feet return). In the present case, however, our riser is at a distance of 250 feet from the boiler, and if we allow 150 feet as equivalent to the riser connections, elbows, etc., we must figure on a circuit of 650 feet between the boiler and the first floor radiator on riser No. 1. This requires a pipe a little larger than 3 inches. A 3-inch pipe will, however, be satisfactory. The size required for a first floor radiator connection for 200 square feet of surface on a 650-foot circuit is 2½ inches.

This brings us to riser No. 2. A ¾-inch pipe is ample for the third floor. The second floor riser should be 1-inch pipe with ¾-inch connections to the second floor radiator. The first story would call for 1¼-inch pipe. From the point, *s*, however, to the main, we must use a much larger pipe on account of the distance and the number of elbows. The length is $12' + 12' + 12' + 12' = 48$ feet, or say a 100-foot circuit. If we assume the diameter to be 2 inches, twelve elbows will call for 1200 diameters more or 2400 inches (an addition of 200 feet) making a circuit of about 300 feet or its equivalent in resistance. The drop in head within this circuit should be equal to the drop in head from the point where riser No. 2 branches from the main up to the first floor radiator on riser No. 1. In the latter case we figure on a drop of $\frac{550}{650}$ or $\frac{11}{13}$ of the first floor head.

If $\frac{11}{13}$ of the first floor head is then to be used in a 300-foot circuit, it is exactly the same as if the first floor head were to be used in a circuit of $\frac{13}{11} \times 300 = 354$ feet, or its equivalent in resistance. This, according to Fig. 32, would call for a pipe 2 inches in diameter. The connections to the 100-square foot radiator on a 354-foot circuit would be 1½ inches.

We have now to find the diameter of the mains between rising line No. 2 and the boiler. This should be figured for the circuit from the boiler to the first floor radiator on riser No. 1. The circuit we have previously determined to be 650 feet. The total amount of surface is 580 square feet. From Fig. 32 we see that a circuit of 650 feet supplying 580 square feet should have a 3½-inch pipe.

It will be noticed that I have shown the end of the flow main connected to the return main. Where it is possible to carry the return main near the basement floor, it is advantageous to connect the end of the flow main in this manner. A circulation will then be maintained in the mains, independent of the radiators, and even though nearly all of the radiators are shut off, the water in the flow main will remain warm and water will circulate quickly through any radiator that may be turned on.

There is one danger in the use of small pipe sizes, to which I wish to call the attention of the reader. In the cutting of pipe a burr is formed at the end of the pipe. With small pipes this burr may be sufficient to reduce the cross-sectional area at this point by more than one-half. With larger pipes the reduction in area will not be so large in proportion. If the pipes are properly reamed this burr will be removed, but in practice it is often found difficult to secure the proper reaming of all pipes.

Another point to which I wish to call the attention of the reader, is one which may be called the inertia effect of water. It may become of considerable importance, particularly if small pipe sizes are used and if the velocity of the water in the pipes is high. For example, care should be taken to see that the water in two return pipes does not meet " head on " when coming from opposite directions. In the same way it may in some cases be desirable for the water in a flow pipe to run into a full headed tee so as to divide equally in two directions rather than that the first connection should be taken from the side of the pipe where inertia will tend to carry the water past this branch rather than into it.

CHAPTER XV.

SINGLE CIRCUITS.

Single-Circuit Mains, and How to Run Them—Table of Standard Dimensions of Wrought-Iron Pipe—Cases Where the Inlet and Outlet of the Radiator Should be Larger than Ordinary—Resistance within Radiators and Coils—Resistance of Flat Coils—Resistance of Box Coils—Resistance of Wall Coils.

In running a single circuit from a boiler, the head caused by the total height is to be considered.

Fig. 34 shows two single circuits run from the head of a boiler, one vertical and one horizontal. The vertical one is 50 feet high and the horizontal is 50 feet long to first story; both 100-foot circuits with 100 feet of surface each. For a loss of 20 degrees the vertical pipes, 50 feet high, will require a pipe very little over one inch, while the horizontal circuit requires a pipe 1½ inches, which is about 2¼ times more area than the former.

The resistance for radiator connections—elbows and valves—is not considered. If we add resistance equal to 100 feet to each, for reasons explained earlier in these papers, we would have to use a 1.71-inch pipe in lieu of the 1½, and 1.15 instead of the 1-inch pipe.

The fitter must now use his judgment as to whether he will take the next larger commercial size or be content with the diameter for 100 feet of length. To assist his judgment I would suggest that he refer to a table of standard dimensions of wrought-iron pipe which I here introduce to facilitate the matter and make the subject more complete.

The branches of the risers in the diagram, Fig. 33, should have the diameters given in Tables V or VI (pages 83 and 84), as the case may be. In long single circuits, however, when the diameter of the flow and return pipe is enlarged to compensate for length and extra resistance of bends, the connections into the radiator or coil should be of the same diameter as the pipe. This in some cases may become impracticable if the radiator is a long distance away, and consequently the largest diameters possible for inlet and outlet under the circumstances must be employed and elbows avoided, with particular atten-

TABLE VII.—STANDARD DIMENSIONS OF WROUGHT-IRON PIPE FOR STEAM, WATER, ETC.

Nominal inside diameter	Actual inside diameter	Length of pipe per sq. foot, outside surface	Internal area	Length of pipe containing one cubic foot
Inches	Inches	Feet	Inches	Feet
1/8	0.270	9.44	0.0573	2500.
1/4	0.364	7.075	0.1041	1385.
3/8	0.494	5.657	0.1917	751.5
1/2	0.623	4.502	0.3048	472.4
3/4	0.824	3.637	0.5333	270.
1	1.048	2.903	0.8627	166.9
1 1/4	1.380	2.301	1.496	96.25
1 1/2	1.611	2.01	2.038	70.65
2	2.067	1.611	3.356	42.36
2 1/2	2.468	1.328	4.784	30.10
3	3.067	1.091	7.388	19.50
3 1/2	3.548	0.955	9.887	14.57
4	4.026	0.849	12.730	11.31
4 1/2	4.508	0.764	15.939	9.02
5	5.045	0.629	19.990	7.20
6	6.065	0.577	28.889	4.98
7	7.023	0.505	38.738	3.72
8	7.982	0.443	50.039	2.88
9	9.000	0.394	63.633	2.26
10	10.019	0.355	78.838	1.80
11	11.25	0.318	98.942	1.455
12	12.000	0.293	116.54	1.235
13	13.25	0.273	134.582	1.069
14	14.25	0.255	155.97	0.923
15	15.25	0.239	177.87	0.809

tion being paid to reaming the ends of the pipes and nipples and the avoidance of valves or fittings that cause sharp or abrupt shoulders.

There is furthermore a resistance caused by the water passing through the radiator that we have not considered heretofore. It is small in ordinary cast-iron hot-water radiators, whose tubes are connected top and bottom, or even in wrought-iron radiators so constructed. With coils, however, it becomes very great and cannot be overlooked.

For instance, if an inch pipe is capable of carrying water to the inlet of a 1-inch flat coil (for any reasonable loss of heat), it may probably be entirely inadequate to carry it through the coil and have favorable results. It would probably carry sufficient water through a radiator because the large chambers cause so little extra resistance, but in the flat coil there is its own pipe and return bends of the same diameter as the

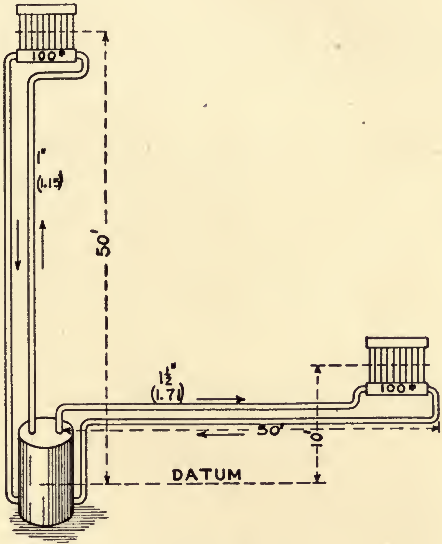


FIG. 34.

flow-pipe that probably add several times more resistance than there is within the mains or connections.

Take the example of a coil 5 feet long and 10 pipes high. made of 1-inch pipe, as shown in Fig. 35.

It has 50 feet of plain pipe and 9 return-bends, and assuming them to be of the very best pattern, it will be no exaggeration to consider each of them to cause as great a resistance as a common elbow, if an ordinary close pattern bend causes resistance equal to 142 diameters (see page 45).

In this case then we have 9 bends × 100 diameters ÷ 12 inches

= 75 feet. In other words the bends alone add a resistance equal to 75 feet of straight pipe, so that the resistance of the coil is equal to that of 125 feet of 1-inch straight pipe, and with carelessly reamed ends may reach a resistance equal to 150 feet, and adding to this the resistance of ordinary connections—10 to 15 feet long or thereabouts—with a valve and six elbows, which was shown earlier to be about equal to that of 100 feet of straight pipe, we have a total resistance from the flow main through the coil and back to the return-pipe equal to that of 250 feet of 1-inch pipe when straight.

If we notice where the second and third curved lines—200 and 300 feet respectively, in the diagram, Fig. 31—cross the line for 25 square feet of heating surface, we will see that in the case where the loss of temperature is about 20 degrees—Fig. 31

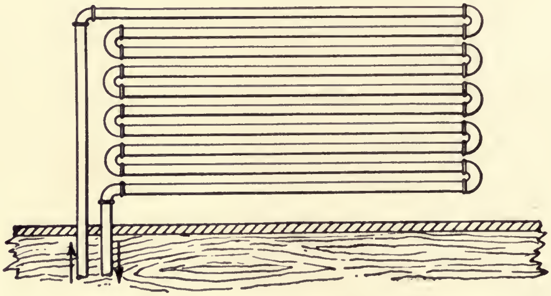


Fig. 35.—Flat Coil.

—they cross close to the 1-inch line. This shows that a coil one inch in diameter with its valves and connections cannot be greater than ten pipes high and five feet long, and circulate with a less loss than 20 degrees, provided it is no higher in the house than the first floor. For every return bend that is omitted 8 to 10 feet of inch pipe can be added in the coil by increasing its length between the return bends and diminishing the number of pipes high.

In considering box coils and their relation to flat coils, in the matter of their sections, the resistance of the valve and connections is to be omitted.

The leaf of a box coil 5 feet long and 10 pipes high will have a resistance equal to between 125 and 150 linear feet of one-inch plain pipe. This is about 20 square feet of surface to the leaf and would call for about a *one*-inch pipe for a loss of about 15 degrees.

This is probably the greatest length of section of that diameter that should ever be used in a box coil for direct radiation. For indirect radiation they should be shorter, and this question will be treated hereafter.

In the construction of flat coils, therefore, the resistance within the coils must be carefully considered, as the diameter of the pipe of the coil must always depend on the length of the circuit and the amount of heating surface it contains. In treating of radiators we did not consider the resistance within them. Usually it is small, but this depends on the make and how closely they resemble a coil, and particularly a coil of small diameter. For instance, the resistance caused by the passage of water through the base of an ordinary vertical radiator and through the aggregate of its pipes may well be taken as no greater than the resistance of a short 3-inch pipe. If this radiator, then, can be supplied by a $1\frac{1}{2}$-inch pipe under a scanty head of $\frac{1}{2}$ or $\frac{3}{4}$ inches, the extra resistance caused by the radiator will be the same as that caused by the 3-inch pipe. And under the rule that when *quantity and length are constant the head will vary inversely as the fifth power of the diameter*, we have fifth power of $1 = 1$, and fifth power of $3 = 243$, so that the extra resistance caused by a properly made radiator is only $\frac{1}{243}$ part what the resistance of the connection would be, and consequently I have omitted it to prevent introducing elements that would unnecessarily complicate the subject.

The resistance of the rising lines are omitted in considering the horizontal mains, and their resistance is not added in consideration of the augmented head due to their elevation, which, as explained before, probably more than compensates for the resistance caused to the flow of the water.

Let us consider the resistance of a $1\frac{1}{4}$-inch diameter coil of the class known as flat coils, Fig. 35. Assume it is 4 feet long and 12 pipes high, a common size and form for small rooms. There is 48 feet of $1\frac{1}{4}$-inch pipe and 11 return bends. The return bends will each have a resistance equal to 100, even if they are of the best form of merchantable fitting. So that we have

$$\frac{1100 \times 1\frac{1}{4}''}{12} = 114\frac{7}{12} \text{ ft.} + 48 \text{ ft.} = 162\frac{7}{12} \text{ feet in length,}$$

or, more properly speaking, the equivalent of $162\frac{7}{12}$ feet in length, so far as resistance is concerned.

We have now to determine its heating surface, and as 2.3 linear feet of $1\frac{1}{4}$-inch pipe is a square foot, according to the manufacturers' rating, we have

$$\frac{48}{2.3} = 21 \text{ square feet,}$$

to which may be added about a square foot for every *three* return bends, so that the coil contains 25 square feet of surface. This calls for the passage of about $1\frac{1}{2}$ gallons of water per minute (see page 69), if the loss of heat from the water is to be 10 degrees, in its passage through the coil. By Table III (page 36) we find that one gallon requires a head of .033 inches to pass through a $1\frac{1}{4}$-inch pipe *ten* feet long, and under the rule that *the head varies as the square of the quantity passes through a pipe*, we will have for $1\frac{1}{2}$ gallons a head of .07325 inches. Thus $1^2 = 1$, and $1.5^2 = 2.25$, or $2\frac{1}{4}$ times the times the head required for the single gallon.

This is for 10 feet of pipe, and our coil is $162\frac{7}{12}$ feet long or its equivalent, so that the total head for the coil is

$$\frac{.07325 \times 162.6'}{10'} = 1.19 \text{ inches of head,}$$

or the total resistance of the coil, provided it is exactly $1\frac{1}{4}$ inches in diameter.

As a matter of fact it is a little larger, the standard table giving the inside diameter of $1\frac{1}{4}$-inch pipe as 1.38 inches.

A question here arises as to the propriety of considering the extra diameter due to the commercial pipe. It not only applies to coils but to all pipes. After a pipe is in use for some time it corrodes more or less and an incrustation forms on its inside. As this incrustation is about of the same thickness for small and large pipes alike it certainly affects the flow in small pipes more than it does in large ones. If we also consider careless cuttings with wheel-cutters and the neglect to ream the ends, our judgment would not be to allow anything for it, or rather not to take into consideration the excess of commercial sizes over the nominal diameters.

On the other hand, however, the coating is not as great as might be suspected from the fact that the air is expelled from the water, and as it is desirable to use flat coils in many cases without increasing the total resistance beyond .8 inches of head, we will consider the increase of diameter that we may the better find how long a connection we can use without getting our total resistance beyond .8 inches or .9 inches. Therefore, as " the head varies inversely as the fifth power of the diameters of pipes," we have fifth power of 1.25 = 3.05, and fifth power of 1.38 = 5, from which we get

$$\frac{1.19'' \times 3}{5} = .714 \text{ inch}$$

as the head for a 1.38 inch pipe (the commercial 1¼-inch).

This calculation is on a 10 degree drop in temperature. We can, therefore, double the coils' length (without connection) if we have a 20 degree drop in temperature, or with a 20 degree drop in temperature we can add about one-third to its surface and use a set of ordinary connections 1¼ inches in diameter, with elbows and valve, and not exceed a first floor head.

This shows that a flat coil of 1¼-inch pipe should not exceed 33 square feet of surface, with pipes 4 feet long, if it is to be used on the first floor of a building, and it is well to add here that no flat coil should be supplied with a pipe of a smaller diameter than itself.

As the coils go higher in the house, the lengths may be increased with the head, or the diameter decreased. I am not in favor of a decrease of diameter for the second floor with this class of coils, but as it may be necessary, the rule, which is the converse of the last given, is, that the diameter will vary inversely as the fifth root of the head for constant lengths and quantities of water. It must also be remembered that the heating surface is decreased in the proportion of the diameter of the pipe, so that the length must be increased to have equal heating surface.

Example: For the first story the head was shown to be about .88 inches, and for the second story twice as much, or 1.76 inches; so the heads are in the ratio of one and two, and so on for higher stories, or for elevations of 10 feet each. Then as the fifth root of 1 is 1, and the fifth root of 2 = 1.16, we will have

$$\frac{1.25'' \times 1}{1.16} = 1.08 \text{ inches}$$

as the diameter for the pipe of the coil for the second floor that will pass the same quantity of water as the 1¼-inch would on the first floor—other things being the same—and the divisors 1.25 and 1.32 will give the diameters for the third and fourth floors respectively, so that for the third floor the diameter becomes just one inch. The length of the 1-inch pipe or coil will now have to be increased until it has the same heating surface as the 1¼-inch coil; and as 2.3 lineal feet of 1¼-inch pipe is equal to a square foot, and three feet of 1-inch has a like surface our resistance will be increased in the proportion of the increase of length. Therefore the head 1.19 inches, as found before, will be

$$\frac{1.19'' \times 3}{2.3} = 1.552 \text{ inches of head.}$$

If we made corrections for the commercial size over the nominal, it would lessen the head thus found, but for obvious reasons this had not better be done. It shows, however, that an inch diameter coil on the second floor will do almost equal work with a 1¼-inch coil on the first floor, the surfaces being the same, and that for the third floor an inch pipe or coil of the same surface will pass more water than a 1¼ on the first floor.

There is an advantage in using connections to a flat coil of a larger diameter than the coil itself. There is no object, however, in designing work in this manner, and the rule should be to have a flat or return bend coil and its connections of the same diameter throughout by making the flat coil of the proper diameter at the commencement.

In the improvement of a defective circulation considerable can be gained by so doing, as in that case the water will be carried to the top pipe of the coil with a reduced resistance and consequently more power or head will remain to overcome the resistance of the coil.

Resistance in Wall Coils.

Header or wall coils, sometimes known as mitre coils, have a low resistance when compared with flat coils. Fig. 36 shows a coil of this arrangement: *a* is the inlet or connection pipe; *c c* the headers at the ends; *b b* the pipes or heating surfaces, and *e* the outlet connection.

We will assume that the inlet *a* is an inch pipe and that the pipes, *b b*, are also *one* inch in diameter and 15 feet long, giving the coil about 20 square feet of surface, not including the headers or elbows, nor will we consider the resistance of the elbows or headers for the present.

We can also assume the resistance in the inlet and outlet pipes to be equal to 100 feet of 1-inch pipe, or, say, about one

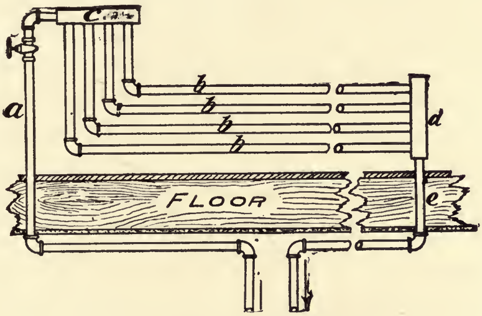


Fig. 36.—Wall Coil.

inch of head for the quantity of water necessary for a coil of 20 square feet.*

The question now is: What additional resistance is caused by the coil alone to the passage of the water around the circuit; or, in other words, what is the total head necessary to pass the water through the coil when the head to pass it through the flow and return pipe is one inch?

A convenient rule is, that when a pipe is branched into any number of pipes of the same diameter as itself, that the resistance in these pipes for equal length with the first pipe, will be in the inverse ratio of the square of the number of branches.

* Note.—It matters not what resistance we assume for the inlet and outlet of the coil, but in cases of this kind it is better to assume a close approximation to the truth, the better to familiarize ourselves with the subject.

For example, the water flowing through *a* and *e* has a resistance equal to one inch. When it is divided into four branches, *b b*, etc., each pipe has to take care of *one-fourth* of the water; and under the rule that the friction in pipes increases or diminishes in the proportion of the square of its velocity, it is evident that as but $\frac{1}{4}$ of the water goes through one pipe, the resistance in one pipe will be but $\frac{1}{16}$.

The resistance of the 4 pipes taken together is the same as that for one of the 4 pipes, because the water, which goes through any one of the 4 pipes, does not go through any of the others; and the resistance which the water encounters in passing from one header to the other, is the resistance of the one pipe through which it goes.

In the case of the first example, Fig. 36, we have connections with resistance equal to between 90 and 100 feet of straight pipe or its equivalent, while the pipes of the coil are only 15 feet in length, or about $\frac{1}{6}$ of the length of the connection. Then, under the rule that the resistance in pipes varies directly as the length, our 1 inch would be reduced to $\frac{1}{6}$ of an inch if the coil had 1 pipe only or to $\frac{1}{16} \times \frac{1}{6} = \frac{1}{96}$ of an inch for the 4 pipes. Thus it is that though the total resistance in the connections or that part of the circuit *a* and *e*, in Fig. 36, is 1 inch, the resistance in the coil is but $\frac{1}{96}$ of an inch, or rather it would be if there were no elbows or fittings in the coils; but there is an inch elbow to each 15 feet of length of coil, which adds as much resistance as 100 diameters of pipe, or about 8 feet more to the length in the point of resistance, and there is the resistance of the branch tees at both ends of the coil, which we are unable to determine with much accuracy but which cannot be greater than the resistance of the elbows. Allowing them to be the same as the elbows, then we have 8 feet for elbows and 8 feet for headers, and as the length of our coil in the first place was 15 feet, we have $15' + 8' + 8' = 31'$ as our length for resistance.

Therefore the elbows, etc., just above double the resistance of the pipes of the coil, and instead of adding $\frac{1}{96}$ we must add $\frac{1}{48}$ of an inch as the head necessary to overcome the resistance of the coil.

Ordinarily, then, the resistance for well-made wall-coils is so little we need not take them into consideration any more than we did resistance through radiators unless they are very long.

CHAPTER XVI.

INDIRECT HEATING APPARATUS.

Proportioning an Apparatus for Indirect Heating—Heat Given Off per Square Foot of Surface—Object of Indirect Radiation—Heat Lost through the Walls and Windows of a Room—Example of Same—Heat Lost by Ventilation—How to Consider it—How to Find the Heating Surface to Warm a Room by Indirect Radiation—Comparative Experiments with Hot-Water Coils—Diagram of the Size of Main Pipes for Indirect Radiation.

It has been shown, by the experiments of different investigators earlier in these papers, that a square foot of direct radiating surface gave off heat to the surrounding air in amounts varying from 1.25 to about 2.25 B.t.u. per hour for each degree the radiating surface was warmer than the air. The variation is due, primarily, to the form and nature of the surface, and secondly, to its arrangement for the free passage of the air.

With direct radiation the movement of the air usually depends solely on the form of the surface. When the air can reach all of the surface readily and pass rapidly upwards the best results are obtained, and each increment of heat imparted to the air causes an increment of upward velocity, though in a less ratio.

With the best ordinary radiators, however, it is not safe to count on imparting to the air more than 2 heat units per square foot per hour per degree of difference of temperature. If, however, the air for indirect radiation is forced over the radiators by the draught of warmed flues or by fans, a square foot of surface will do more work, and in steam coils where the pipes are large enough to keep up a constant pressure the increase of work or heating is nearly proportional to the increased volume of air passed through the coil. With hot water, however, this does not follow, for the simple reason that the water when it is cooled passes but slowly away to make room for more, and that nothing is gained by abstracting heat from it any faster than it can be supplied.

The ability of hot water to supply and maintain the heat depends on its velocity. Its velocity is also somewhat accelerated by the greater abstraction of the heat, but this acceleration of velocity bears such a small ratio to the heat taken away, that with an artificial draught the water in the coil is so much cooled as to be entirely useless for heating unless the pipes are of such a diameter that they will convey more heat, under their most unfavorable conditions, than the maximum quantity of air to be passed can take away.

We must assume some standard loss of temperature, to be occurring while the water passes through the coils, that will satisfy us. For an " open " apparatus, or one in which the maximum heat and pressure depends on the height of the building, a temperature of about 212° fahr. is the greatest that can reasonably be expected to be maintained at the boiler. If we get the water to the coils at 210° fahr. and cool it to 190° fahr. in the coil we have a limiting condition, and it is on this basis that we shall consider the following problems in indirect work.

There are two reasons for warming by indirect radiation. The first and most important one is to obtain ventilation as well as heat, and the second is to avoid having the room encumbered by a direct radiator or coil. The first is the only one we will consider.

It is understood, of course, that heat is lost in two directions from a room warmed by indirect radiation. A certain amount of heat is lost through the glass of the windows and through outside walls, and this loss is a constant amount irrespective of the amount of air passed through the room. The other is the heat carried out through the vent-flues, and taken together they form the total heat necessary for a room warmed by indirect radiation.

The heat lost through the glass and walls is about the same no matter what mode of heating is used. If the walls of a room were perfectly air-tight the heat lost through them by conduction, radiation, etc., will be just equal to the heat given off by a direct radiator suitable for the same room. An indirect radiator must furnish this heat and also enough heat to warm, to the mean temperature of the room, the air escaping through the vent-flues.

Assuming that we have a corner room 14 x 18 feet on the floor and 10 feet high, with 4 windows of 25 square feet each, we will find that we have 220 square feet of outside wall and 100 square feet of glass passing heat from the room. Assuming again that 10 square feet of wall cools the room about as much as one square foot of glass, the cooling effect of the walls and windows will be equal to 122 square feet of glass.

According to Mr. Hood's experiments (page 63) the loss of heat per square foot of glass is equivalent to about 1.28 cubic feet of air cooled from the inside to the outside temperature per minute, and if we take the room to be 70° fahr. and the outside air zero, we have $1.28 \times 70 \times 122 = 10{,}931.2$ cubic feet of air cooled one degree in a minute or 655,872 cubic feet per hour, which if we divide by 50 gives us the B.t.u. lost per hour.* Thus

$$\frac{655872}{50} = 13117.4 \text{ B.t.u.}$$

that are passing each hour through the walls and windows of this room on a very cold day.

To this must be added the heat required for ventilation. This amount of heat must be taken as the difference of temperature between inside and outside, multiplied by the cubic feet of air admitted in an hour divided by the constant 50.

* The divisor 50 may be taken as a constant for our purpose when finding the B.t.u. in air. It is obtained thus: One pound of air at 32° fahr under the pressure of an atmosphere (29.9 inches of mercury) will occupy a space of 12.38 cubic feet and its specific heat is .2379 when water is unity at the same temperature. In other words, a pound of water will hold 4.2 times as much heat as a pound of air and, therefore, 4.2 pounds of air require only the heat of one pound of water for the same increase of temperature. Thus 12.38 cubic feet $\times$ 4.2 = 52 cubic feet of air will absorb as much heat as one pound of water to warm each one degree.

Corrections for humidity are not considered, nor for the increase of volume of air when warmed above 32° fahr. The weight of 52 cubic feet of air at 32° is about the same as that of 60 cubic feet at 100°, but corrections for average humidity will reduce it somewhat, but for all ordinary ranges of conditions that we have to deal with in warming 50 is a good average, as in winter weather we may be taking in air as cold as zero, though the average is presumably not below 36° for a winter in or near New York.

The room contains a little over 2500 cubic feet and requires a change of air every 15 minutes, or four times in an hour, which will be 10,000 cubic feet of air per hour warmed to 70° fahr. Thus

$$\frac{10000 \times 70°}{50} = 14000 \text{ B.t.u.}$$

Thus it will be seen we require a total heat for this room equal to 13,117.4×14,000 = 27,117.4 B.t.u. per hour.

There are two methods, either of which we may follow, to find the coil surface. One is—we have shown that it requires 14,000 heat units to warm this air (2500 cubic feet four times an hour) 70 degrees, consequently the heat necessary for the walls and windows (13,117.4 B.t.u.) will warm it 65.58 degrees additional, so that the air entering the room must have a temperature for all purposes of 135.58 degrees.

The coil having a mean temperature of 200 degrees, and the initial temperature of the air being zero, the mean difference of temperature between the air and the coil is 132.2 degrees. As each square foot of surface will give off heat equal to two heat units per degree of difference per hour, we have the total heat units divided by 132.2×2. Thus

$$\frac{27117.4}{132.2 \times 4} = 102.56 \text{ sq. ft.}$$

as the necessary surface of the coil.

The units of heat given off by the coil or radiator surface is the variable factor. We have taken it here as 2, which is probably a safe medium for all work. If the coil surface does better, more water will be cooled. The cooling accelerates the velocity of the water, but as it is only in a ratio of about the square root of the cooling, the water gets rapidly cooled, and soon becomes unable to warm the air. Therefore the coil should be proportioned so as to do its greatest work under the least difference of temperature, and when it is not called upon for its greatest duty the water simply circulates hotter and slower.

I do not wish to convey the idea that it is absolutely necessary to make indirect coils as large as in the example, as by the rough and ready rule often used it figures out about one square foot to about 25 cubic feet of space in the room. With my present knowledge on the subject, however, I would advise those who use this rule to limit themselves to 1 to 30, and to work inside of it when possible, keeping in mind however that the amount of air moved for the purpose of ventilation affects any such arbitrary ratios.

I regret that I have no experiments but my own to offer on the effect of cooling in indirect hot-water coils. They were made some few years ago with the view of determining the value of a square foot of a new form of surface when compared with a box coil, which latter may be taken as a standard, and throws some light on the subject under consideration. The following are extracts from a report made at the time:

" In my experiments with hot-water heating on a ' compound ' indirect coil, *six* pipes wide by *two* pipes high by forty and one-half inches ($40\frac{1}{2}''$) between the bends and headers *versus* an ordinary box coil *six* pipes wide by *ten* pipes high by thirty-six inches ($36''$) between the bends.

" The twelve pipes of the compound coil, exclusive of bends, contained forty feet and six inches ($40'\ 6''$) lineal of 1-inch pipe. The sixty pipes of the box coil, exclusive of bends, contain one hundred and eighty feet ($180'$) lineal of 1-inch pipe.

" The commercial rating of the compound coil was 48 square feet of heating surface, and the commercial rating of the box coil 74 square feet.

" The analysis of the surface of the box coil is as follows: 180 feet lineal of 1-inch pipe = 62 square feet—

$$\left(\text{thus, } \frac{180 \text{ feet}}{2.9 \text{ sq. ft.}} = 62\right).$$

The two headers and fifty-four bends made over twelve square feet additional, but I allowed only that amount for them, as some makes of bends on the market are found to be smaller than those used.

" The twelve pipes of the compound coil have each a helical coil of No. 14 square wire wrapped about it—also in the form of a helix—and from which it takes its name of ' compound ' coil.

" The coils were set, as shown in Figs. 37 and 38, and connected to a Hitching's hot-water, base-burning boiler; the vertical distance between the inlet to each coil and the return outlet to the boiler being six feet and nine inches (6′ 9″), and the flow and return pipes in all parts being 1½ inches wrought iron with ordinary cast-iron fittings.

"On the first day's trial the bottoms of the coil boxes were removed, and the outlets on top were 12″ x 16″ or 1⅓ square feet.

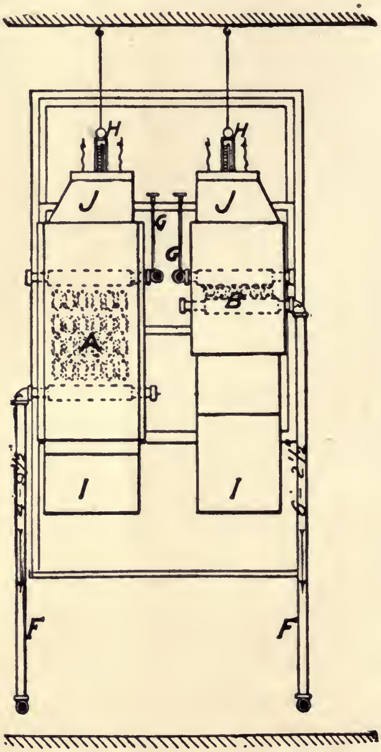


FIG. 37.—Front Elevation.

"On the second day's trial the bottoms of the coil boxes were restored and connected with the outside atmosphere by 12″ x 12″ tin ducts, and the apertures on top were also made 12″ x 12″, being drawn in from 12″ x 16″ by suitable inverted hopper-shaped tin ducts. The heights from the tops of the coil to the tops of the outlets were 20 inches, and the whole apparatus was set up to imitate an apparatus when set within a basement of from 7′ 6″ to 8′ in the clear, and supplying air to the first floor registers; or, in other words, about the poorest ordinary condition to be met in practice, as the air to the upper floors of a house will always move with a greater velocity—other things being the same.

"The following table gives the results of the observations of two days' trials.

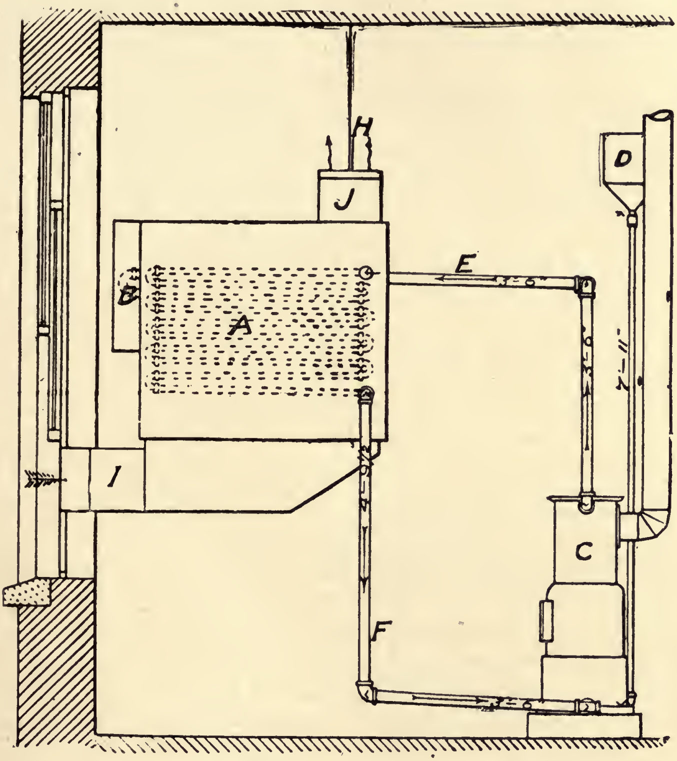


Fig. 38.—Side Elevation.

"The illustrations show side and end views of the apparatus as used; *A* being the box coil, *B* the compound coil, *C* the boiler, *D* the expansion tank, *I I* the cold-air inlets, *J J* the warm-air outlets, and *H H* the thermometers.

"The flow pipes to each coil were taken from opposite sides of the boiler, and the return pipes entered the boiler at oppo-

TABLE VIII.—AVERAGE OF THE OBSERVATIONS FOR EACH DAY.

		Observations.	Temperature of air as it entered coil box.	Temperature of air as it escaped, top of box.	Mean temperature of air.	Velocity at top through 12x16-inch aperture. Feet per minute.	Velocity at top through 12x12-inch aperture. Feet per minute.	Temperature of water entering coil.	Temperature of water leaving coil.	Mean temperature of water in coil.	Vol. of air per minute in cubic feet.	Vol. of air per hour in cubic feet at 32°.	Total heat units in air for an hour.	Units of heat given off per sq. ft. of commercial surface for each degree fahr. difference of temperature between air and coil.	Difference between air entering and leaving coil boxes.	Volume of air per hour passed at top of box in cubic feet.
			F.	F.	F.	Ft.	Ft.	F.	F.	F.						
Compound coil, 48 sq. ft..........	1st.	3	85°	143.3°	114°	86.5		195°	185°	190°	115.336	5,644	6,310	1.73	58.3	6,920
Box coil, 74 sq. ft	day.	3	85°	134°	109.5°	119.3		191.66°	175.5°	183.58°	159.1	7,900	7,422	1.353	49.	9,546
Compound coil, 48 sq. ft..........	2d.	4	78°	166°	122°		151.22	206.4°	194°	200.2°	151.22	7,144	12,050	3.21	88.	9,073.2
Box coil, 74 sq. ft	day.	4	78	150	114		229.	206.4	186.38	196.39	229.	11,090	15,310	2.51	72	13,740
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

site sides, so as to have no branched pipes, and in all cases to have both coils under exactly similar conditions.

"The difference of temperature of the water entering the coils on the first day (col. 9) is accounted for by the fact that the temperature of the water was advancing at the time the observations were taken; the box coil being always noted first. This, however, does not affect the result as deduced in col. 15, except to be slightly in favor of the box coil.

"The units of heat were obtained by finding the heat added to the air. This method, of course, is subject to error, except for comparative purposes. Care was taken, however, with the use of the anemometer, and probably fully as much air passed as was recorded.

"It shows in the case of the box coil for the first day, when used almost as a direct radiator, a loss or passage of 1.343 heat units per hour per square foot, per degree of difference between air and coil, and it shows a loss to the water of 16.16 degrees; and on the second day, when used exactly as an indirect coil, the loss or passage of 2.475 B.t.u. with a loss of temperature to the water of 20.06 degrees.

"Reference to col. 15 will show the units of heat lost per square foot of surface.

"In the case of the compound coil the units of heat given off are greater. It must be remembered, however, that this secondary surface had an actual surface per nominal square considerably in excess of the box-coil. The box coil's actual surface and nominal surface are the same. The actual surface of the compound coil including that of the wire is much greater than its nominal surface; hence though a commercial square foot of it will do more work, an actual square foot of it, wire included, does less work."

The compound coil, however, has but one-third as much pipe per nominal square foot as the box coil has, hence the loss of heat to the water was but 10 degrees when the units of heat given off per square foot were 1.735, and on the second day the loss to the water was but 12.4 degrees when the units of heat were 3.18 per square foot. This, of course, is on account of the less resistance to the flow of the water in the compound coil, as it had but two pipes per section to the ten pipes in the box coil with their return bends.

Pipes for Indirect Radiators.

We have next to find the diameters of flow and return pipes for indirect radiators.

A total head of .35 inch is the greatest that we should allow for indirect work in an ordinary cellar or basement. The head for 10 feet we found to be .88 inches, therefore, the head for 4 feet will be a little under .4 inch.

Taking the example of the indirect radiator already considered for a corner room of 2500 cubic feet of space with outside wall surface and glass equivalent to a total of 122 square feet of glass in cooling power, and moving 10,000 cubic feet of air for ventilation,* when the external air is zero, we are at liberty to assume a loss of 20 degrees to the water as it passes through the coil. Our total loss in heat units being 27,117.4 it is plain we will have to pass only one-twentieth of that many pounds of water if we cool it twenty degrees, hence 1355.8 pounds of water will have to pass through the coil in an hour.

A U. S. gallon of water at 200° fahr. weighs 8 pounds and a very small fraction. The total pounds of water required, therefore, being $\frac{1355.8}{8}$ it is plain we require just 169.5 U. S. gallons of water per hour, or 2.82 gallons per minute.

By Table III we find 2.82 gallons will pass through a 2-inch pipe 10 feet long with a loss of about .027 inches of head. It is plain from this that a pipe 10 times as long or 100 feet, or a shorter pipe or circuit with elbows and valve sufficient to make a resistance equal to 100 feet, will cause 10 times the resistance so that the head for 10 feet becomes $.027 \times 10 = .27$, plainly showing us that we require about a 2-inch pipe for this radiator for a loss of 20 degrees.

This leaves a little for resistance caused by the coil itself or for resistance through boiler, etc. We have something in our favor by a 2-inch pipe being actually 2.07 in diameter.

On the whole a 2-inch commercial pipe is ample for this radiator doing this work if carefully reamed and easy bends are used with a gate valve instead of an angle or globe. The coils or radiators, however, should be of a class that offer little

* This room is a fair example of a corner room in a private residence. and probably forms nearly a maximum of wall and window surface to cubic contents. As rooms increase in cubic contents the walls and windows increase in a less ratio. Hence I consider this an ample illustration.

resistance and if box coils are used have as many sections in the width as possible, as the more branches the large pipe discharges its water into the less the resistance. The advantage of large diameters for coils or sections it is not necessary again to refer to.

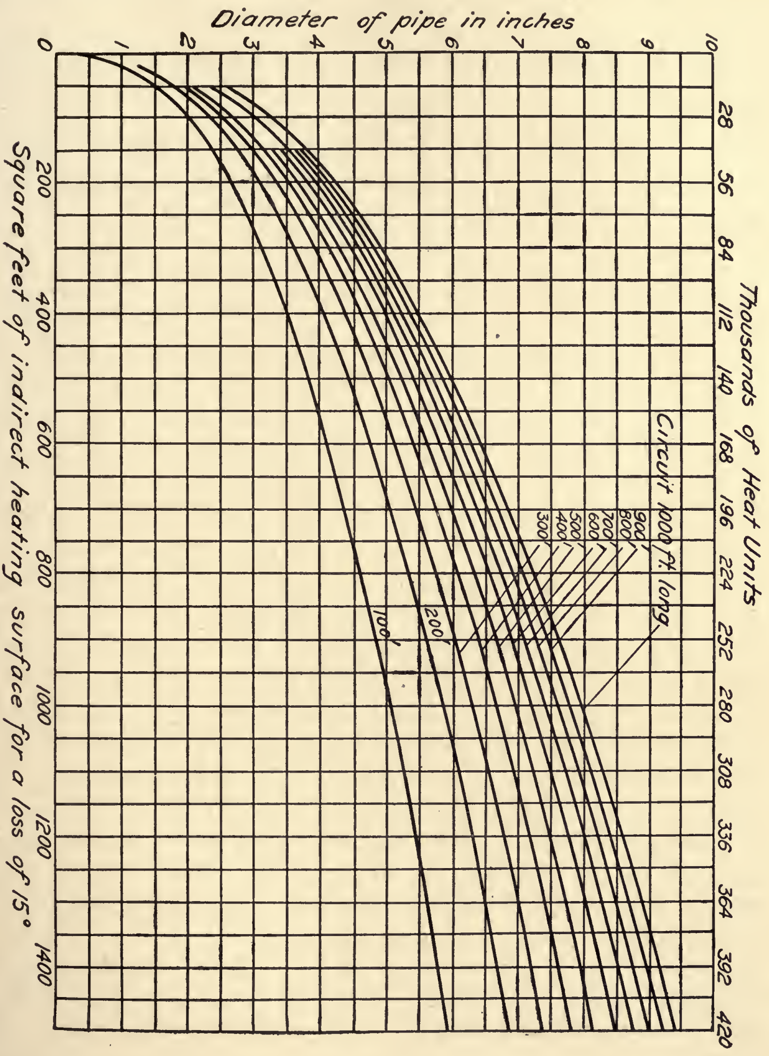


FIG. 39.

The following diagram, Fig. 39, is for mains for indirect work, on the assumption that it requires a 2-inch pipe for 100 square feet of surface for a 20-degree loss.

CHAPTER XVII.

SYSTEMS OF PIPING USED WITH HOT-WATER APPARATUS.

Systems of Piping Used in Hot-Water Heating—Simple-Circuit Apparatus—Compound Circuits—Branched Circuits—Table of the Ratios of Increase of Diameters for Increase of Surface or Increase of Length, or Both, with Examples.

The main pipes and systems of piping used in the warming of buildings by hot-water may be classed under two principal heads, as simple or single circuits and as compound circuits.

A compound circuit is made up of a number of simple circuits branching from a main circuit, whereas the simple or single circuit has no branches, and the water that is sent out through it from the boilers has no alternative but to pass forward and through the coil or radiator at the end of the loop, and return by the way of the return-pipe to the boiler again.

A good example of a simple or single circuit apparatus appeared in Volume 17 of *The Engineering and Building Record* in a description of Mr. Wyld's residence in Toronto, Canada, the boiler and other parts of which are here republished.

Seven circuits are here taken directly from the head of the boiler and returned into manifold headers at the bottom of the boiler. In this case, though for the sake of convenience they enter headers, there is no reason why they should not enter the side of the boiler, and in fact it would be a little better if they did, as less obstruction would thus be offered to the return flow of the water. An absolutely simple circuit has no branches, and usually supplies but one radiator or coil. In practice, however, it often becomes necessary to supply two or three radiators from near the end of a loop of a single circuit to avoid running too many pipes in one direction. The fact, therefore, of two or even three radiators on the same level being supplied from a simple circuit does not make it what is usually called a compound circuit or one in which large mains are run with branches to the rising lines, etc., as is the usual practice in the United States in the large buildings for the Government.

On the other hand, in many buildings in Canada, warmed by hot water, the practice very much in vogue, if not the only one now resorted to, is to run separate circuits of main pipes from the top of the boiler to the principal divisions of the house or to one or two radiators. This practice seems to have its advantage in the fact that the fitter who has not thoroughly studied the subject is much more likely to secure nearly uniform results in all parts of the house in the way of equable temperatures of the water in the radiators or the coils than he would if he were to run a large main and branch from it to the sections or rising lines.

In reality, this separate-circuit system is unnecessary if the work is planned by one who has time and ability to consider carefully the conditions and requirements of the different lines and branches of a system, or if one is willing to use a main so large that there is no question of its ability to carry water hot enough to the remotest branches and radiators no matter how slow its current may be.

Currents through a branched or compound system will unquestionably take the direction of least resistance and will short-circuit unless planned by an expert, or unless the mains exceed their actual requirements in all parts; while, as has been said, the separate circuit must circulate to the end, if it circulates at all, and hence the practical man often finds it to his advantage to use it.

In this house, as seen by Figs. 40, 41, and 42, the separate system is carried out almost to the extreme. The circuits are all of 2-inch pipe, except the branches to the radiators, which are smaller. The return-pipes are also 2-inch, as they properly should be, the shrinkage of volume of the water being so inconsiderable between the flow and the return that no attention should be paid to it.

The circuits are numbered from 1 to 7 inclusive, and may be traced on the basement plan to the points where the connections or rising lines run through the floor. Corresponding numbers are also found on the elevation and plan of the boiler so the lines or circuits may be readily followed.

Circuit No. 1 (2-inch diameter) supplies the two box coils in the lower hall, which have a surface of 144 and 110 square feet respectively, making 254 square feet on the circuit which loses about 20 degrees between flow and return. Circuit No. 2 supplies the parlor and pantry on the main floor, and then runs to the bath-room heater on the second floor; and thence to the expansion tank; the total surface on this circuit being

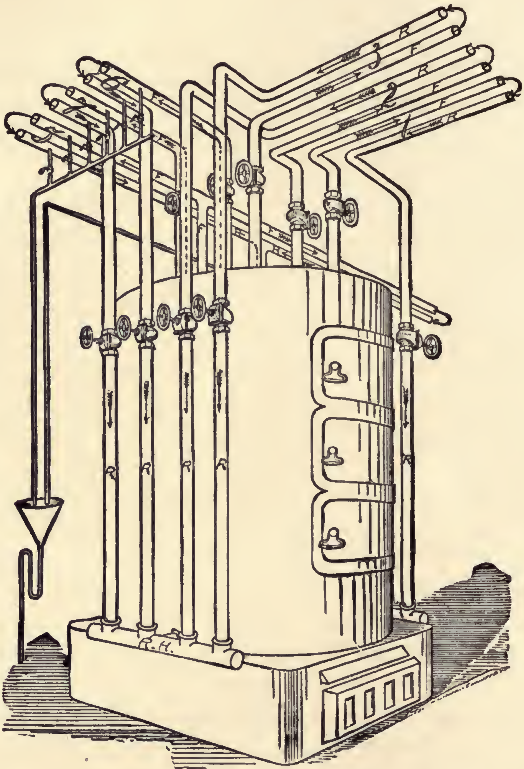


FIG. 40.—Perspective View, Showing Boiler and Pipes in Residence of F. Wyld, Esq., Toronto.

182 square feet. No. 3 goes to the two heaters in the drawing-room, one of 108 square feet and the other of 96 square feet or 204 square feet on the 2-inch circuit. No. 4 supplies the two breakfast-room coils of 66 square feet each; No. 5, the two dining-room coils of 112 square feet each; No. 6, the indirect coil under main hall, made of 1-inch pipe and containing 84

square feet, and No. 7, the front hall coil, second story, of 200 square feet, and the coil in the front chamber next to it of 108 square feet.

The connections to the coils are fairly ample—1½-inch for large coils, 1¼-inch for medium, and 1-inch for the small one in the pantry.

The circuits are treated very much in the way that plumbers in New York treat the circuits for domestic supply in their best work. The flow and the return pipes are supplied with valves close to the boiler, as plainly shown in the illustrations of the boiler. A line of small "draw-off" pipes are placed in the flow and return pipes on the house side of the stop-valves

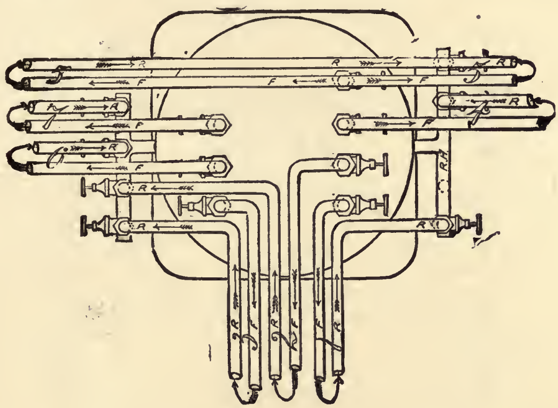


FIG. 41.—Plan Showing Boiler and Pipes in Residence of F. Wyld, Esq., Toronto.

to allow the water to be drawn from a line or circuit. This is plainly shown in Fig. 40, and also the funnel into which they empty. This funnel is trapped into the sewer in the usual way, and the overflow-pipe of the expansion tank is brought to it to prevent a dry trap.

The letter, *F*, for flow, indicates the outgoing pipes of the circuit and *R* the return pipes. Arrows also show the direction of the flow of the water in both pipes, so that a little study of the diagram will readily show the relations of one pipe to the other.

The pitch and flow of the pipe is always upward until it reaches the heater, so as to free itself of air at the highest point of the coil (the upper header), at which point an air-vent is used. The box coils are screened and have marble tops.

The total radiating surface in square feet, not including the mains, is a little over 1500, and the boiler has about 51 square feet of surface of all kinds—that is, fire-box and flue surface—which gives a ratio of boiler surface to radiator surface of 1 to 29.8.

The house was formerly heated by a hot-air furnace in the basement. With this arrangement 32 tons of coal were formerly burned in a winter without sufficient heat. The consumption of coal with the hot-water apparatus is said to be 19

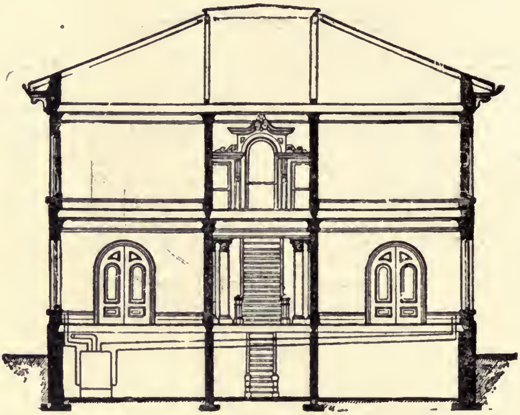


FIG. 42.—Residence of F. Wyld, Esq., Toronto.

tons, and the owner says the house is comfortably warmed in the coldest weather.

The size of pipes used in most of the circuits is about that called for by diagram, Fig. 31, while some of them are larger, so that a careful examination of the temperature of the pipes would probably show that while some of the circuits lost only 15 degrees in passing from flow to return, the most of them lost fully 20 degrees.

The accompanying plans and diagram (Figs. 46, 47, and 48) show the hot-water heating apparatus in the house of Mr. W. H. Carrick, of Toronto, Canada.

It is selected because it shows the hot-water plant of an average city residence that would ordinarily be warmed by a furnace in a comparatively cold country, and is typical of the system of piping largely followed in Upper and Lower Canada in the warming of buildings by hot-water circulation.

The plant had been one winter in use when the writer examined it, and is now several years old, and it has proved ample for the warming of a fairly well built wooden structure, that

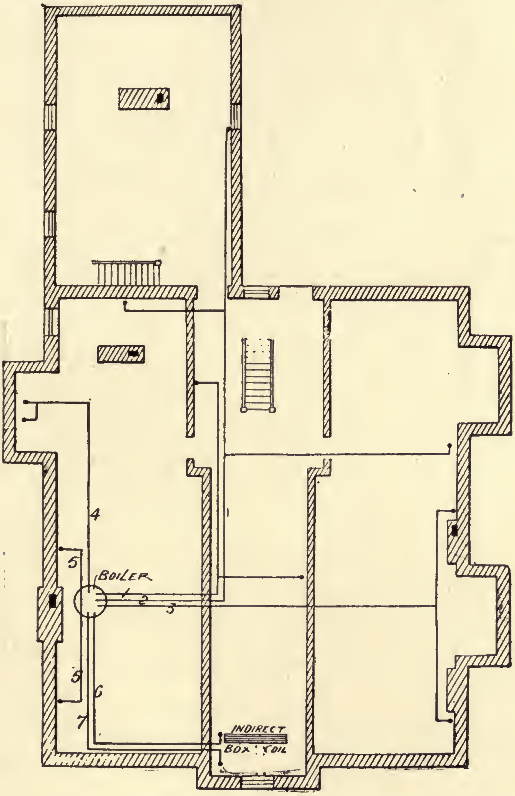


Fig. 43.—Basement Plan.

has been kept warm with water ranging from 120° to 190° fahr. according to the state and requirements outside, and from which deductions may be drawn leading to the formation of data for heating surface for future reference by persons interested in heating problems.

It will be noted that the sizes of windows are shown, the cubic contents of rooms marked, the position of heaters shown, and their sizes marked, the figure attached to each indicating the number of "Bundy" loops, each loop being nominally $3\frac{1}{2}$ square feet of heating surface in the hot-water radiator.

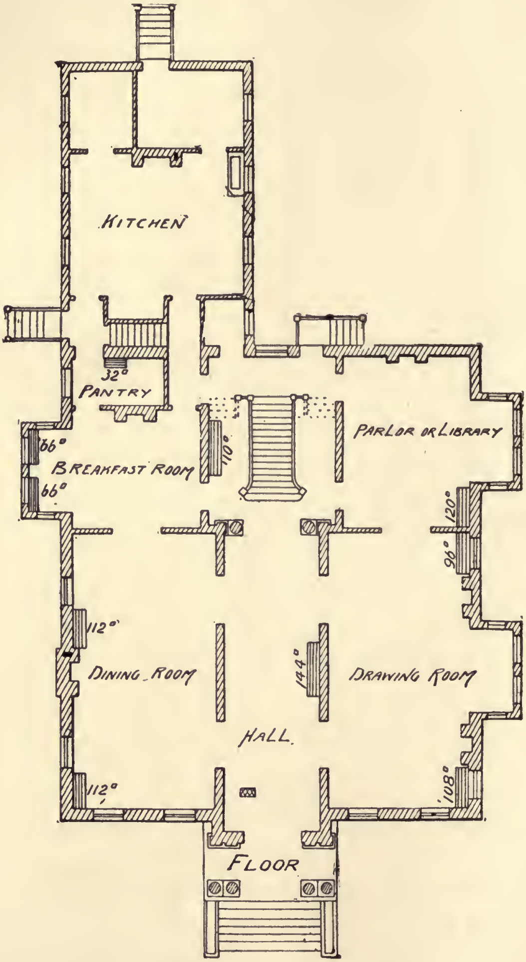


FIG. 44.—First Floor Plan.

For any one who wishes to work out the wall-surface I give the heights (in the clear) of floors; the principal or *first* floor (called in Canada ground floor) 10′ 6″; the *second* floor (called in Canada first floor), 9 feet, and the *third*, or attic, 8 feet.

The sizes of the mains and floor-pipes are marked on the plans, and the boiler is a No. 25 Gurney, old pattern; the consumption of anthracite coal for a season being seven tons or just about 100 pounds per day in cold weather; the climate of Toronto differing very little from the cities of Northern New York, Ohio, Michigan, Western Pennsylvania, and the Eastern

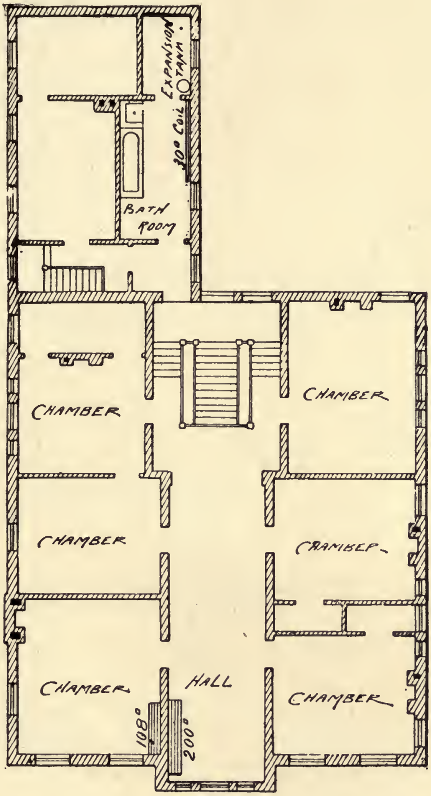


FIG. 45.—Second Floor Plan.

States. This, then, may be taken somewhat as a guide to the plant and its maintenance for a $5000 house on a 20-foot city lot in the new districts of New York or in Brooklyn.

The diagram (Fig. 46) shows the skeleton apparatus, and a reference to the plans will show its relation to the house. The boiler is in the front cellar, pretty well central. There is some advantage in having a hot-water plant balanced in this respect, though when it cannot be carried out larger flow-pipes to the long side will compensate for the increased distance. The

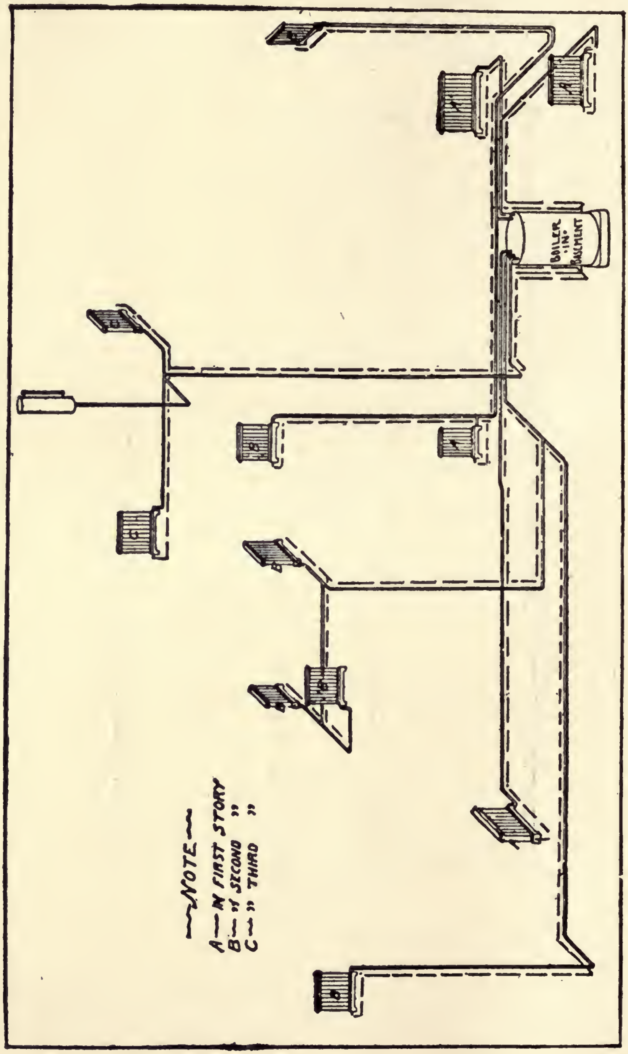


Fig. 46.

radiators marked *A* in the diagram are on the principal floor, those marked *B* are on the second floor, and the ones marked *C* are on the top floor.

The circuit No. 1 starts from the boiler $1\frac{1}{2}$ inches in diameter, runs along with the rest of the pipes to near the pantry, where it turns upward and runs through the partition to the top floor, where it comes out and branches to the two radiators and expansion-tank.

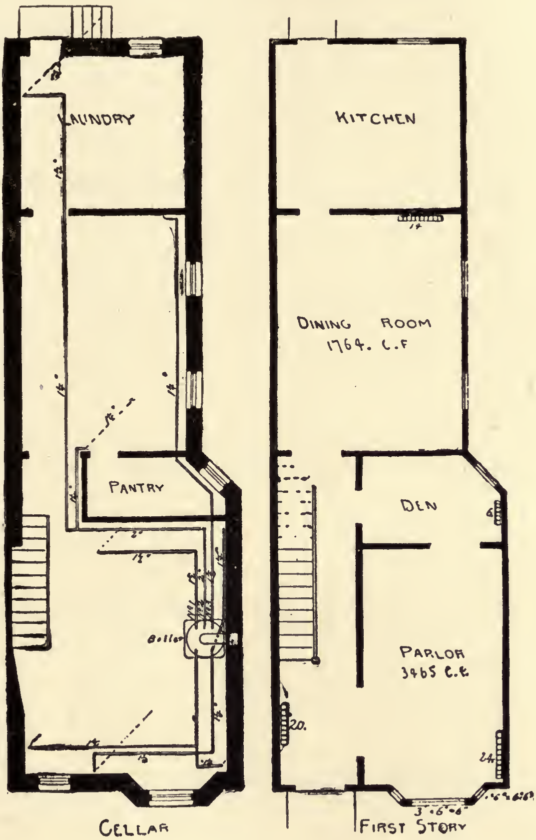


FIG. 47.

Circuit No. 2 starts from the boiler two inches and continues on to the end of pantry, where it has a tee $2 \times 1\frac{1}{4} \times 1\frac{1}{4}$; one branch of which goes along parallel with side of pantry to pantry-door and then goes up through the partition and feeds sewing-room, bath-room, and upstairs hall. The other branch runs straight to the back end of house, and up through the kitchen to the nursery, where it heats the 1 x 10 radiator near the window. It may seem strange that this break was made in this way, but it was found when split at the point where the first pipe went up that the circulation was very sluggish, and that the nursery radiator did not heat properly, hence the change of running the two pipes parallel to this point.

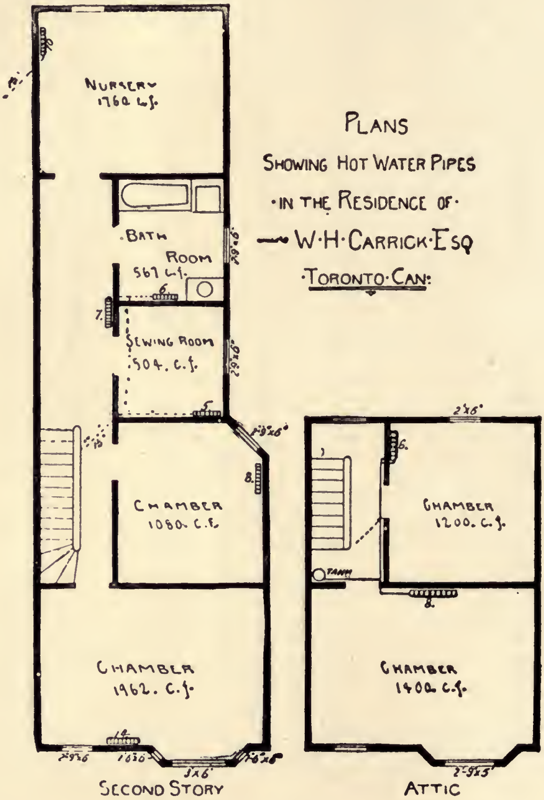


Fig. 48.

Circuit No. 3 starts from boiler $1\frac{1}{2}$ inches in diameter, and heats the 6-pipe radiator in the den, and then continues $1\frac{1}{4}$ on to one radiator in dining-room which has 14 loops.

Circuit No. 4 starts from boiler two inches in diameter, and branches to a $1\frac{1}{2}$-inch pipe to the lower hall, and $1\frac{1}{4}$ inches to parlor.

Circuit No. 5 breaks at the boiler into two 1¼ pipes, one going to front chamber where it heats the fourteen loops, and the other to the back chamber (second floor), where it heats the eight loops.

The flow and return pipes of a circuit are exactly alike in size and almost identical in the manner of being run. The pipes are near the ceiling, with a pitch of about one inch in ten feet.

Each radiator has an angle valve on the inlet end and an air-cock in the top chamber. Although air collects in this chamber a neglect of a week is not sufficient to affect the flow of the water. The dotted line in the plans indicate pipes under floor or in partitions, while the dotted lines in the diagram indicate the return flow pipe. The pipes through the cellar are covered with a plastic non-conductor. On the expansion tank is a glass to show the height of the water, and a connection with the city water-pipe is made to be used when required, but the waste is so small a ball-cock was not considered necessary.

In some of these cases the pipes are smaller than I would advise, still, fairly good results are obtained, and when the advantages of using pipes of large diameter and of reaming their ends and connecting them with long-radius elbows and other fittings are once fully appreciated, the results in hot-water circulation will leave very little more to be desired, as by a careful study of the laws that underlie the subject an engineer can predict beforehand with assurance under what loss of temperature the water of an apparatus will circulate.

Branch Circuits.

All that can be said of a simple circuit applies also to the branch circuits from a large main. The one leads directly from the head of the boiler, the other from the large mains; and when the latter is of ample size and a proper circulation is maintained therein, branches from it will give results equally as good as with those taken directly from the boiler. In fact, in long, low buildings better results can be obtained, and at a less first cost, by carrying a large trunk main through the centre of the building and branching it properly, than can be obtained by a number of long simple circuits that are of necessity of a comparatively small diameter, and so give a very much greater resistance for the amount of water passed than that of a single large main. I may repeat again that single parallel circuits carried from the head of a boiler to the remote divisions of a building will only be used by those who are not skilled in proportioning and branching large mains into proper subdivisions. It is the practical means used, however, for preventing complete failure and securing reasonably equable temperatures, as the hot water from the boilers is so divided at the start that each circuit takes its share, the amount passing in any direction being regulated by the diameter of the pipe, its length and bends, and the height of the end of the circuit above the boiler.

I do not wish to be understood, however, as saying that the simple circuit system is always a panacea for defects of circulation. Unfortunately many simple circuits fail to circulate properly, but in such cases the defect is circumscribed and can be located at once and the alterations necessary for its remedy will not affect adjacent circuits. A common cause of failures in circuits is the insufficient diameter of the pipes. Short circuits generally work well while long ones give trouble. If a long circuit is correctly proportioned and the pipes are fairly well covered from the air the result at the radiator will be as good as with the short circuit or so nearly so that the difference will not be readily discernible. Of course this is on the assumption that the alignment of all pipes is perfect, and that air-pockets or mechanical obstructions do not exist.

If we have constructed an apparatus that circulates satisfactorily in some of its circuits while one or two others fail to do so, then we should see that the defective ones are proportioned by the following figures, taking the conditions of length and turns of a satisfactory circuit as a standard.

For instance, assume that we have a coil or radiator of say 60 square feet on a 1¼-inch pipe and the length of the circuit is 40 feet, 20 feet flow and 20 feet return, and it gives you satisfactory results. Then to get the same results at 80 feet or 120 feet, or any other multiples of the first length, you must increase the diameters in the ratio of 1.15 for the second length, 1.25 for the third, and so on.

When the radiator or coil on a new line is greater or smaller than the line that is taken as a standard, the diameters used for the standard circuit must in the new circuit be increased or diminished in the ratio of 1.32 for a coil of double the size and reduced to .75 for one-half the size; and the following columns of figures, Table IX, are arranged to show the ratio of increase of diameters for increased amounts of surface and increased lengths of circuits.

To use it we have simply to multiply our original diameters, that we have found and know to be satisfactory, by the corresponding number in the column next to that which contains the number of times the heating surface or length of circuit has been increased and we have the proper diameter to satisfy

TABLE IX.

Ratios for the increase of surface		Ratios for the increase of length	
Ratio of surfaces	Ratio of diameters	Ratio of lengths	Ratio of diameters
.5	.75	..	....
Unity.	1.00	Unity.	1.00
2.	1.32	2.	1.15
3.	1.55	3.	1.25
4.	1.75	4.	1.32
5.	1.90	5.	1.38
6.	2.05	6.	1.44
7.	2.18	7.	1.48
8.	2.30	8.	1.52
9.	2.41	9.	1.55
10.	2.52	10.	1.59

the new conditions. For instance, to find the proper diameter for a circuit that has three times as much surface as the standard of comparison, you must multiply that of the standard by the number under ratio of diameters that is next to the right of 3 under ratio of surfaces and you have the new diameter.

If the circuit is to be increased in length, and at the same time has to supply three times as much heating surface as the standard circuit, then supposing the new circuit is *four* times as long as the standard, its diameter must be further increased by multiplying it by the number under ratios of diameters next to the right of 4 in the column of ratio of lengths.

In the following examples the standard circuit is supposed to be of 1¼-inch pipe.

Example 1.—With three times the surface we have 1¼″×1.55 = 1.937″ as the diameter for the new circuit.

Example 2.—With four times the length, but with no change of surface, we have 1¼″×1.32 = 1.65″ as the diameter for the new circuit.

Example 3.—With three times the surface and four times the length and we have 1¼″×1.55×1.32 = 2.556″ as the diameter of the new circuit.

Should this table be required for numbers beyond 10, say for 50 times the surface or 50 times the length, it is only necessary to separate the given number into two or more factors and to multiply in succession by the corresponding ratios of diameters. Thus, for 50 times the surface, since 50 = 10×5, 1¼″×2.52×1.90 = 5.985″, or say the ratio of the diameter for 20 times the surface is required as 20 = 4×5 or 10×2, then either 1.75 and 1.90 may be multiplied together for the new ratio, or 2.52×1.32, which in either case gives 3.325 as the ratio for 20 times the surface. If it was for 200 times the surface multiply again by the ratio for 10 (2.52), which gives 8.38 as the ratio for the new diameter. The same rule applies to finding ratios of diameters for increased lengths.

CHAPTER XVIII.

COMPOUND MAINS.

Compound Mains of the Heating System in the State, War and Navy Department Building—Eccentric Fittings—Fittings of a Small Residence—Fitting of the Westchester County Almshouse.

Compound mains are made up of a number of simple circuits taking flow from a trunk main and returning into a similar main return-pipe, the trunk mains only joining with the boiler.

The State, War and Navy Department building at Washington, D. C., is a fine example of this class of work, a full description of which appeared in *The Engineering and Building Record*, January 22, 1887, and part of which is here reproduced* (Figs. 49–54).

The building is 500 feet long from north to south, and 275 feet from east to west, and is shown entire in the block plan—Fig. 49. The centre and west wing (War Department), shown by shade lines on the block plan, comprise the new part of the building. The darker shading comprises that part of the building shown in enlarged detail in Fig. 50, which has within it a set of boilers and a warming apparatus. Within the entire building there are six such apparatus, one in the north and one in the south wing, and two in each of the east and west wings, the centre being supplied from the west wing.

The cellar of the building is principally given up to the warming and ventilating apparatus. The remaining floors of the building, which consist of basement, first, second, third and fourth floors, are for offices. The warming of the basement and first floor is by direct indirect radiation. The remaining floors, second to fourth, inclusive, are warmed by indirect radiation.

* It was through the courtesy of General Thomas Lincoln Casey, Corps of Engineers, U.S.A , under whose direction the work was done, that access to the drawings and data was obtained.

The plan of the greater part of one of the six plants of this building is shown in Fig. 50.

Fig. 51 is a vertical longitudinal section of the same, showing one of the boilers, and the trunk mains both flow and return, and Fig. 52 is a cross-section (looking south) showing the two boilers of a plant, and the main connections with the trunk mains, both flow and return.

The boilers used in this section are full of tubes. They are 54 inches in diameter, and contain 121 3-inch tubes, and 60-inch boilers used in the other plants of the building have 148 3-inch tubes each. Fourteen-inch cast-iron necks join the boilers

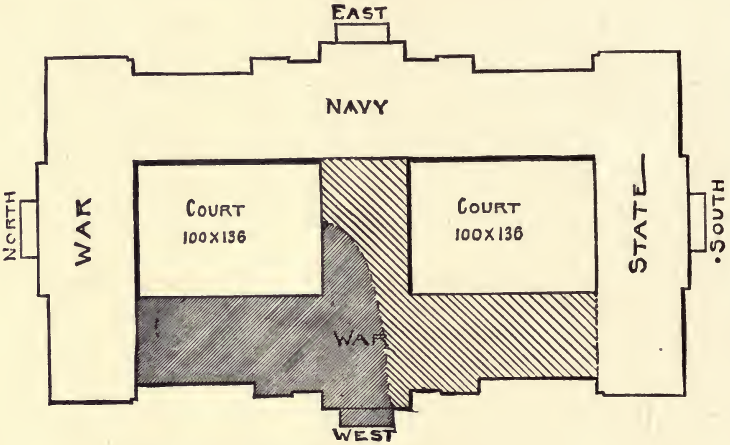
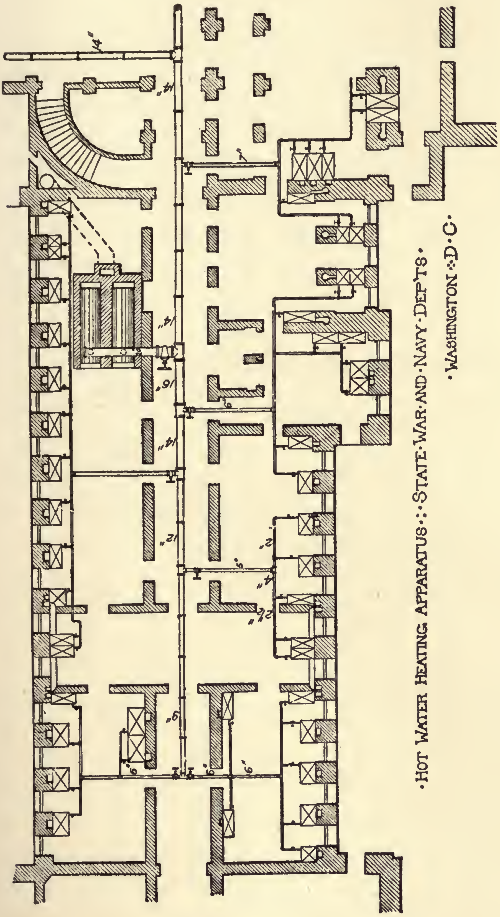


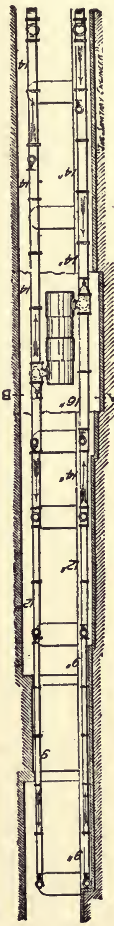
FIG. 49

with a 20-inch cross drum, both above and below, as shown in Fig. 52. These drums are carried full size into the main passageway under the halls of the building. Twenty-inch gate-valves are here used as seen in Fig. 50 basement plan. They are the main stop-valves of a single plant. The pipes then branch into a 16-inch and a 14-inch main, as shown, the former running north and the latter south and central. The flow-pipes only are shown in this figure, but the return-pipes are identical with them in size and may be seen in Fig. 51 in elevation. The flow-pipes rise very slightly as they go from the boilers. Where they reduce in diameter from a large to a smaller size—as, for instance, from 16 to 14 inches—eccentric fittings are used, so as to have the top of the pipe on the same common alignment, and slightly rising to the ends. This is to prevent air-traps or lodgments of air at any point of the pipes. This can be noticed in Fig. 51. The branches from the mains are also



·HOT WATER HEATING APPARATUS·:·STATE·WAR·AND·NAVY·DEPT'S·
·WASHINGTON·:·D·C·

FIG. 50.

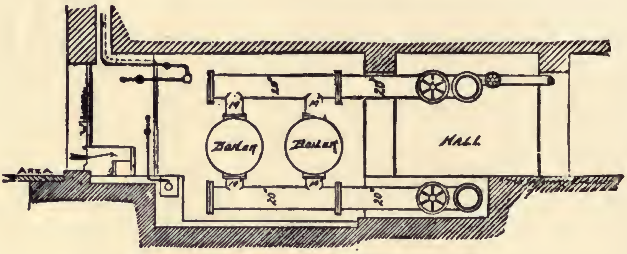


SECTION THROUGH HALL OF WEST-WING
SUB-BASEMENT

FIG. 51.

taken out on a level with the top of the main through special eccentric branch *tees*, the object being the same. This can be seen in Fig. 52, and Fig. 53 shows one of this class of fittings in detail. They prevent the formation of air-pockets where a line reduces in size, which pockets must necessarily follow with common fittings, and in the case of branches that leave the side of a main instead of the top, they distribute the air evenly, more evenly among the branches, and they further admit of keeping the main pipes near the ceilings, so the top sides of all the pipes will be on the same common alignment, an advantage in low basements.

Fig. 54 is a diagram showing the sizes of the rising lines. For a large window radiator on the basement and first floors the branch leaves the main three inches in diameter and reduces to two 2-inch branches, one 2-inch branch for the basement and one of the same diameter for the floor above. This is about theoretically correct, when the augmentation of head due to the additional height between the basement floor and the first floor is considered. A 2½ branch from the main at



SECTION A-B SUB-BASEMENT

FIG. 52.

the cellar ceiling runs 2½ inches to the first floor, with a 2-inch branch to the window radiator on that floor; then to supply a large radiator on the fourth story it is only 1¼ inches the remainder of the distance. The connections that supply the indirect coils on the cellar ceiling are mostly two inches, and the average surface of the indirect coils about 200 square feet each. It is well to call attention to the fact that the connections to these coils are short and have few elbows, and that, therefore, with water entering at 200 it will probably leave the coils at a temperature not much below 160° fahr.

It may be said of this work, that the system followed is almost identical with that followed in steam-heating, with the exception of the increased diameters of the pipes, and the absence of anything like relief-pipes. Nearly all the Government buildings that are warmed with hot-water have modifications of this simple principle, which consists of nothing but mains and their branches, which latter are again divided into smaller ramifications to suit circumstances.

It is well to impress on the fitter, however, that unless the pipes of an apparatus of this class are properly proportioned, and ample at every stage of their progress, he will have "dead" ends or circuits; or, more properly speaking, sections of the apparatus will work sluggishly, and the uniform heat of the radiators cannot be kept up.

The cause of this is, all the water that passes out through a contracted or insufficient main will find easy circulation through the central part of the apparatus, leaving the more distant circuits poorly or almost entirely unsupplied, and the whole apparatus may be compared to a sluggish circulation of the blood on a cold day—the extremities are cold because of the lack of force and volume at the center. In man, however, the circulation is mechanical, and may be accelerated by exercise, but in an apparatus that depends entirely on difference of density no amount of firing will help the ends to any considerable extent, as long before the necessary force could be obtained steam would be formed and the apparatus proved a failure in any event.

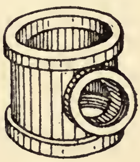


FIG. 53.

Large buildings, such as the State, War and Navy Department, cannot be warmed by any other system than compound mains. It would be wholly impracticable to warm it by single circuits, as there would be hundreds of them running to the boiler room, filling the passages, etc. The apparatus in the house of Notre Dame, Toronto, Canada (shown in Chapter 32), with all its circuits would not be a circumstance to the bewildering mass of pipes that would be required for this building in a single one of its sections—there being six such sections and plants in all.

As an illustration of an extremely small apparatus of the compound-main class, though sufficient to warm a residence comfortably, the reader is referred to Figs. 55 and 56.

Going from large to small work—although the principle is the same—I will describe a small hot-water apparatus, fitted in the most simple manner, in one of the numerous small brick houses, intended for one family, now being built in New York and vicinity. These houses are now a feature of immense districts of Brooklyn, N. Y. They rent for from $300 to $450 a year, according to circumstances and location, and are the homes of many thousands of small business men, professional men and clerks who do business in New York and vicinity, and who thus have accommodations in pretty brick or brownstone front houses, all to themselves, who would be forced to live in apartment houses in New York at greatly advanced rents.

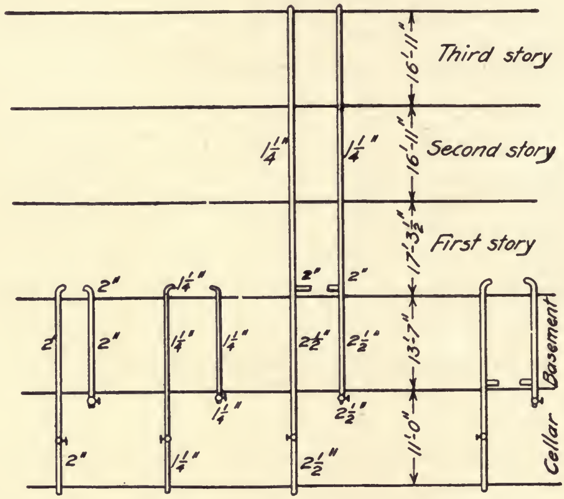


FIG. 54.—Diagram Showing Size of Rising Lines for Hot Water, State, War and Navy Department.

The drawback to these houses, however, is their method of heating. They are, almost without exception, warmed (?) with a fireplace heater in the dining-room, with a flue to the parlor and front bedrooms. During the cold weather people are either forced to freeze or be suffocated with the nondescript half-furnace, half-stove that warms the dining-room and sends gas, ashes and dust to the upper floors, as not one in twenty of these fireplace heaters are in order during the second winter, and whether they are in order or not the houses cannot be warmed by them in ordinary cold weather. Such, however, is the writer's experience with two different ones, and it seems to be the experience of all his neighbors. No air is admitted from out of doors, so the advantage of fresh air cannot be claimed for them, as they depend on the return of the air down the stairways for a supply to keep up the circulation.

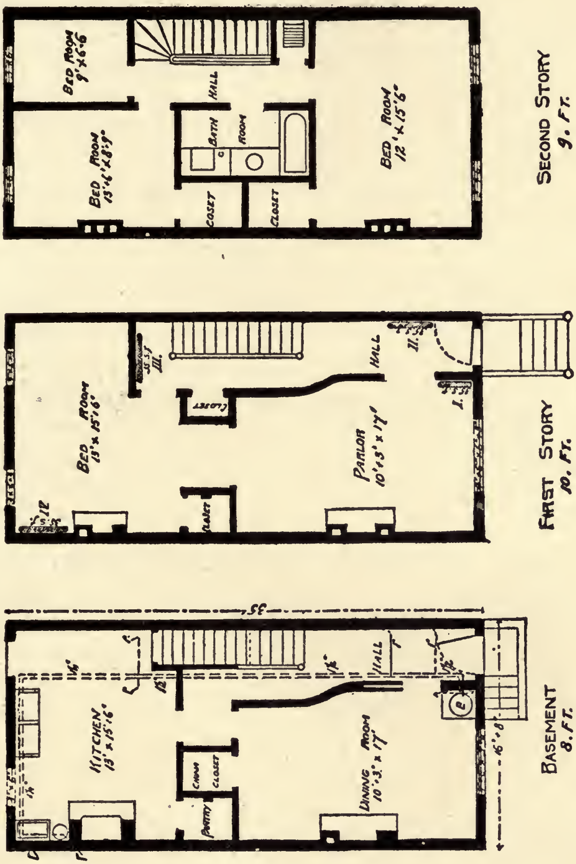


FIG. 55.—Plans Showing Method of Heating a Small House in Brooklyn by Hot Water.

Almost invariably, however, the leakage of gas is from the heater into the air-flues of the house. A 3-inch smoke-pipe is run up within the principal air-flue, and when the air-flue draws better than the chimney and smoke-pipe the inhabitants keep warm on a mixture of warm air and coal-gas, especially when the damper in the pipe is shut, which is the invariable rule at night, to save coal, by those who follow the instructions of the makers. Fortunately, this 3-inch damper has a 1-inch hole in its centre "to carry off the gas," and, therefore, people do not die suddenly from coal-gas poisoning, but of the impairment of health from this cause there is no doubt in the judgment of any intelligent person who has investigated the subject.

To escape this state of affairs the apparatus shown here was put in and is now in use the third winter with a satisfaction that is beyond comparison with the old hot-air method. There is

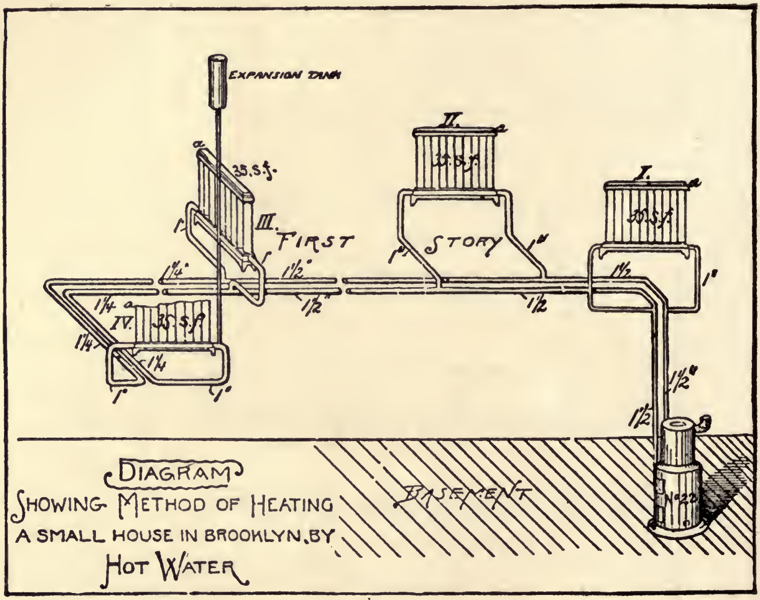


FIG. 56.

no patent on it and its cost, which is trifling, will be given in detail hereafter. The radiators and boiler used are, presumably, patented by the maker, but any hot-water boiler of the many good ones now before the public can be used, and flat coils of 1-inch pipe or any hot-water radiator can be placed in the rooms, any one may set them up at a small outlay; the principle of piping being old and it is the property of any one who wishes to use it.

In this case a No. 22 Hitchings hot-water base-burning boiler was used and placed in the corner of the dining-room at *B*, Fig. 55. It looks like a base-burning stove and takes up no more room. The object of the position was two-fold. It warmed the dining-room and brought the boiler very near the basement door, so ashes, etc., could be quickly removed to the area under stoop, the usual receptacle for it in these houses. The only objection to this position is the length of the stove-pipe necessary to reach the chimney now built. In the summer, however, this is taken away, and in the winter (with all the heat that comes from a fire in a hot-water boiler), a Russia iron pipe five inches in diameter is not very objectionable. In fact, to the man who had to wear his overcoat at breakfast when he depended on his Baltimore heater it is most welcome.

From this little boiler, that has about twelve square feet of fire surface in it, there is carried a 1½-inch flow-pipe to within six inches of the ceiling. Just below the elbow there is taken the flow or supply pipe for the parlor radiator, plainly shown in the diagram, Fig. 56, which diagram is an exact reproduction of the pipe in the house, and, to a practical man, shows all there is to be seen. For the unpractical, however, I will explain further. After supplying radiator No. 1, the 1½-inch main passes into the hall, or just through the partition. From there it is carried straight to the rear wall of the house, through the basement hall and kitchen, reducing to 1¼ inches in size after the *third* heater is taken off, and thence carried 1¼ inches to the end or fourth heater. This main rises all the way to the last heater, there being about three inches rise in its whole length. The return-pipe is an exact reproduction of the flow-pipe, and is set side by side with it, the only difference being in where it enters the boiler—at the bottom. The radiators are all of the same size, with an angle-valve to the inlet end of each. They are nominally 35 square feet of surface each, being single-row Bundy hot-water loops, regular height, 10 long, taken at 3½ square feet of the loop, making, in all four, 140 square feet of surface, which has proved itself ample to warm the house when taken in connection with the mains and boiler, which are not covered.

The upper or bedroom floor requires no heaters. Sufficient heat escapes from the parlor floor to keep it warm enough for bedrooms in the coldest weather, with water at 170° fahr., the windows on the upper floor can be kept open an inch or two, and, ordinarily, a temperature of 150° fahr. in the pipes keeps the house warm and comfortable, and allows for opening the windows, as above, for a change of air. The apparatus runs day and night, and a variation of ten degrees is never experienced.

The average consumption of hard coal is less than 50 pounds per day; a ton a month more than doing for all purposes. With the old heater a ton would last not quite twenty days for all purposes.

The houses are in blocks, thirty such houses being in the row this one is in. The end houses would require a more ample apparatus, as they have more windows and a greater outside wall area; for the centre ones, however, the apparatus described here is ample.

The sizes of windows are marked on the plans, Fig. 55, and also the sizes of the rooms.

A difference of about sixteen degrees exists between the temperature of the flow and return pipe at the points where the one flows out of the boiler and the other enters it.

The cost of such an apparatus is as follows:

The boiler, or one of equal power, can be purchased and delivered for about	$60
140 square feet of good hot-water radiator will cost about 30 cents per square foot	42
The cost of mains is about $25	25
The cost of valves and cocks	5
Six days' labor, man and helper, $7.50	45
Smoke-pipe and zinc	10
One thermometer on flow-pipe at boiler	3
Galvanized sheet-iron expansion tank and sundries	10
	$200

This is the actual cost, and does not allow a profit to the contractor.

Another modification of branched mains is shown in Figs. 57, 58, and 59. They are diagrams of the pipes once put into the Westchester County (N. Y.) almshouse, and show a wonderful ramification of pipes, a separate compound system being run for each floor or common level of the building.

Fig. 59 is an isometrical drawing of all the flow-pipes as they are used and their sizes, and a reference to the basement plan (Fig. 57) shows plainly their relation to the building. The return-pipes (not shown) are almost identical with the flow-

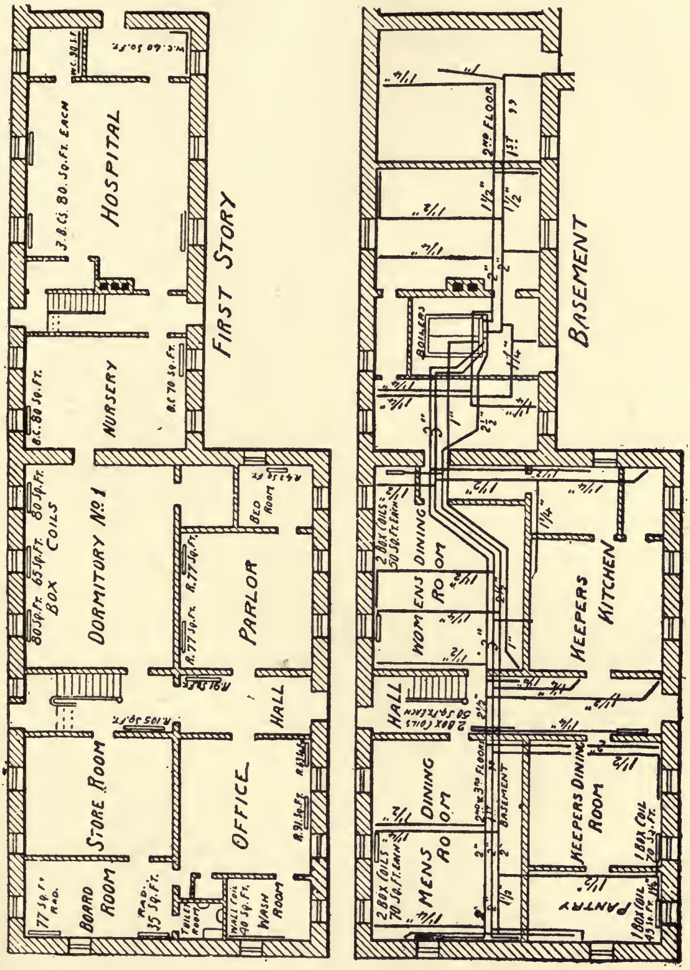


FIG. 57.—Plans Showing the Method of Heating the Westchester County Almshouse.

pipes so far as position is concerned, and in size they are equal.

Figs. 57 and 58 are plans of rooms of the buildings that have been warmed by this system. They comprise all the rooms of the first, second and attic stories of the main building, and the first and second stories of the hospital building, the asylum wing being as yet heated by the furnaces. The building is a very old one, though of solid masonry, and is in good repair.

Fig. 57 shows the basement plan and the position of the

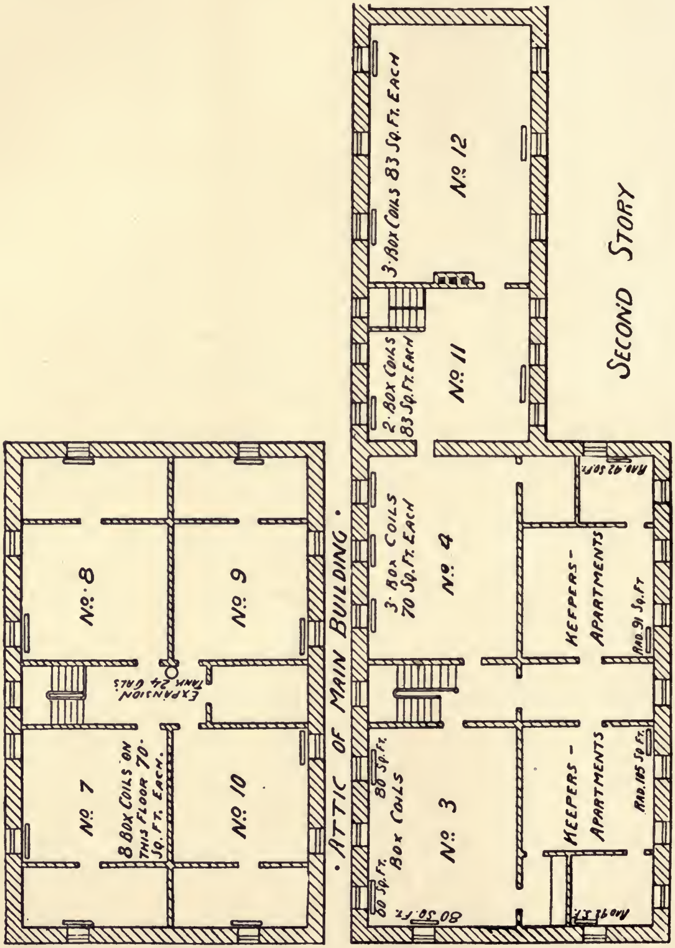


FIG. 58.—Plans Showing the Method of Heating the Westchester Almshouse.

pipes and boilers, as well as the male and female dining-rooms, keepers', and other rooms that are warmed in the basement.

It will be noticed that a separate flow and return pipe is used for each floor or common level of the building with the exception of the third, which is warmed by branches of the second-floor system. The basement contains about 450 square feet of surface, not considering the surface of the mains, and for this amount of surface, under the limited height of the basement, eight feet, the main or flow-pipe, *C*, starts $2\frac{1}{2}$ inches in diameter from the cross-drum at boilers and is carried up to the level of the second floor (*a*), within a closet, where an air-chamber and air-vent is attached, thence down to again the level of the basement ceiling, close under which it runs. At the hall, under the centre of the main building, it reduces to 2 inches, and at the end it is $1\frac{1}{4}$ inches to the two last coils. Its branches are $1\frac{1}{4}$ and $1\frac{1}{2}$ inches to the coils—$1\frac{1}{4}$ inches to coils of 50 square feet, and $1\frac{1}{2}$ to larger coils. The return-pipes are similar, but in this case are on or near the floor, so as to get the water back to the boilers, as the heaters are nearly as low as the bottoms of the boilers.

The loop, *a*, Fig. 59, with air-chamber, was introduced for the purpose of quickening the circulation to the lower floor.

It may quicken it in a slight degree. The extra bends and length, however, add resistance, and the difference of temperature between the up and the down leg of the syphon is infinitesimal when the water passes with any reasonable velocity. The up-leg of the loop and the pipe from the boiler is carefully covered, the object being to secure as great a difference of temperature between the legs as possible; or, in other words, to secure a greater loss of heat in the down-leg, and consequently maintain a greater constant difference of the density of the water in the legs. The motive power then, for the basement—considering gravitation as the cause of motion—is in the down-leg of this syphon, and the pipes which drop to the coils and heaters and the heaters themselves.

The amount of heating surfaces on the first or principal floor, main building, is about 1383 square feet, part Bundy hot-water radiators and part box-coils. A close study of the plan will show the different locations, the coils being marked "Box-Coils," and the radiators "Rad." There is no advantage in the use of radiators or coils in one position over another, excepting appearance, the radiators being in the best-finished rooms, parlors, etc.

About 843 square feet of this surface is in the centre building, first floor, and 540 square feet in the nursery and hospital. The pipe to the main part of the building (*A*) starts three inches in diameter and runs, as shown, under the basement ceiling. About the middle of the building, under the hallway, it reduces to two inches, thence runs to the end of that diam-

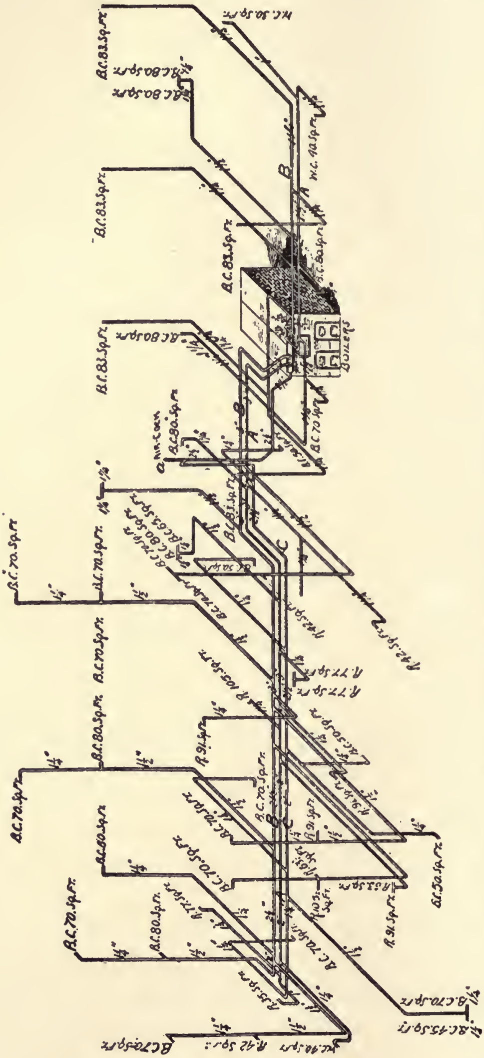


Fig. 59.—Diagram Showing Hot-Water Pipes in the Westchester County Almshouse, N. Y. A, First story mains. B, Second story mains. C, Basement. B C, Box coil. W. C, Wall coil. R. Radiator.

eter. To any one particularly interested in the matter, all its branches can be traced in Fig. 59, with their sizes, etc. The pipe to the nursery and hospital part is 2½ inches (*A*, right, Fig. 59), and is run as shown and marked, and requires no more explanation from us, as it may be traced on the drawing easily.

The pipe, *B B*, in the drawing is for the second and third floors. It is three inches to the main building, and 2½ inches to the centre building, and can also be traced, with the quantity of surface, at each branch.

In a few cases a pipe branches to two radiators, or coils, but usually a separate riser goes to each heater. The third floor, however, is always a continuation of the second story riser, though of a smaller size.

The loss of heat between the flow and the return-pipes of the basement circuit of this building is certainly not less than between 40 and 50 degrees, there being 450 square feet of surface of coils on a 2½-inch circuit, the radiating surface of which is nearly all on the level of the boiler or partly below it.

The 1383 square feet of surface for the principal or first floor is divided into 843 square feet for the circuit on the left of the boilers, and 540 square feet for the right circuit, and the former being a 3-inch compound circuit, and the latter a 2½-inch compound circuit. The result is a loss of temperature of about 40 degrees between the flow and the return pipes on the left, with slightly better results on the right.

Nearly 2000 square feet more surface is divided between a 3-inch left circuit and a 2½-inch right circuit for second and third floors. Though there is considerable more surface on these circuits than on the ones for the first floor, of equal diameter, still on account of the increased height of the circuits the results at the radiators are not much inferior to the floor below.

* To compensate for this great difference in temperature between the flow and the return-pipes large radiators and coils are used, and there is no lack of warmth in the building, but from the standpoint of a designer it is better to use ample mains and less radiating surface, and secure a less difference between the temperatures of the flow and the return-pipes.

* The author does not desire to convey the idea that he approves of every kind of apparatus that he shows in order to illustrate some principle in the art. For example, he would not approve of separate mains for the various levels of a building. The Westchester County Almshouse was a very early example of hot water heating and the methods that were originally used there are now never resorted to.

CHAPTER XIX.

BRICK-SET HORIZONTAL BOILERS.

Boilers Used for Hot-Water Heating—Brick-Set Boilers—The Horizontal Tubular Boiler—Placing Tubes in Horizontal Boilers—Diagrams of Head Sheets for Horizontal Boilers—Illustrations of Brick-Setting for Horizontal Boilers—Leakage of Air through Brickwork of Boilers—How to Prevent it—Table of Dimensions, Thicknesses, Heating Surface, etc., of Horizontal Boilers, and Its Use.

Nearly every boiler that will answer for making steam will also do for warming water.

There are some forms, however, that are not desirable for making hot-water for warming purposes for the simple reason that their internal resistance to the passage of the water through them adds too much to the total resistance of an apparatus.

One of the chief points in the design or selection of a boiler for water heating is to secure one that will give the minimum of resistance.

Another point in the choice of a boiler is to secure properly disposed surfaces. Surfaces that will absorb the greatest amount of heat possible from the fire, and surfaces that are easily kept clean or that will remain comparatively clean in consideration of their angle, the effect of the draught on them, or other predisposing causes.

Anything that quickens the circulation through or within a boiler or over its fire surfaces will increase its capacity per unit of surface. The faster the water rushes over a surface the more units of heat there are taken away in a given time. Therefore, fairly well disposed surfaces, combined with free and easy water passages from bottom to top through a boiler, when taken together, conduce to give better results than can be obtained by sacrificing one point of excellence to the good of the others.

There are also other points of importance, such as the life of a boiler, the area of the flue passages, the grates, room the boiler requires, its cost—all of which enter into a good boiler.

The horizontal multitubular boiler, that has done so well for steam, also does well for hot-water heating. When made for hot-water work, however, it is usual and profitable to have it entirely filled with tubes, or nearly so, having suitable distances between the tubes for the free and easy passage of the water.

This distance, however, need not be as great as for steam boilers, as there is not the necessity for as great a local circula-

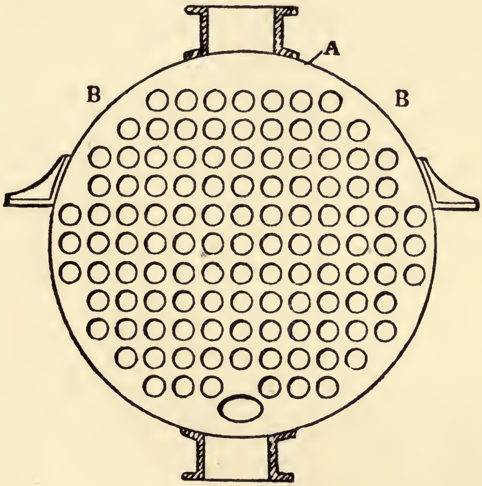


Fig. 60.

tion in a hot-water boiler as there is in a steam boiler, and in fact it may be said there is no necessity for it, if the water can be made to push forward through the pipes as fast as it is warmed. This rarely happens, however, and therefore, to prevent the formation of steam bubbles on the very hot surfaces a local circulation is necessary to maintain a somewhat equable temperature of the water in the boiler, or in divisions of the boiler, as it will be found that as a general thing the upper parts will be the warmest, and when the hot water cannot flow away it should return and diffuse with the remainder and cooler parts.

The distance between the tubes of a horizontal boiler, therefore, for hot-water work may be regulated as much by the practical side of the question as by any other—in other words, the distance between tubes is to be sufficient to secure a good boiler head, or one that will have sufficient metal between the tubes to prevent the cracking of the bridges, and probably $\frac{3}{4}$ of an inch should be the minimum in this respect. In a boiler 12 feet long this will give $\frac{3}{4}$ of a square foot as the horizontal area of each space between any pair of tubes, and as there will be from 12 to 15 such spaces in an ordinary boiler there will be from 9 to $10\frac{1}{2}$ square feet of vertical passages at the centre of

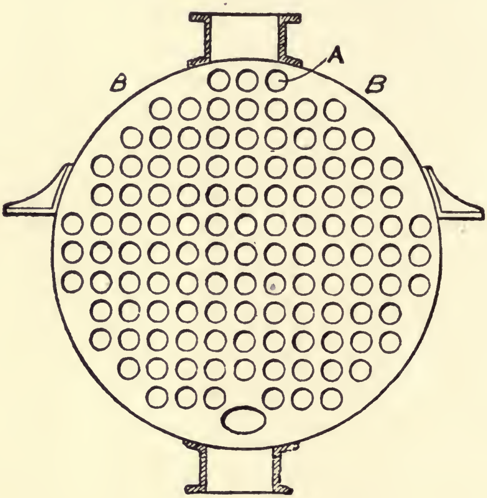


FIG. 61.

the boiler. As the boiler is a cylinder, however, the waterways are lessened in number at the top and bottom, as will be seen in Figs. 60 and 61, but as the outer tubes are always about 3 inches from the shell, this will not materially add to the resistance.

There is one point of special note, however, that is often overlooked, which is, that, in the anxiety to get all the tubes possible into a boiler, the upper horizontal row is often brought too close to the shell, and consequently to the discharge nozzle, causing obstruction to the passage of the water into the flow pipe, as shown at *A*, Fig. 61.

At the bottom the corresponding row of tubes is omitted to make room for the hand-holes, and thus the obstruction that would directly interfere with the free passage of the water into the boiler, is, through accident of circumstances, removed. To prevent an obstruction to the flow, therefore the tubes, *A* (Fig. 61), should be omitted and a space maintained as in Fig. 60 at *A*.

It would be an advantage also to use a bell-mouthed nozzle at the flow, as the water, meeting at this point from all directions, may cause considerable resistance before the change of direction is accomplished, unless the nozzles are very large, as shown in the cuts.

Boilers of this class are used for very large plants, and it would be well for those who require them to have their boiler shells made in two pieces, with their longitudinal seams at *B B*, (Fig. 60) and no girth seams except the seams of the ends.

This makes a boiler that has but one seam in the fire-box, and that is the seam of the back head sheet, and when made of mild boiler steel there is no trouble to obtain sheets sufficiently large for a boiler 16 feet long.

A boiler of this class, made this way, for low-pressure hot-water heating will probably never require repairs, except to receive new tubes, until it is entirely worn out by natural use and deterioration.

The setting of these boilers for hot water is always substantially the same, and may be said to differ from the setting of a steam boiler only in the formation and position of the "back-connection arch," which of course must be always higher than for steam, so as to come above the extra tubes that fill the upper third of the boiler.

This arch is often made of cast-iron, for the reason that when it is of fire-brick it must be at least two courses of brick on edge thick, or nearly 9 inches. This will bring the top of the arch up into the flue space, when the flue is returned over the top of the boiler, and it is on this account iron is used. The iron arch, however, will not last long with a temperature often of between 800° and 1000° fahr. below it, and therefore nothing but an arch of fire-brick should be used, as shown in Fig. 62.

Fig. 62 shows the setting when the flue is returned over the boiler, and Fig. 63 shows it when the boiler projects through the front, and the smoke is taken to the chimney in a direct flue.

It is claimed for the return flue that it is the most econom-

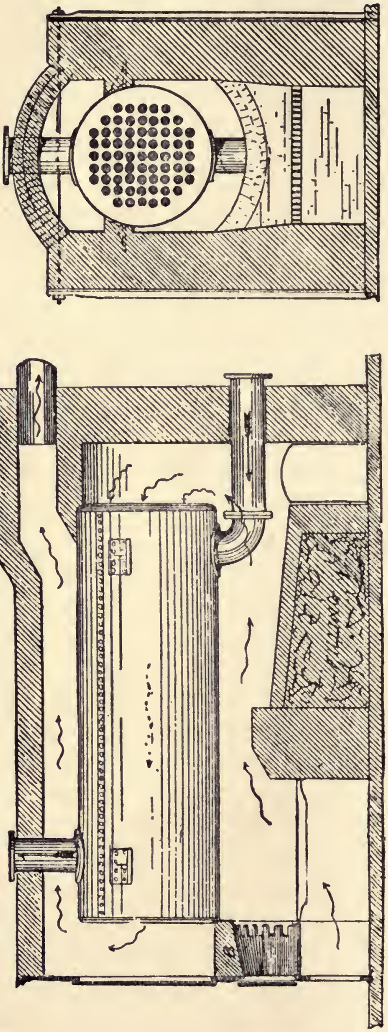


Fig. 62.

ical. This may appear to be the case to a small extent in some cases, as nearly one-half the shell—the upper part—is apparently good heating surface.

As a matter of fact, this surface is of little or no value (1) because the gases of combustion have passed through the tubes before they reach it; (2) on account of the accumulation of soot and ashes which lodge there; and (3) for the reason that the infiltration of air through the upper side of this brick flue, whose surface is so large, materially affects not only the temperature of the gases of combustion and their power to impart heat to the shell, but lessens the power of the chimney, both by the extra volume of air that is admitted to it, that never passes the fire, and by cooling it and increasing the density of the upward column of air. The writer has examined a boiler set this way where the escaping gases were not over 112 degrees the leakage was so great.

For the reasons given, therefore, especially the two first, I prefer to let the gases escape from the front end of the boiler as a general thing, and Fig. 63 shows the setting I usually use. It is also better than a flush front setting, as the rivets of the front head sheet are carried so far forward that the seam cannot be affected by the heat should the brick-work at *B* about the door fall out, as it frequently does, and often remains so for days and weeks without being renewed or repaired.

When the boiler setting is arranged as shown in Fig. 55, the heating surface of the top half of the shell is of great value and it is for this reason that I have shown the brick-work lifted above the boiler. In this case the gases about the top of the boiler are very hot as they have not passed through the boiler tubes. Less soot also is likely to be carried on to the top of the boiler in this case, than when the space above the boiler is used as a return flue. There is a chance for air leakage through the brick-work at the top of the boiler, but this can be reduced to a minimum if proper care is used.

The infiltration of air through the brick setting of boilers is always a serious quantity and often impairs their general efficiency more than is usually suspected. For this reason the best hard brick and mortar should be used. Although lime mortar is the fittest, so far as heat is concerned, mortar with considerable cement in it makes a tighter wall. All the joints should be filled with mortar the same as for hydraulic work, and when a full lining of fire-brick is used no deterioration of the cement mortar in the remaining parts of the brick-work is noticeable. Hot asphaltum applied to the outside of the walls or asphaltum paint is a great assistance to prevent the passage

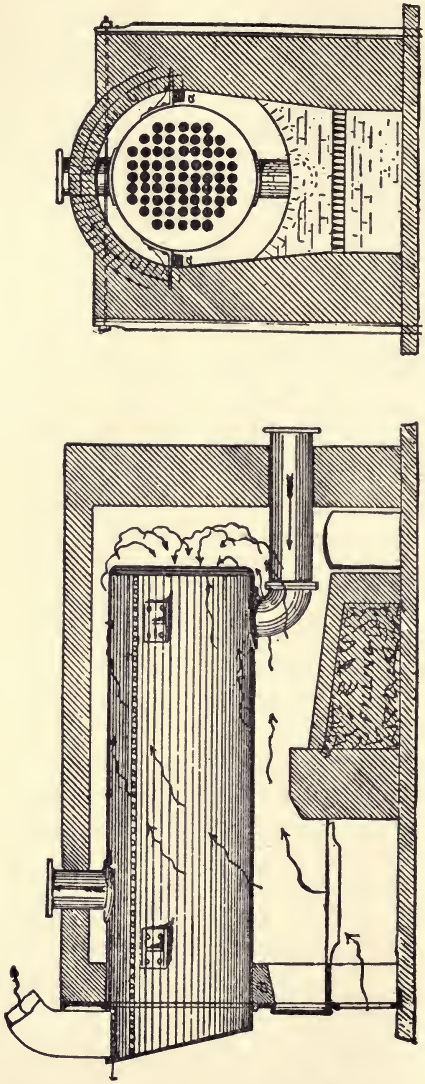


Fig. 63.

of air through a wall. Whitewash with soap and alum also makes a wall comparatively impervious to the passage of air.

I have compiled the following table for the benefit of the

TABLE X.

DATA ON HORIZONTAL TUBULAR BOILERS.

Diameter of boiler shells.	Number of tubes in boiler.	Diameter of boiler tubes.	Thickness of boiler shells.	Thickness of boiler heads.	Sq. ft. of heating surface to one foot length of boiler; tubes and shell included.	Sq. ft. of heating surface in tubes only for one foot of length.	Sq. ft. of surface to one foot length of shell.	Lineal feet of tubes to one sq. ft. of surface.
24-in.	34	2- in.	¼-in.	⅜-in.	22.39	16.11	6.28	2.11
"	28	2¼-in.	"	"	21.38	15.10	"	1.854
"	24	2½-in.	"	"	20.62	14.34	"	1.674
30-in.	58	2- in.	¼-in.	⅜-in.	35.34	27.49	7.85	2.11
"	46	2¼-in.	"	"	32.66	24.81	"	1.854
"	44	2½-in.	"	"	34.35	26.3	"	1.674
36-in.	66	2½-in.	¼-in.	⅜-in.	48.84	39.42	9.42	1.674
"	50	3- in.	"	"	45.83	36.41	"	1.372
42-in.	86	2½-in.	¼-in.	⅜-in.	62.37	51.37	11.00	1.674
"	68	3- in.	"	"	60.52	49.52	"	1.372
"	54	3½-in.	"	"	57.07	46.07	"	1.172
48-in.	94	3- in.	5/16-in.	7/16-in.	81.02	68.46	12.56	1.372
"	72	3½-in.	"	"	73.99	61.43	"	1.172
"	58	4- in.	"	"	69.20	56.64	"	1.024
54-in.	118	3- in.	5/16-in.	7/16-in.	100.12	85.99	14.13	1.372
"	86	3½-in.	"	"	87.51	73.38	"	1.172
"	72	4- in.	"	"	84.44	70.31	"	1.024
60-in.	148	3- in.	⅜-in.	7/16-in.	123.49	107.79	15.70	1.372
"	106	3½-in.	"	"	106.19	90.49	"	1.172
"	86	4- in.	"	"	99.68	83.98	"	1.024
66-in.	172	3- in.	⅜ in.	9/16-in.	142.55	125.27	17.28	1.372
"	136	3½-in.	"	"	133.32	116.04	"	1.172
"	106	4- in.	"	"	120.79	103.51	"	1.024
72-in.	216	3- in.	⅜-in.	⅝-in.	176.17	157.32	18.85	1.372
"	172	3½-in.	"	"	165.60	146.75	"	1.172
"	136	4- in.	"	"	154.59	135.74	"	1.024
1	2	3	4	5	6	7	8	9

fitter. The first five columns are from a pamphlet of Messrs. Bartlett, Hayward & Co., who have used horizontal multitubular boilers in all their large work, and the remainder has been calculated from the usual data. The first column gives the diameters of boilers ordinarily used. The second column shows about the number of tubes of the diameters given in the third column that can properly be used in shells of the diameters given in the first column. The fourth column gives usual thickness of plate for the shells, and the fifth column the thicknesses for the head sheets. The sixth column, which is calculated from the data given by the National Tube Works Co. for their standard boiler tubes and other data, gives the number of square feet of heating surface in one foot of length of a boiler, shell and tubes considered, but with head sheets omitted. The seventh column gives the surface for tubes for one foot length of boiler. The eighth column the surface for one foot length of shell, and the ninth column the length of tube to one foot of internal surface.

The use of the table is obvious to any one wishing to select a boiler of a given capacity. The sixth column multiplied by the length of a boiler in feet will give a very close approximation to the square feet of surface required in the boiler. The seventh column gives the tube surface alone in the same manner. If the shell or half the shell surface is to be omitted, it is found by the eighth column. If some of the tubes are to be omitted the ninth column furnishes the data.

The thicknesses of boiler shells and heads, given in the fourth and fifth columns, may be varied slightly by the designer, but as a general thing the dimensions for thickness should not be made less; not that they require this thickness for strength, however, but that they may the longer withstand the action of corrosion and wear.

CHAPTER XX.

VARIOUS BOILERS USED IN HOT-WATER HEATING.

Various Boilers, etc., Used in Hot-Water Heating.

In further considering this question of boilers it would be well to classify them under the head of " brick-set " and " portable " boilers, or ones that require no brick-work, except it be a foundation or ash-pit or brick-work.

Coil boilers were early used for hot-water purposes. They are of two distinct classes: The box coil class, Figs. 64 and 67, and the spiral coil class, Fig. 65.

The spiral coil is the most primitive form of a closed hot-water boiler for heating, and Fig. 66 shows the earliest form the writer is acquainted with. Mr. Perkins, of London, Eng., used this form of heater for his high-pressure work, though it was undoubtedly used by others before his time.

It is the safest form for high-pressure apparatus, as the pipe may be of any thickness. It may be used on a simple or branched circuit, but Mr. Perkins usually used it on a simple circuit, the flow-pipe being carried about the room or building to be warmed, forming a continuous pipe and returning to the coil at the bottom. He used an expansion chamber of strong pipe of sufficient capacity to hold the increased bulk of water when the latter was warmed and expanded to its utmost. The air was retained in this chamber, so the expanding water compressed it; the result being to put the apparatus under very high pressure.

The best-known form of this apparatus at the present day is the " Baker " car-heater; the only essential difference being a safety-valve on the expansion chamber. Mr. Joseph Nason, of New York, was the first to make and use this coil heater in the United States to any appreciable extent, and to him also belongs the credit of introducing the box coil heater.

The objection to a spiral heater is the resistance it causes to the flow of the water and its lack of economy of fuel. If the coil is made sufficiently long and high to have surface enough to absorb a reasonable amount of the heat of the fire its resistance is very great, and it often happens the resistance is so great as to retard the passage of the water until steam is formed, when the water is forced out of the coil at both ends, performing the operation technically known as "kicking-backwards."

The box coil heater as made by Mr. Nason was a simple box coil of bent pipes joined to headers top and bottom, as in Fig. 64. Later the return bend was substituted for bent pipes, still for very high pressures it is preferable to use bent pipes, thereby doing away with many joints within the furnace. His

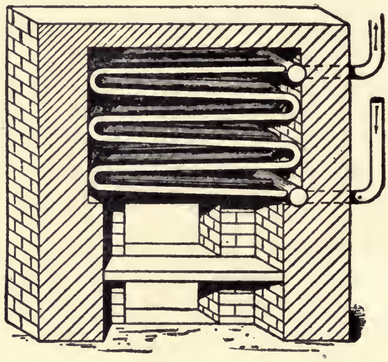


FIG. 64.

method of setting was a simple brick furnace over which the coil was placed and enclosed in brick-work, with doors for cleaning, etc.

The "Pascal Iron Works" of Philadelphia, now the Morris Tasker Co., Limited, early made an improved boiler on this principle in which the sides of the fire-box were formed by pipes of the coil, the lower tier of pipes also forming every second bar of the grate, an ordinary bar being used between them. This boiler is fully shown in Fig. 67. The connections at the ends of the pipes are box bends, a bridge wall being formed by two sets of them. In the illustration the boiler appears at first glance to look like a steam-boiler, the drum with "try-cocks" and safety-valve adding to the impression.

This drum, however, is the expansion tank, and the system is an improvement of the Perkins, but designed for lower pressures and temperatures. Mr. Perkins made an absolutely tight apparatus, and the pressures were enormous and dangerous, and would be prevented by the fire commissioners and underwriters now. His apparatus consisted of a coil of very thick pipe of small diameter with an expansion chamber of very strong pipe as shown in Fig. 66, in which *B* was the heater,

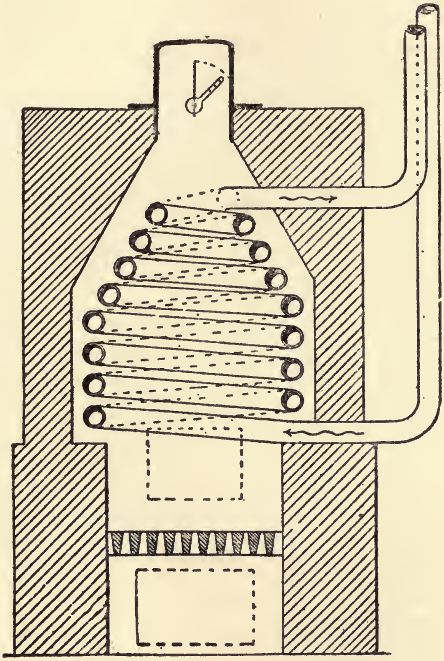


Fig. 65.

f the flow-pipe, *T* the tank, *C* the coils, and *R* the return-pipe. The tank was of large capacity—one-third or one-fourth of the apparatus—and the apparatus was made absolutely tight and filled to the hole, *h*, in the side of the tank near the bottom, then this hole was plugged, and the water, as it expanded, was allowed to compress the air in the head of the chamber (*T*), giving pressures that it was almost impossible to estimate.

The boiler, Fig. 67, is not intended nor would it withstand any such pressures or temperatures as a welded spiral coil, and therefore they can be made on an ampler scale, the principle remaining the same; the tank which is on its side being supplied with cocks to gauge the height of the water within it, and a safety-valve being applied to let off the excessive pressure of the compressed air.

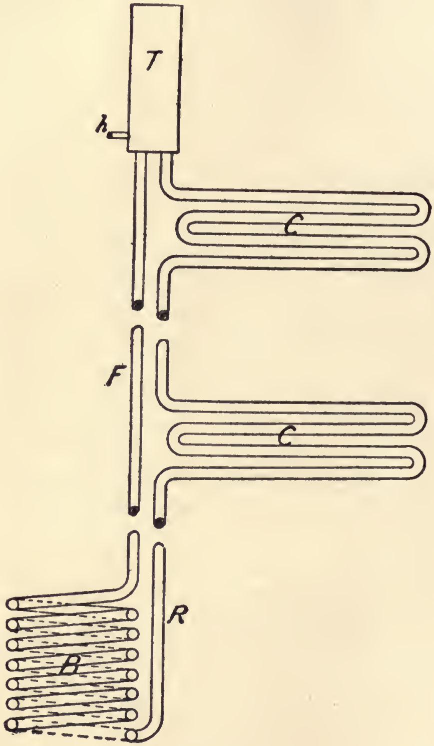


FIG. 66.

It will be noticed the flow pipe leaves the tank as low as it enters it, so the air will be disengaged and imprisoned above the water and not carried into the circulation. This method also allowed the flow pipes to be carried above the tank level, though as a general thing it is not advisable to do so, for should the air get out of the tank it fills with water and the apparatus will have to be partly drawn off and filled again to get it to operate properly. These boilers were usually used with the coils or radiators no higher than the flow pipe.

A convenient form of this class of boiler was used in the Westchester County (N. Y.) Almshouse. The sides of the fire-box and grate were formed with the sections of the boiler. Figs. 68, 69, 70 and 71 show drawings of the boiler, being respectively longitudinal section, front and side elevation and ground plan.

They are twin hot-water boilers, and each contains 700 feet of extra heavy $1\frac{1}{2}$-inch pipe. They are separately connected,

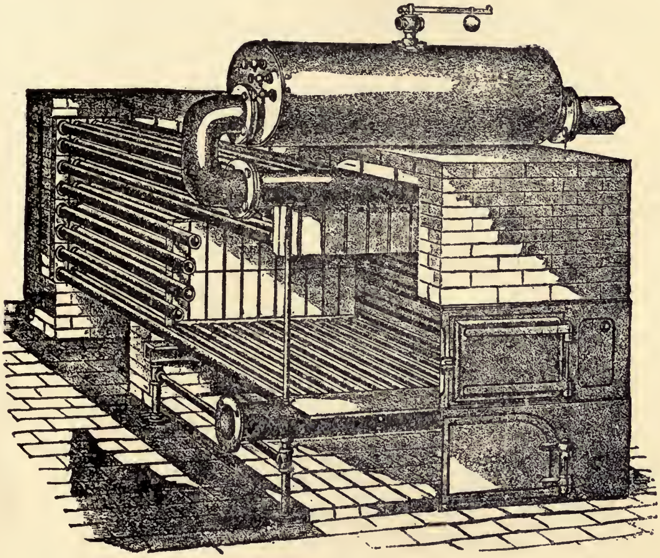


FIG. 67.

as shown, by a 6-inch header, with 4-inch connection from each boiler.*

* The total heating surface in this building was about 3,860 square feet, not including any of the running pipes. The boiler surface is about 700 square feet; therefore, there was one of boiler to $5\frac{1}{2}$ of radiating surface, not considering mains, of which there were a great many. It is probable the mains would make the ratio of boiler to surface 1 to 7, and in reasonably cold weather one boiler was sufficient, so that 1 to 14 proved sufficient at times. All box coil boilers are liable to form steam unless the diameter of the pipe is large in proportion to its length. It is difficult to determine a ratio and the type has gradually dropped out of use.

The drawings show thoroughly what the boiler is, and require very little description. They are, in brief, box coils, with the fire-box or furnace sides formed by flat coils. The heat of the fire, after leaving the furnace, is made to travel about the baffle plates, *D D*, to the top, thence down the rear to the flue, *F*. Doors are provided for cleaning at the sides, *A*, *B*, so as to reach all the tubes, and the door, *C*, is to remove ashes from the flue, *F*. The dimensions of the walls, etc., on the ground plan are given. The elevations show the positions of the stop-valves and connections, and also the fire and draught doors. Each boiler in this case has a separate chimney.

This class of boilers offer considerable resistance to the flow

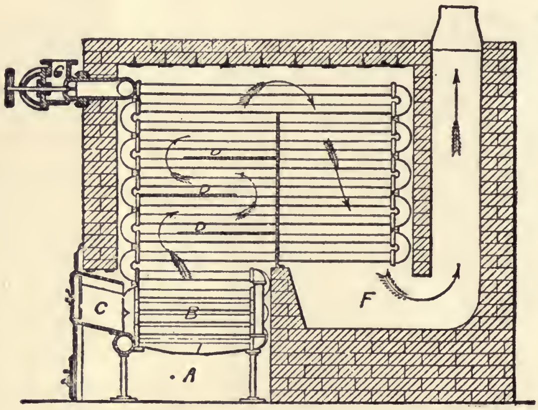


Fig. 68.—Longitudinal Section.

of the water, however, each section being a "flat coil" with many short bends and pipe ends to encounter, a section will offer more resistance, therefore, than a spiral coil of the same length and diameter. As these sections, however, are connected with headers top and bottom, the water that flows into the bottom header has ten or more channels to pass through on its way to the upper header, and, therefore, for equal surface and like diameter it will, as a boiler, present less resistance than the spiral form. When, on the other hand, however, it has ten times the surface of the spiral boiler of the same diameter pipe, and has to pass ten or nearly ten times as much water then its resistance is greater than the spiral.

This class of boilers should always be made of large diameter pipes and as few bends as possible. To double the diameter of the pipe means to reduce the velocity of the flow of the water to one-fourth and the resistance to one-sixteenth.

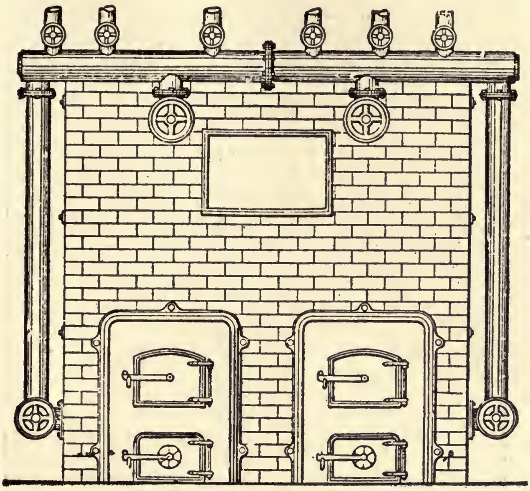


Fig. 69.—Front Elevation.

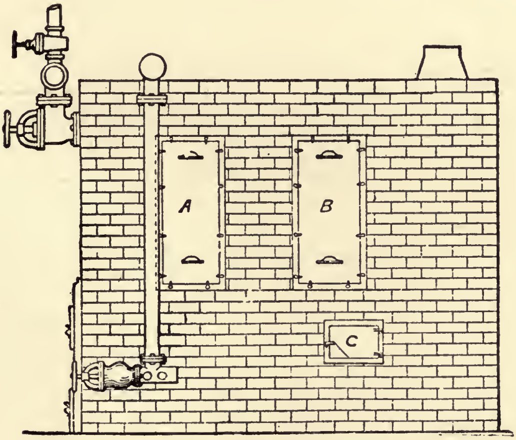


Fig. 70.—Side Elevation.

Assume a boiler of this class with 10 sections of $1\frac{1}{2}$-inch pipe, whose total area of waterway is 20 square inches. Now it will be very probable the resistance in these 10 sections, with their bends, etc., will be greater than in one 4-inch pipe

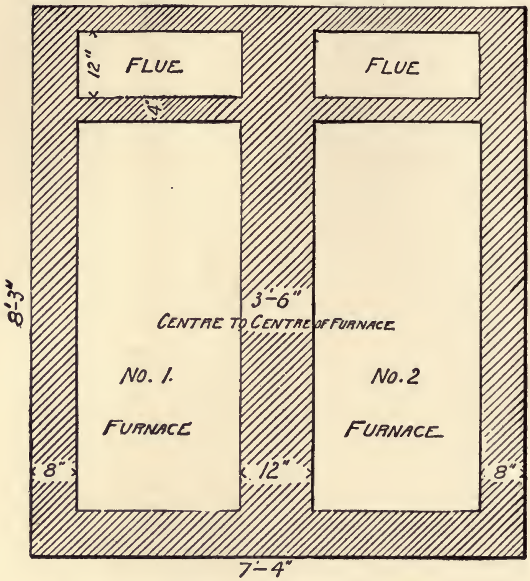


FIG. 71.—Plan of Brickwork for Furnace.

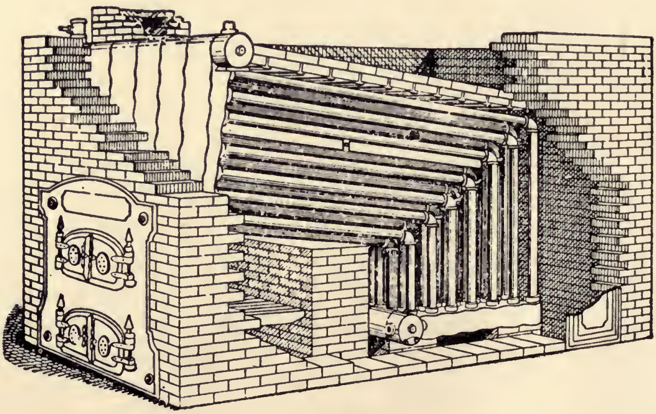


FIG. 72.

of the same length, so that the boiler offers more resistance than the flow-pipes, which of course is not the best practice. An increase of the pipes to only two inches in diameter, however, will very materially lessen the resistance of the boiler compared to the flow-pipes, and is a decided advantage. It is assumed, of course, that with the increase of diameter the length of each section is proportionally reduced, so that the surface of the boiler remains the same for comparative purposes.

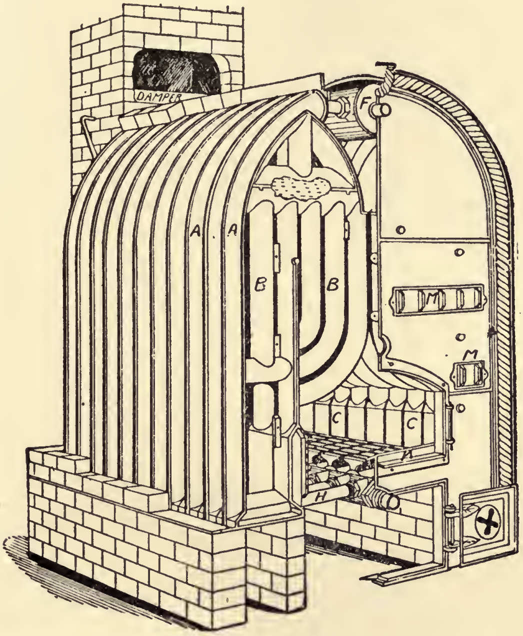


FIG. 73.

My object in introducing the cuts, Figs. 69, 70, and 71, is to give an idea of the usual setting for large boilers of the box-coil class, and the method of connecting the flow and return pipes with the boilers, and to show a pair of interchangeable boilers that may be used separately or together.

The "Blake" boiler shown in Fig. 72 is another form of wrought iron coil boiler that is set in brick-work. It has a very much lower resistance to the passage of the water than the box-coil type, as the pipes run from header to header with but a single elbow in each pipe. In other respects it is much the same. When used for hot water a separate flow pipe may be taken from each header for single or simple circuits, and the return treated in like manner.

There are other modifications of coil boilers, but it is hardly necessary to refer to them here, as they have generally become obsolete. Where it is necessary, however, to make them for high pressure and high temperature the sections should be short or the diameter large, by which means the resistance is lessened without decreasing the surface.

Passing from wrought iron coil boilers we come to a class of boilers that are made of cast iron but which are in substance cast iron pipe boilers.

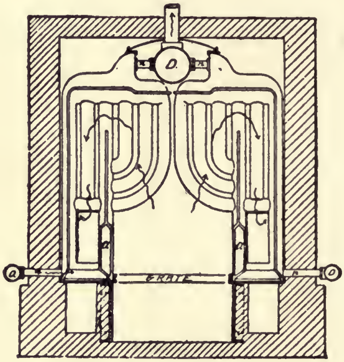


Fig. 74.

The "Mills" boiler, Figs. 73 and 74, and the "Clogston" boiler, Figs. 75 and 76, are examples of this boiler.

They are used for hot-water or steam, and their resistance is less than that of wrought-iron coil boilers on account of the greater relative diameters of the parts. Their resistance is increased by the use of small diameter nipples between the sections and the headers, and were it not for this fact their resistance would be practically negligible. When used for hot-water heating, therefore, the nipples should have as large diameters as possible. These boilers require brick setting.

A modification of this class of boiler that requires no brick-work is the "Mercer," Figs. 77 and 78.

In many respects it resembles the "Gold" sectional boiler

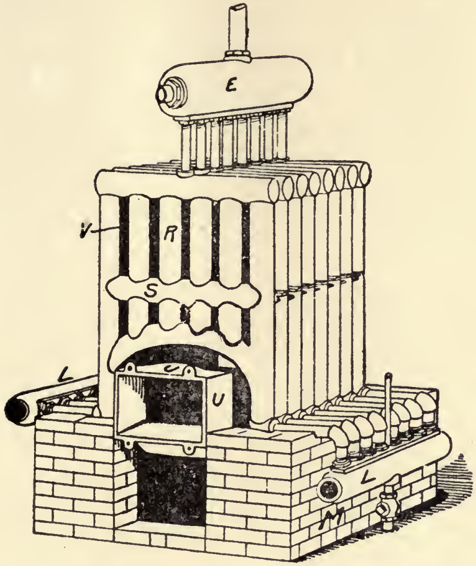


FIG. 75.

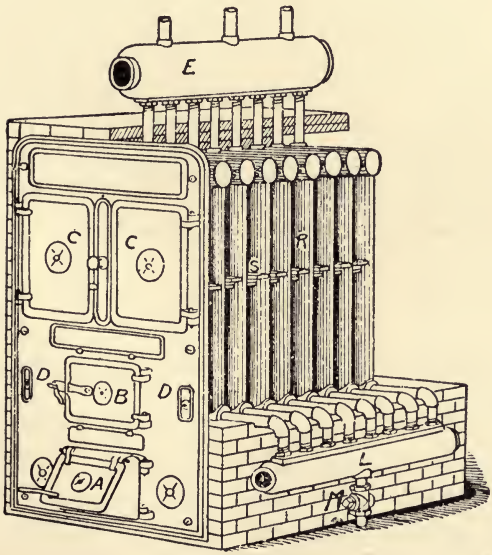


FIG. 76.

made by the same company; its present modification being expressly designed to meet the requirements of the trade for a horizontal return-flue boiler in sectional form, which it substantially is when put together.

It consists of a number of cast-iron vertical sections, *A A*, set on a cast-iron base, *G*, which forms the ash-pit. The front section is arranged to receive the fire-door and double-flue doors to give access to the flues for cleaning. The rear section

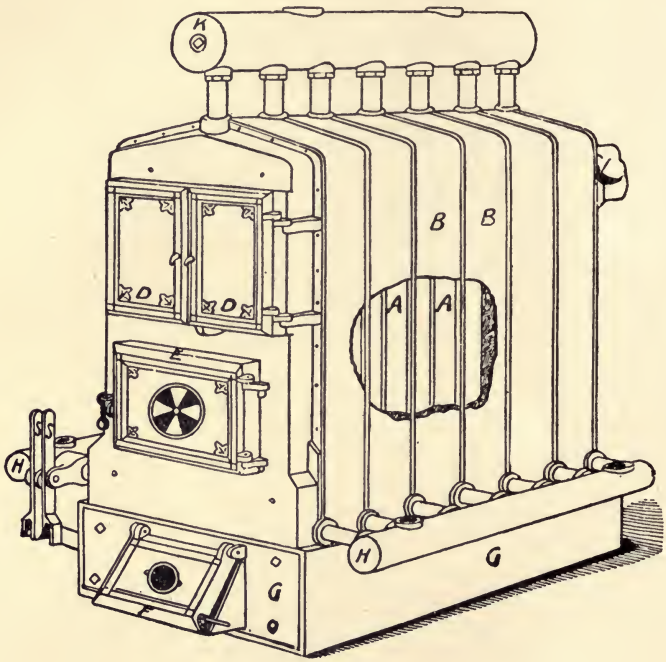


Fig. 77.

forms the fire-back and connection to lower set of flues as designated by arrows in Fig. 78.

The intermediate sections form the sides of the fire-box, and their number determines the capacity of the boiler.

All these sections have planed surfaces at points of contact and are connected to the return headers, *H H*, at each side of the bottom leg, and to the supply-header, *K*, at top with extra heavy lock-nut nipples as shown.

The flues consist of two sets, upper and lower, five in each, with an intervening water space between them, and also between the upper and lower rows. Fig. 79 shows the flue arrangement, it being a half section through first and second section.

The dimensions of these flues are seven by two and a half inches, and their length is determined by the number of grate sections of six inches each. The smoke connection, as will be noticed, is at the rear and is arranged with a damper or slide,

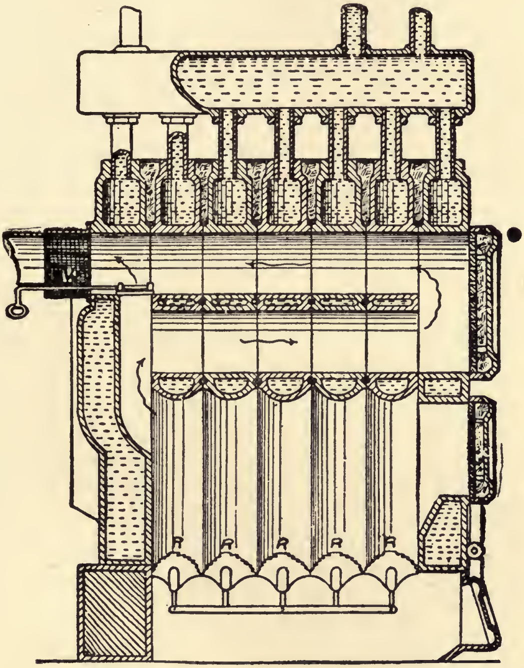


FIG. 78.

V, for temporary use during the making of the fire, and this slide when open also gives access to the rear section and flue connection for cleaning.

A special feature of this type of boiler (the " header-boiler ") is the facility with which it can be enlarged or diminished, and the sections and ash-pit being in parts admit of its being placed in buildings already constructed and without sufficient opening for the admission of ordinary shell boilers. The accessibility of the parts of the boiler and flues to the brush for cleaning is apparent.

Asbestos, mineral wool or any other plastic, material can be used as a covering; the rib or extension on the sections as shown at *A A* being perforated at intervals for rods or wire.

When used for hot-water, any desired number of circuits may be taken from the supply and return headers by tapping them at intervals.

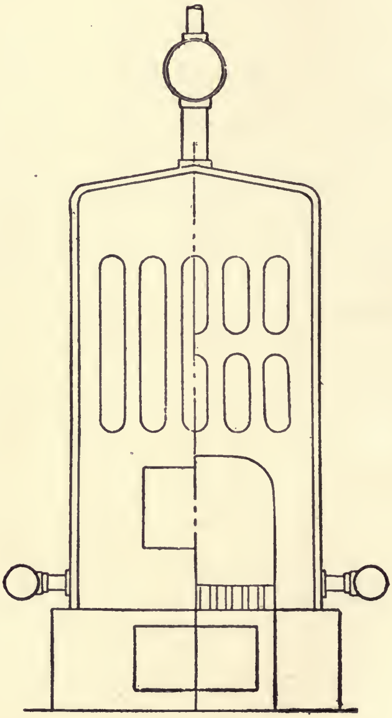


FIG. 79.

Its internal resistance is low, considerably less than with coil boilers. It is desirable to have large diameter nipples in all cases between sections and headers—say not less than 2 inches when used for water heating, and larger if possible.

Figs. 80 and 81 show the "Expert" hot-water boiler. It can be made up in any number of sections greater than two. The cuts show the boiler in its different aspects. Fig. 80 represents a 3-section boiler complete, with the doors thrown open, exposing the ash-pan, fire-box, and flue-passages, and Fig. 81 is a sectional cut, showing the water-ways of the boiler and the shaking grate.

The boiler belongs to a class of vertical sectional boilers that practically form a return flue horizontal boiler, when made up in many sections. As the boiler is increased in size the grate surface is proportionally increased. No headers are used to join the sections. A peculiarity of a section is that it is made up of two elements that are exactly alike, they being made

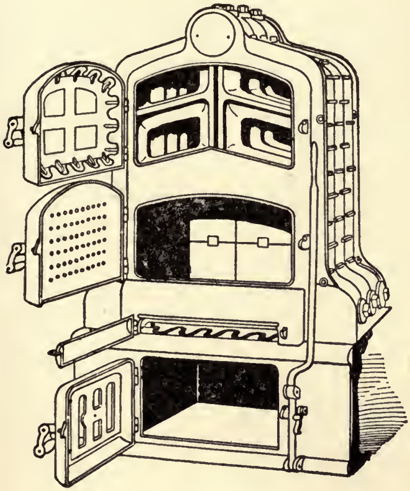


FIG. 80.

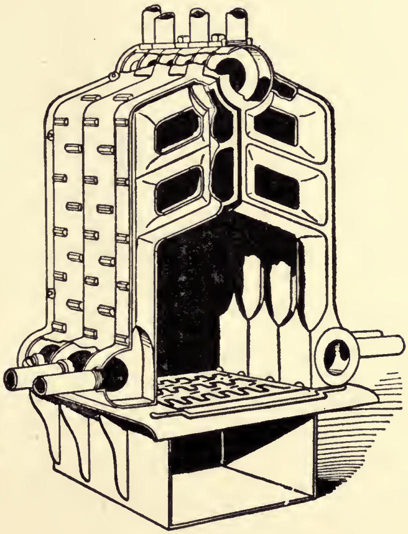


FIG. 81.

from the same pattern. By reversing, say, the one on the right, it becomes a left element, and will interlock with the right element forming the section. The joint thus formed at the top is somewhat like a hinge, and can be noticed in Fig. 81 when attention is called to it. Waterways of $3\frac{1}{2}$ to 4 inches are formed between the legs and heads of the sections, and joined with bolts. Each section is six inches deep, and the back of the fire-box is formed with fire-brick. The direction of the flame and products of combustion is backward through the furnace, thence upward and forward through the middle passages, and backward again to the chimney. The local water circulation within the boiler is upwards and towards the center column of an element over the fire, and returns through the upper passage from the head to the side of the leg. It is proposed with this boiler to fill a want for a comparatively low-priced hot-water heater for residences. It has a shaking grate, and is usually set without brick-work. The illustrations show other details of construction, such as door linings, etc.

A cast-iron boiler that may be said to be a modification of the spiral coil boiler is the "Florida," Fig. 82. It was an early

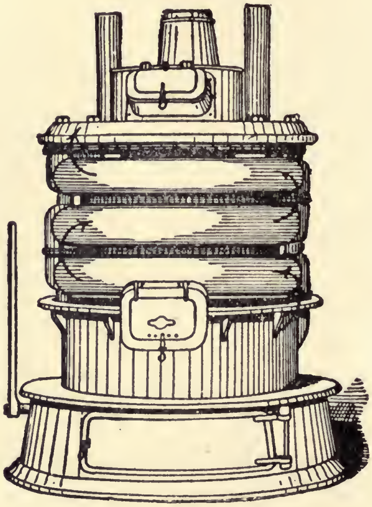


Fig. 82.

modification of a hot-water boiler and is substantially the coil as shown by the arrows. In a later modification, with direct vertical connections, less resistance is offered to the passage of water than in the earlier type, through which the water had to pass in a serpentine course in its passage from inlet to outlet, while in the later type the passages are straight, the water diffusing through the intervening parts of the rings by local circulation.

Figs. 83, 84, and 85 show simple types of boilers that have been largely used for green-house heating. Fig. 83 is the "Hitchings" conical boiler; Fig. 84 the "Scollay" boiler, and

Fig. 85 the "Weathered" boiler. The resistance through these boilers is very small and a unit of surface has a very high efficiency. The heating surface being small, however, compared to the grate, the gases of combustion escape into the chimney at a high temperature. This is not true of the "Scollay" boiler. In boilers in which the gases escape at a high temperature, it is often customary to carry the heated gases in a horizontal flue under the benches, the chimney being at the opposite end of the house from the boiler, thus utilizing the escaped heat.

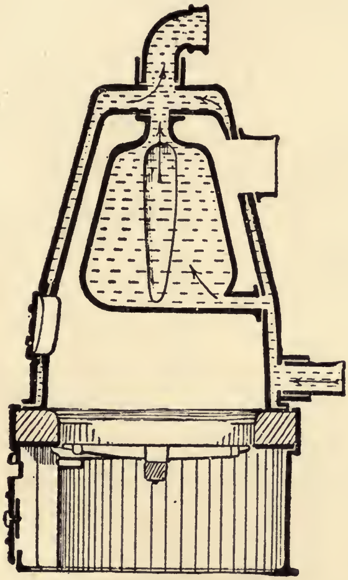


FIG. 83.

I class the "Scollay" hot-water boiler with the "Hitchings Conical" boiler, and the "Weathered" boiler, where it properly belongs. I should, however, have considered the "Scollay" boiler separately, when referring to the temperature at which the gases of combustion escape into the chimney, as on account of the surface of the crown-plate and the arrangement of the flue passages through it and around it, the heat of the fire is largely intercepted and the gases of combustion pass into the chimney very little hotter than the water in the boiler; so that, instead of its not being quite as well adapted for house-heating as for green-house work, it is admirably adapted for both purposes.

Fig. 83 is probably the first of this class of boilers ever made. The elder Mr. Hitchings made it as early as 1844, and the others are simply more recent modifications of it.

Figs. 86 and 87 show the simplest types of boilers made. Fig. 86 is a single casting without joints. It was made in only one size, being 19 inches in diameter with a 17-inch grate, and it was rated for 400 feet of 4-inch pipe. Its total inside surface did not exceed 10 square feet, therefore the boiler surface to

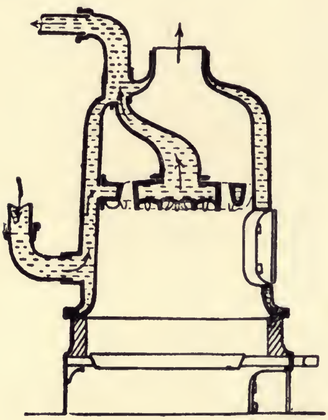


FIG. 84.

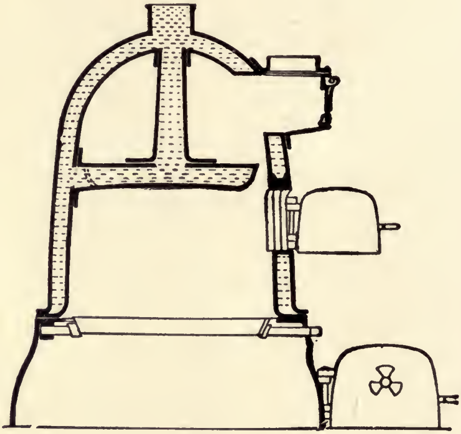


FIG. 85.

heating surface was about 1 to 40. The three simple types mentioned before are about in the same ratio. The gases of combustion escape hot.

Fig. 87 is the "Hitchings" base-burning boiler. It is of cast iron, having a water bottom below the fire and a magazine for coal. They are in the proportion of about 1 of boiler surface to 20 of radiating surface, and the gases of combustion do not escape, as hot as with the preceding four boilers so that it is not advisable to carry them through a horizontal flue when setting. The internal resistance to the flow of water in this boiler and in the one that precedes it is comparatively nothing.

Fig. 88 shows the "Dunning" hot-water boiler. It was made of wrought-iron or boiler steel, being composed of an outer and inner shell, with crown sheet, etc., as shown. It differs from ordinary upright tubular boilers in having a much higher furnace, and in not having the tubes run from crown sheet to head, but in returning down the side, as shown, in an annular ring of tubes, forming a reverberatory draft. It is shown here with a magazine, but where desired they are omitted, in a manner very similar to the door-fired steam boiler made by

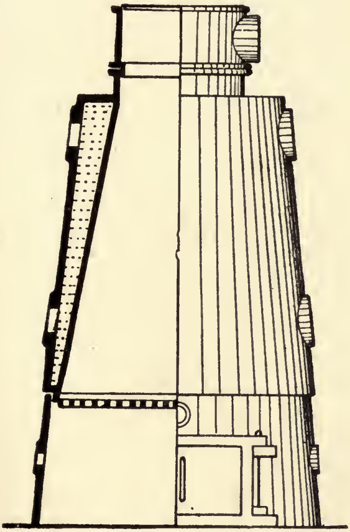


FIG. 86.

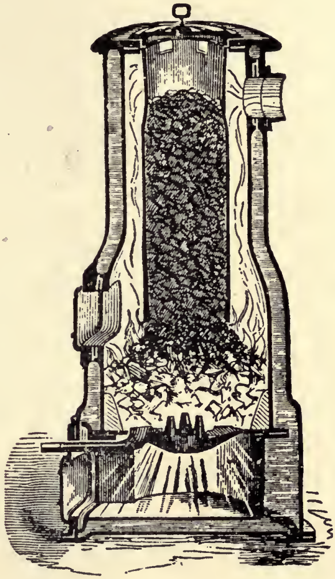


FIG. 87.

the same firm. The internal resistance of these boilers to the flow of the water is very small.

The ordinary upright wrought-iron boiler with vertical tubes makes a good hot-water heater.

Fig. 89 shows a modification of it used by the writer. It is shown without a magazine, but when desired it may have sufficient of the centre tubes omitted and an appropriate wrought iron magazine inserted with cast-iron muzzle. As shown the gases of combustion pass upward in the centre tubes and return by the outer circle of drop tubes to the annular smoke connection at the bottom, from whence it passes into the chimney.

If considered desirable the brick-work can be set three inches or thereabouts from the boiler, and an up-take formed, so as to make heating surface of the outside of the shell. When the porosity of brick-work, and its liability to leakage of air by cracks, is considered, it is questionable if anything is to be gained by such a form of setting, and if the work is poorly done

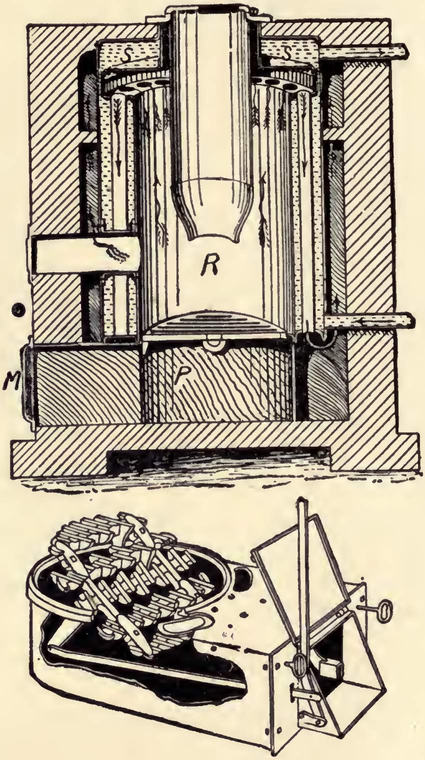


Fig. 88.

a loss will result; therefore, the form of setting shown is the one I approve of with this boiler.

The upper smoke connection is of cast iron made in six parts that are laid into place about the main flow-pipe. They can be removed one at a time and part of the tubes cleaned, even where the apparatus is in use.

These boilers have very little internal resistance to the flow of the water, and have a high efficiency per square foot of heating surface. It is claimed, however, that the wrought iron tubes of these boilers eat or corrode away in a much shorter time than the shells, and especially so when soft coal is the fuel. The reason is not plain, but it does appear that the

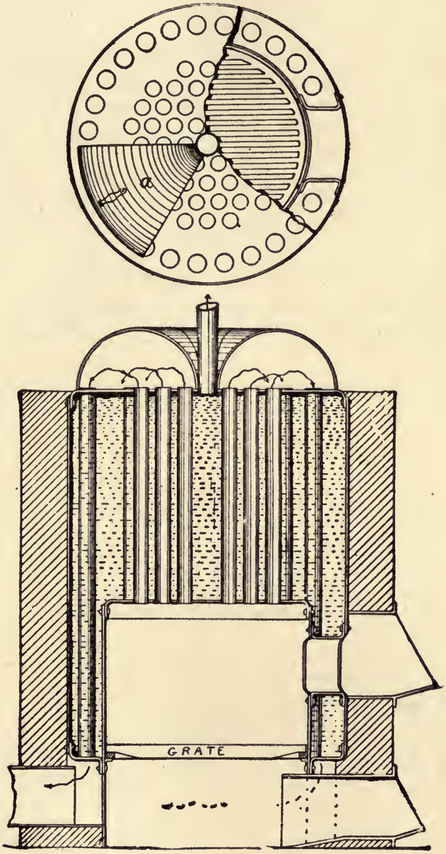


FIG. 89.

wrought iron tubes of a hot-water boiler eat out faster than the tubes of a boiler used for steam. For this reason recent efforts have been made to produce a suitable cast iron upright boiler that will be a proper substitute for the regular wrought iron upright, especially for house heating.

Figs. 90, 91, 92 and 93 show the Bolton Water Tube Heater. It consists essentially of an upper and lower cast-iron chamber, *a* and *b*, forming, respectively, the top and base of a boiler that are connected by wrought-iron water tubes, *c*, screwed into

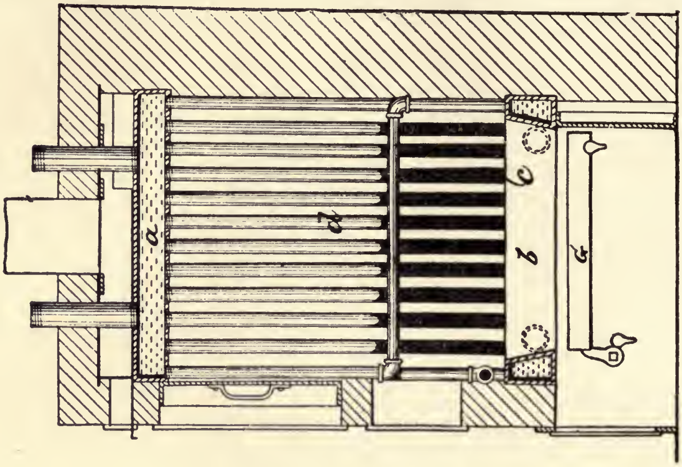


Fig. 91.

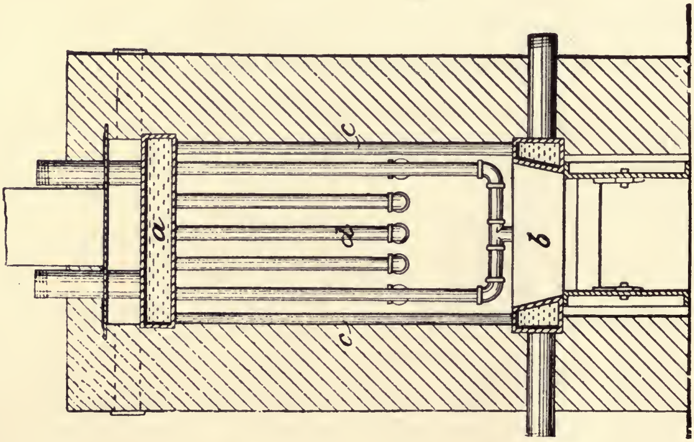


Fig. 90.

the bottom casting and connected with the top casting by the ordinary running thread and lock nut. All the pipes are vertical except one row, which passes nearly horizontal from just above the fire door to the back of the lower chamber, thus forming, as it were, a crown sheet to the top of the fire-box. Above these horizontal pipes is an arrangement of vertical pendant pipes, or drop tubes, *d*, which form the larger part of the heating surface of the boiler. The drop tubes are screwed directly into the upper casting, and inside of each is sustained a circulating tube, extending from top to bottom, through which the local circulation in the heating tube is maintained and intensified. The upper chamber of the boiler is pierced with a number of flue holes for the escape of the gases of combustion into the chimney, seen in Fig. 92. These holes are

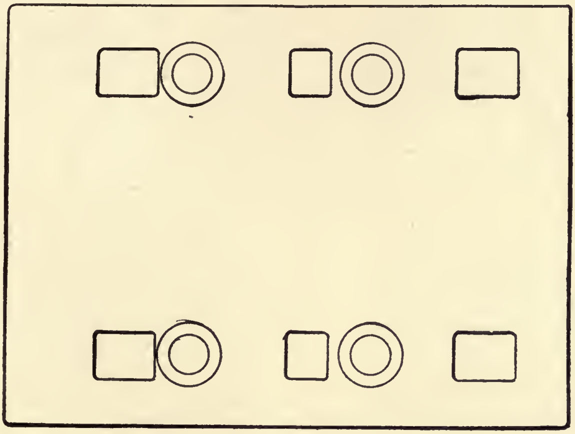


Fig. 92.

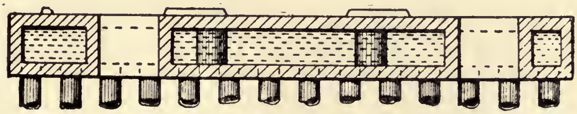


Fig. 93.

covered with sliding dampers for the regulation of the draught. The boiler is set in brick-work in the manner shown, with numerous hand-holes for cleaning, etc. The tubes are brushed or cleaned through a large door directly above the fire door, which also gives access for the removal or the renewal of the tubes directly acted on by the fire, without removing the brick-work. The grate used is of the special shaking pattern, easily removed through the fire and ash-pit doors. The flow-pipe starts from the upper chamber and the return pipes enter the lower one, so that the water is compelled to pass from the bottom to the upper chamber in the continuous tubes, local or return circulation going on only within the drop tubes, making, it is claimed, a positive circulator.

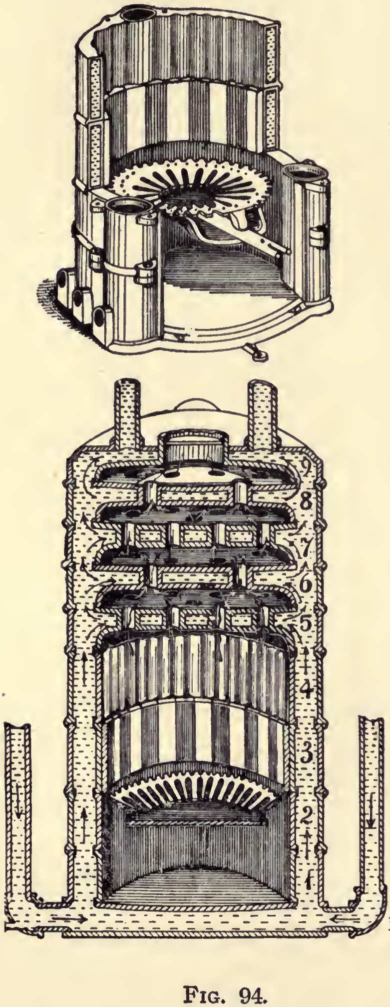


FIG. 94.

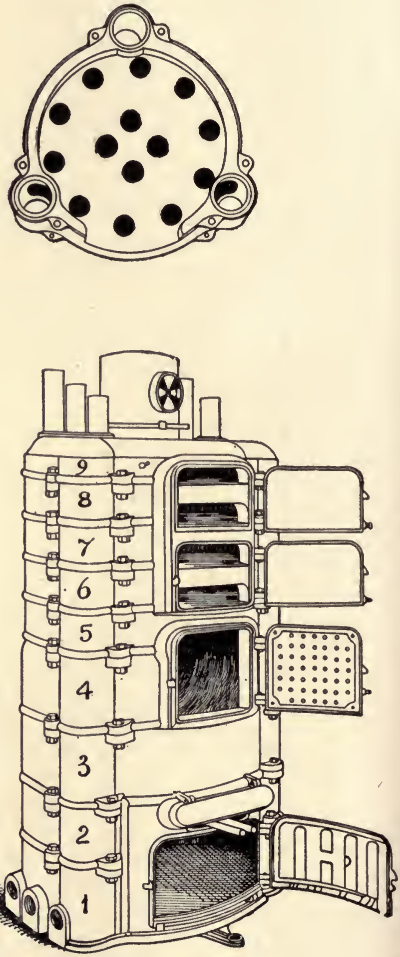


FIG. 95.

The " Gurney " hot-water boiler, shown in Fig. 95, was the first prominent cast-iron boiler of its type put in the market. It was invented by Mr. Edward Gurney, of Toronto, and was first used in Canada.

The illustrations, Figs. 94 and 95, show the boiler in its early form. The lower section (No. 1) forms a " water-bottom " beneath the fire. The second section (2) is technically a " water-leg." Section (3) forms the fire-pot, and is arranged on the fire side so that a little more than half the inside surface is covered with fire-brick. Between the fire-brick panels the iron of the fire-pot projects to the fire, so as to make alternately a fire-brick and an iron panel. The advantage claimed for this is that the fire-brick, when so arranged, is practically indestructible. The explanation given is that when a fire-pot is

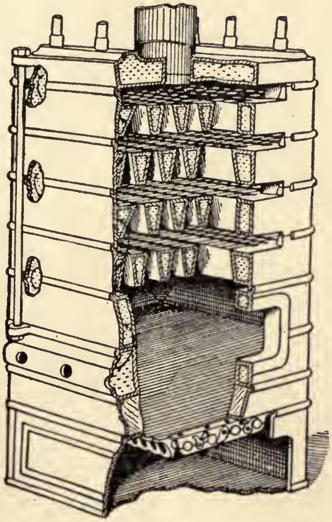


FIG. 96.

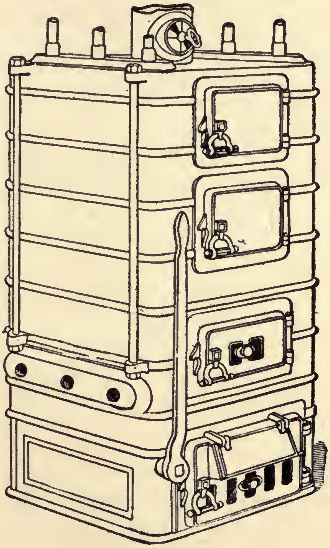


FIG. 97.

all fire-brick the slag of the fire clinkers on it and ruins the brick. On the other hand, when a fire-pot is all iron the heat of the fire is taken away so rapidly that combustion is interfered with and slow fires are more likely to go out, but that with this arrangement enough of the heat of a strong fire is taken away through the iron panel to prevent the adhesion of the slag to the brick, and that with slow fires the brick forms refractory surface enough to prevent the fires from becoming black at the sides. As to the correctness of the theory I do not presume to give an opinion. I do know, however, that the brick lasts much longer arranged this way than when in a continuous ring around the fire, and that they do not clinker.

The fourth section of the boiler is corrugated inside and out to increase the surface. The fifth section forms the crown sheet and above it the tube and flue surface.

A noticeable feature is the system of bolting the sections together. Formerly long bolts ran from top to bottom, but in the improved form short bolts are used, as shown in Fig. 95. Several advantages are claimed for the short bolts, an important one of which is the ability to break any single joint without disturbing the others. In the flue sections all the angles are replaced by curved corners, and the top and bottom surfaces of each section are concaved on the fire side, while the water side is convex, leaving no chance for lodgment of

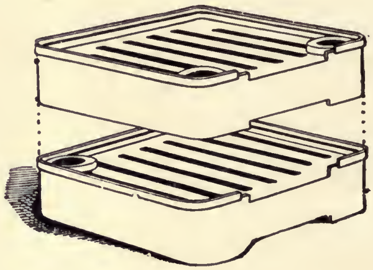


Fig. 98.

air or steam within the sections. Reference to the illustrations (Figs. 94 and 95 with the details above them) show the other peculiarities of the boiler and its general arrangement.

Another of this class of boilers is shown in Figs. 96 and 97. It was called the " Perfect."

It is square and a section lined with fire-brick forms the fire-box. The next two are water sections and form the furnace. The remaining sections form the crown and flue surfaces. This boiler may be said to be a cast-iron box coil, as it fully contains that principle in the arrangement of its water-ways. The water enters the lower hollow section, passes upwards at the front corner into the second section; thence backwards and upwards again to the third section; thence front again, and so on, giving a positive circulation of the water in its passage from the inlet to the outlet. The internal resistance of this boiler compared to a wrought-iron, box-coil boiler is very small.

The Fig. 98 shows two sections of the heating surface above the fire, and the method of joining them at the opposite corners is clearly made apparent. The broken sections, Fig. 96, show

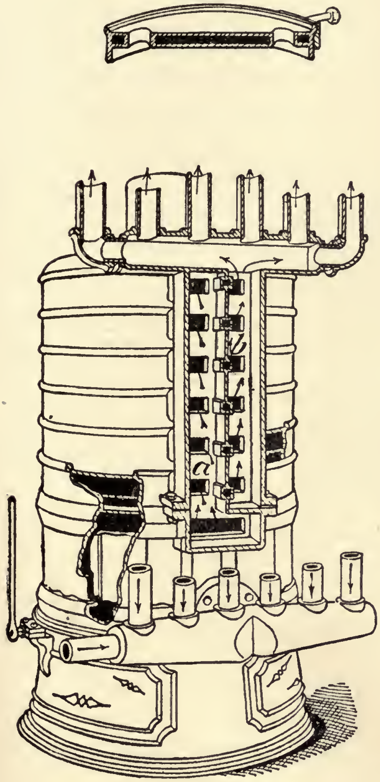


FIG. 99.

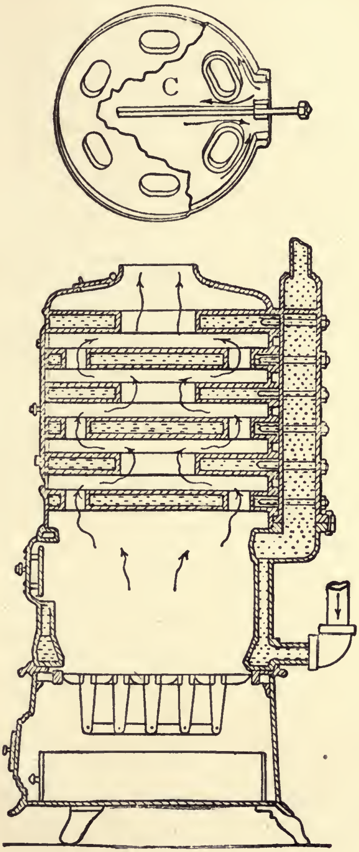


FIG. 100.

the general arrangement and cross section through the V-shaped water tubes.

An early boiler of this class to appear was the "Spence," a Canadian boiler, shown in Figs. 99 and 100.

In general appearance and in some points of detail it resembles the boiler, Figs. 94 and 95, as may be readily seen.

A feature of it is the arrangement of its internal circulation. The water that enters the fire-pot section passes to the second section at the back and enters the upright water passage, *a*, where it is made to flow around the septum, *c*, in each remaining section before it can get into the second upright water passage, *b*, on its way to the flow-pipes at the top. It is a positive circulator, meaning that the water must flow in a certain direction, and is in a measure a cast-iron spiral-coil boiler. Its internal resistance, compared to coil-boilers, however, is low, and in any case it is not of sufficient importance to be

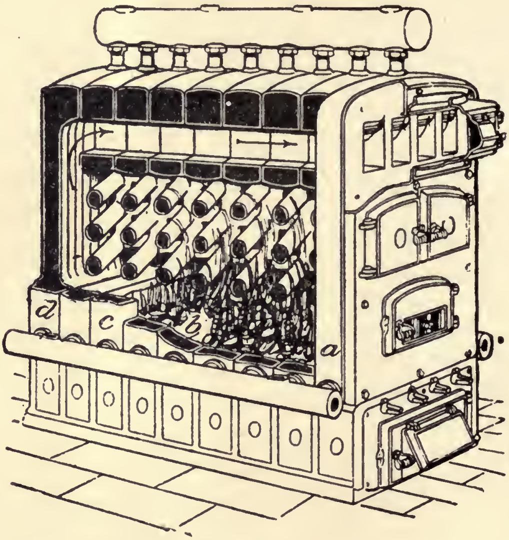


FIG. 101.

particularly objectionable, or to materially add to the resistance of the general circuit.

Figs. 101, 102, 103, 104, and 105 show the Richmond sectional steam and hot water heater. The claims made for this heater are not for any new creation of external form, but for the special construction, arrangement and quality of the fire and flue services, and the system of water-ways, embodying the principle of vertical circulation.

Fig. 101 shows a view of the heater in its ordinary form, but broken, showing the arrangement of the water-ways, fire surface, combustion chamber and flues, and the course of the products of combustion to point of exit.

Fig. 102 shows the front section, which is also a water section, in front of which is placed a shield or front connection, as shown in Fig. 101, and on which the doors are hung. When

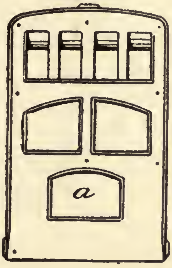


Fig. 102.

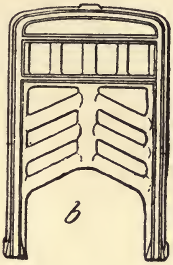


Fig. 103

the heater is to be brick-set a shield or front is furnished, recessed with a flange extending beyond the sides of the heater.

Fig. 103 is a view of leg section, showing the form and arrangement of the surface, placed directly above the fire. This cut also serves to illustrate the system of water-ways and the course of circulation.

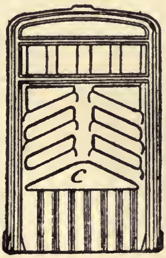


Fig. 104.

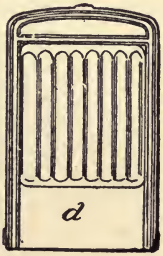
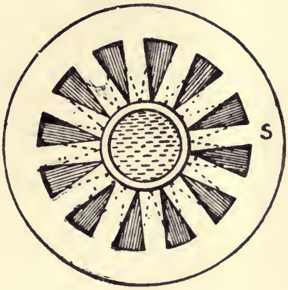
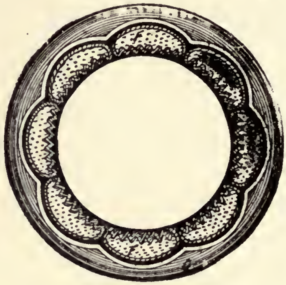


Fig. 105.

Fig. 104 is a view of an intermediate section, which is the first section, placed at the back end of the fire-box, the lower end having a corrugated surface exposed to the direct action of the fire and forming a bridge wall over which the products of combustion pass.

Fig. 105 illustrates a back section, forming the back wall of the heater, and presenting a corrugated fire-surface to the products of combustion in their passage to the flues.





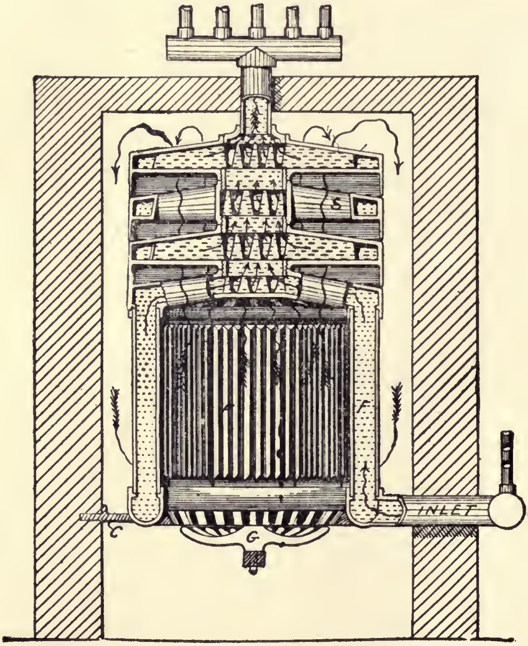


Fig. 106.

The Richmond sectional heater is equally adapted for steam or hot water heating, the steam trimmings being dispensed with, and the necessary provision made for flows and returns when used for hot water.

Fig. 106 shows the Mowry hot-water boiler. It is made up of cast-iron sections with screwed joints, and contains features that may be traced in the boilers shown in Figs. 94 to 99, with many that are particularly its own.

For instance, the fire-box is made up of a number of upright section or "staves," shown in cross section at the upper right hand corner at *F*, which are made into a shoe at the bottom. The upper ends of these staves or fire-pot sections are made into a crown section, which in plan is somewhat like the figure

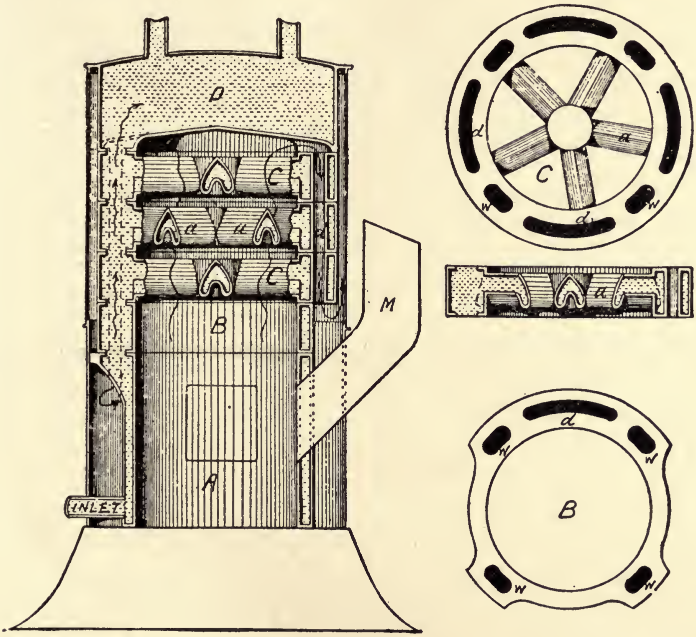


FIG. 107.

in the upper left-hand corner (Fig. 106) and which is composed of V-shaped radial arms. The remaining sections (*s*) are very similar to the crown section, with radial V-shaped arms, arranged one above the other in such a manner that the gases of combustion are deflected from one to the other, so they do not find a straight passage between the arms of the wheel. It is in the V shape of the heating surface of the wheel sections and in the "staggered" arrangement of the flues the similarity to the boilers before mentioned can be seen.

The sections are joined together with 8-inch screwed nipples at the centre as shown, and a manifold header is arranged top and bottom for the flow and return pipes.

Fig. 107 shows the "Auburn" hot-water boiler. It is made entirely of cast iron and consists of a base, in which hangs the grate, the base also forming the ash-pit.

These boilers are jacketed with cast-iron cases up to the centre of the second section, *B*. Above this point a sheet-iron case is used, the lower edge of which rests in the cast-iron case at the bottom, and reaches to the projecting flange at the head of the finishing section, *D*. On the base rests the fire-pot, section *A*, with four openings for the upward circulation of the water. These openings, *w w*, can be plainly seen in the details, *B* and *C*, and correspond in all the sections.

The section, *B*, is the next above the fire-pot: giving additional height to the furnace. Then follows *three* or more sections, of the wheel pattern shown in plan at *C*, in the upper right hand corner of the Fig. 107, these sections form the flue-surface; the arms, *a*, being heart-shaped in section, with the point upwards, the object being to form an upper surface on which no considerable quantity of ashes can lodge, the under side of the same tubes being coved so as to offer as great a surface as possible to the fire. The water-tubes, *a a*, are staggered so as to force the gases of combustion from tube to tube in their upward passage.

Above these flue-sections, which may be of any number, is a cap or finishing section, *D*, from which the flow-pipes start and which forms an upper smoke connection, with the drop flues, *d d*, seen both in the section and plans, *B*, *C*. The gases of combustion are again turned upwards between an iron case and the outside of the boiler, as shown by the arrows in the sectional illustration.

Side magazines are used on these boilers as shown at *M*, and the cleaning-door extends the full height of the flue sections, admitting the introduction of a flue brush at any state of the fire through openings or slots between the sections. The internal resistance of this boiler is very small.

Figs. 108 and 109 show the "Mahoney" boiler. It is simple and efficient, and is made of cast iron in but two pieces, the outer shell, *a*, and the inner casting, *b*, Fig. 109. The internal casting contains the entire fire surface forming no less than the fire-box and the flue surface above it. It is practically an upright-tubular boiler of cast iron, the water being in the leaves, *c*, and the triangular spaces, *d*, between them forming the upright tubes. Fig. 109 is a cross-section through the magazine and flues above the fire-box.

Fig. 110 shows the "Plaxton" hot-water boiler.

It is made in vertical sections, and has the coil principle involved in it. The principle is so apparent with regard to the

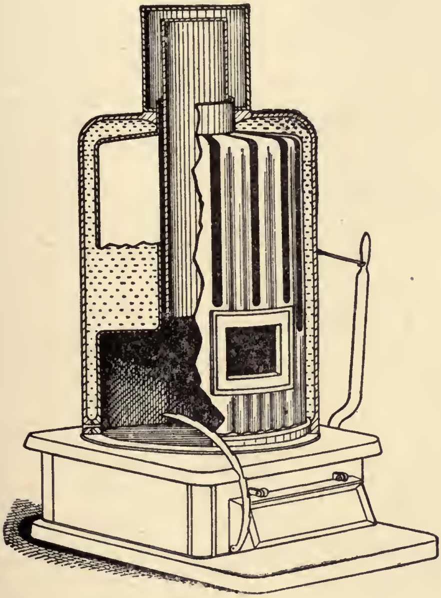


FIG. 108.

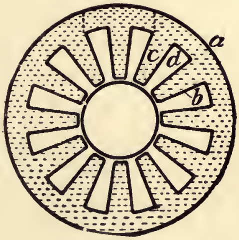


FIG. 109.

direction and movement of the gases of combustion, as well as of the water, that no comment is necessary.

A class of boilers entirely different from anything so far shown is the wrought-iron welded-boiler. They were first made in England, where they are used to a considerable extent.

Figs. 111 and 112 show one of the ordinary forms of this class of boilers. Fig. 111 is the boiler in perspective without setting. Fig. 112 shows it in section with brick setting.

There are many modifications of this boiler made by Hartley

& Sugden, Halifax, Eng. They developed from the simple saddle boiler, *a*, Fig. 113, into boilers like *b*, *c*, *d*, *e*, *f*, and many other forms that it is not necessary to show here.

The form of saddle boiler shown in Fig. 114 has been made in this country for greenhouse heating for many years, by Messrs. Hitchings & Co., of New York. Boilers of this class are set in connection with an ordinary horizontal flue extending through the greenhouse as shown, and the hot-water pipes are

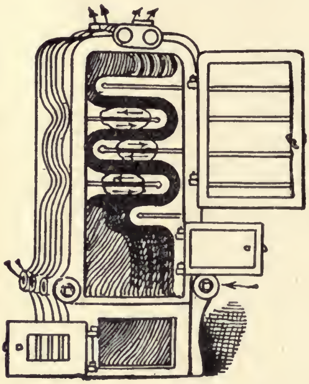


FIG. 110.

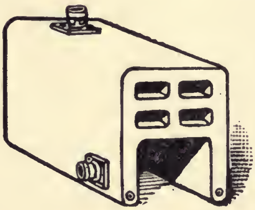


FIG. 111.

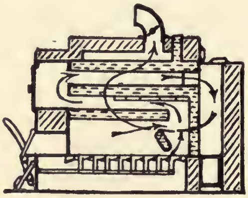


FIG. 112.

carried from the boiler to the side of the house opposite that occupied by the flue, or placed where the heat is most desired, so as to equalize the heat of the house.

The " Champion " boiler, made in Canada, is a type not readily classified. It is shown in Figs. 115, 116, and 117. It has the advantage of presenting a large surface in a small space, however, and may, no doubt, present ideas not suggested by any of the former types. A point about it, which is not purely its own, but which is not apparent in any of the others, is the double grate, where ashes and cinders can be separated and the latter thrown back on the fire, the former being removed at the lower door. There is another and probably greater advantage,

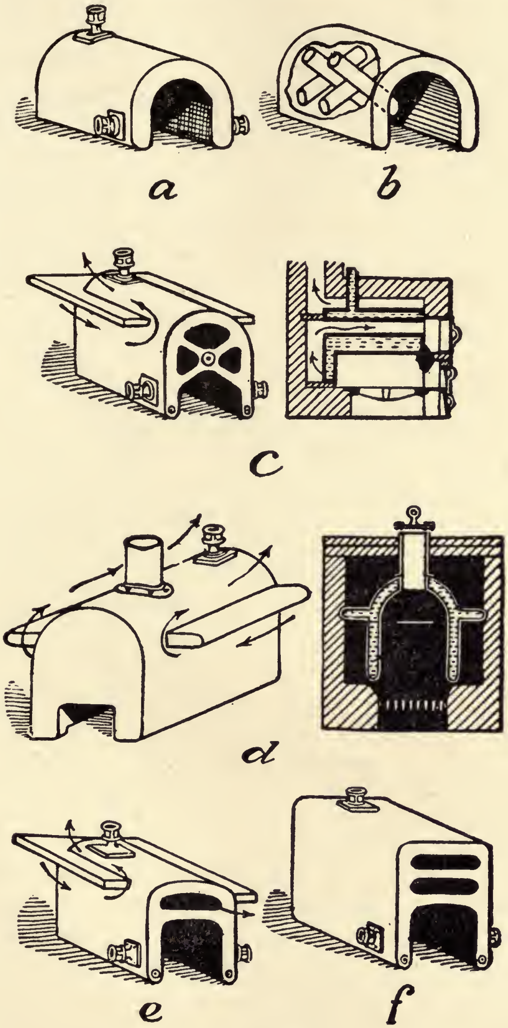


Fig. 113.

however, in the second grate of having the air pass through it and the ashes, etc., it contains on the way to the fire. It results in warming the air on its way to the fire and cooling the ashes and cinders, thereby prolonging the life of the upper or fire grate.

Fig. 115 shows the general appearance of the boiler with the cleaning door, etc., open. Fig. 116 is a back view, and Fig. 117 is a view showing the details of construction.

Before leaving the subject of boilers, or "heaters," as they are often called, I want to refer to a type of small heaters sometimes met with. They are properly water-backs, from which one or two rooms may be fairly well warmed. The one shown, Fig. 118, is a novel arrangement of parlor grate and hot-water heating apparatus, and is simply a suitable open fire-place grate of appropriate design, in which the fire burns, warming the room

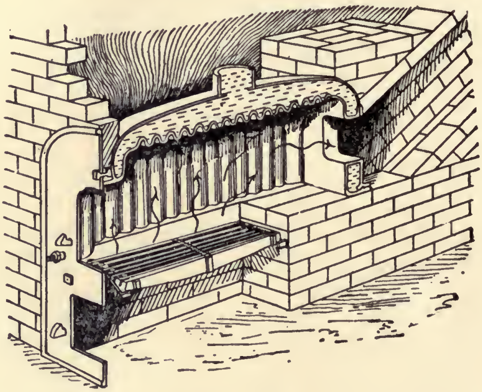


FIG. 114.

in which it is placed, but instead of having the back, sides and top of fire-brick tiles, they are a hollow casting, which properly forms a hot-water boiler.

From this boiler is an ordinary flow pipe of a water-circulating apparatus, as shown at the top in the illustration. A similar return pipe enters the back at the bottom, and from these pipes a system of three or four coils or hot-water radiators can be warmed in a manner exactly similar to that from a regular heating boiler. Usually a room on the second floor of the house can be warmed by the hot water, and when it is necessary to warm a room on the same floor, large diameter pipes and a coil may be used.

To one acquainted with hot-water apparatus, it is enough

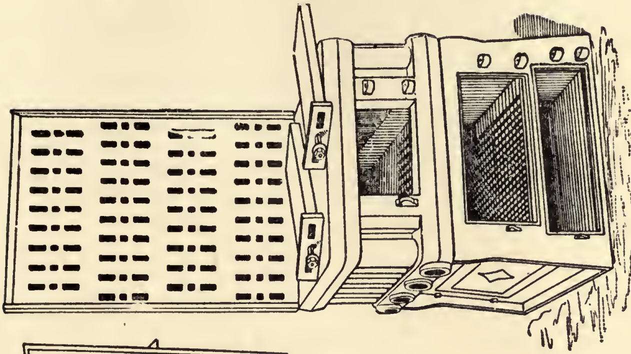


FIG. 117.

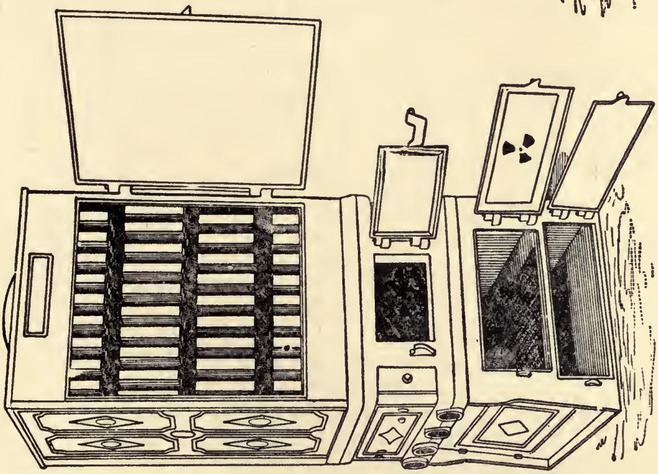


FIG. 115.

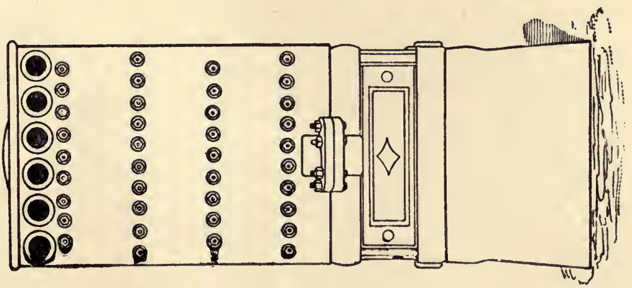


FIG. 116.

to say that an open-tank system may be maintained with it in any usual manner, but it should never be used with a closed tank, on account of the flat sides.

Figs. 119, 120, 121 and 122 show four hot water boilers of the latest types. They occupy a prominent place among the modern hot water boilers of the day.

The use of hot water for warming buildings in the United States is a revival. Steam had almost entirely taken the place of the early methods of hot water heating—except in green-

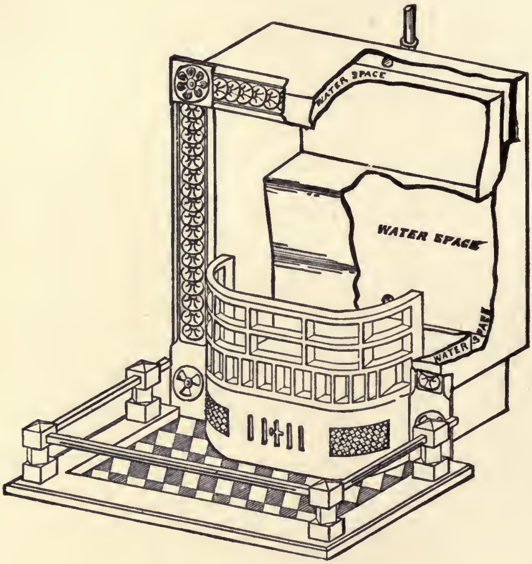


FIG. 118.

houses—when Mr. Edward Gurney of Toronto in the early 80's carried the Canadian system into the United States and substituted radiators for coils in hot water apparatus. This gave the hot water heating apparatus and the steam heating apparatus a similar appearance. The makers of the Bundy radiator converted the steam type into a hot water type (as shown on page 213), and in this way overcame the principal objection offered by American householders. Boston became the headquarters for the hot water boiler trade, until after four or five years the system spread over the country with many

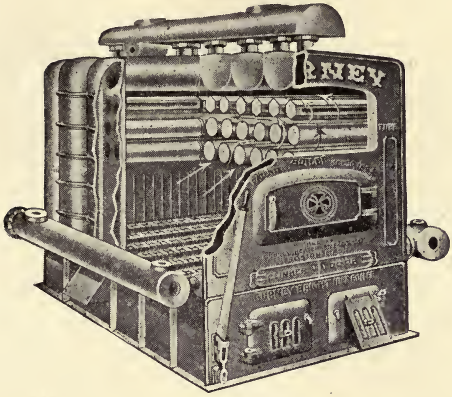


FIG. 119.

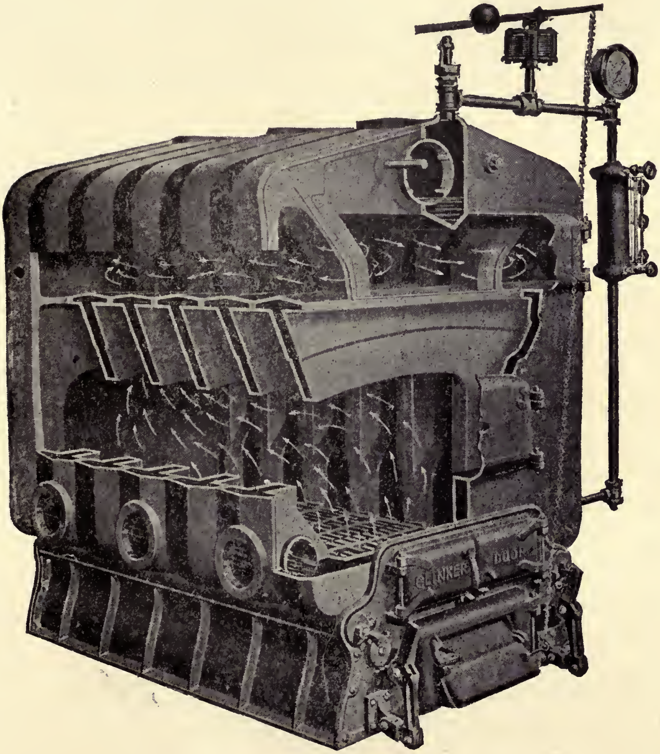


FIG. 120,

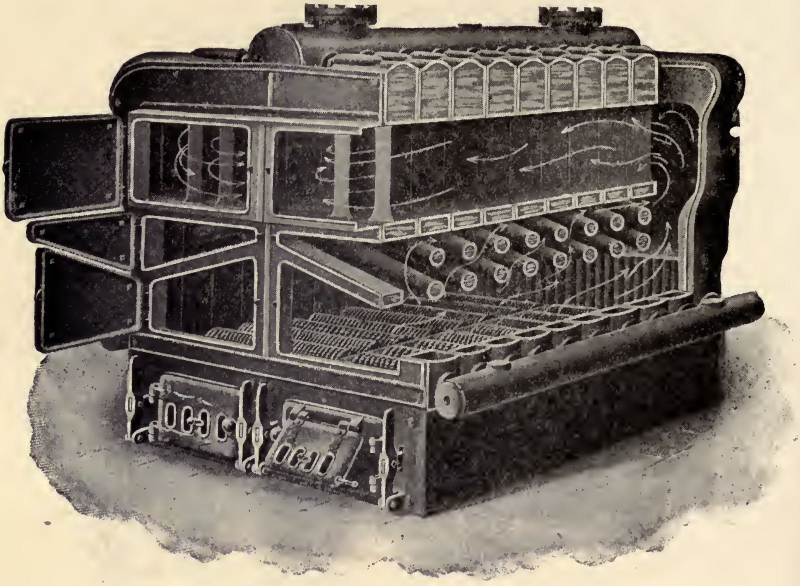


FIG. 121.

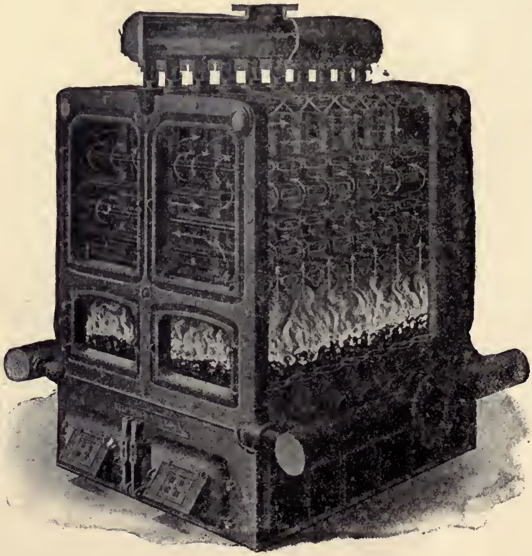


FIG. 122.

improvements in boilers and radiators. This has culminated in the enormous trade, in practical boilers and beautiful radiators which we see to-day, and the great industries which produce them. Fig. 119 shows the Gurney boiler of the present day. It is representative of the drum and header type and its design is such that it is capable of being increased in size and magnitude almost without limit. It is a circulating water tube boiler, the tubes being similar to the Bundy tube. This gives a positive and quick local circulation and a value in heating surface efficiency equal to power boilers. A notable feature of the arrangement of this boiler is that the engineer has power to increase or decrease the grate area. He may, in other words, proportion it as he pleases to the total heating surface of the boiler. This is done by the moving of the bridge wall section.

The writer made the early trial tests of the Gurney Bright Idea boiler and he found the evaporation efficiency very high.

Fig. 120 shows the Ideal boiler. It is made by the American Radiator Company and is probably the finest example of a cast iron sectional boiler without headers or drums. It is a push nipple boiler with extremely effective heating surfaces. It can be rapidly and cheaply put together and the quality of the castings fittings and doors shows an excellence of foundry work and fitting that is extraordinary.

Fig. 121 is a low drum type of the cast iron boiler. It is made by the McCrum-Howell Co. and is a good example of the cast iron sectional boiler, many modifications of which are now on the market. It is known as the Richmond.

The name Boynton has been identified with the cast iron boiler trade for from 15 to 20 years. Fig. 122 shows their latest development of a heating boiler. Their first hot water boiler was without headers and the sections were joined at their corners by asbestos gaskets and long bolts running through the water space. They early abandoned this method of joining the sections and now use the header method exclusively. The writer used one of their "soft-joint" boilers in his own house and despite its defects obtained about 14 years of economical service, before he had to renew it, although it was one of their experimental boilers. In the same house he has the first Detroit hot water radiators and although the upper joints are made on india rubber gaskets, none of their joints have leaked.

CHAPTER XXI.

DEVELOPMENT OF COILS AND RADIATORS.

Development of Coils and Radiators—Indirect Radiators—Box Coils—Wrought-Iron Box Coils—The Clogston Indirect Radiator—The Climax Indirect Radiator—The Eclipse Radiator—The Excelsior Indirect Radiator—The Compound Indirect Radiator—The Pin Indirect Radiator—The Ribbed Radiator.

The earliest hot-water radiators were coils of cast iron pipe carried about the sides of rooms or greenhouses in the most primitive manner. Usually they formed a continuous circuit from the boiler through the consecutive rooms of the building and back to the boiler again, the water from one coil passing into that of another, and so on to the end; each being somewhat cooler than the one preceding it. This is technically known as a positive circulation, meaning that it must circulate in a certain direction if it moves at all.

This principal required pipes of a large diameter, otherwise the resistance would be so great from so much pipe and so many elbows the water would not pass around the circuit in sufficient volume to keep the last part of the circuit or heating pipe at anything like a sufficiently high temperature to be of service as heating surface.

The objection to such a system, aside from it appearance and bulk, was that no part of the circuit could be interrupted without stopping it all, and therefore it was put up without valves as a total interruption of the circulation by their use would cause the formation of steam in the boiler, the consequence of which it is not necessary to go into here. Fig. 66, page 164 is a sufficient example of this style of work, and, of course, it is obsolete now and only used for some special purpose.

The fact of being unable to shut off part of the circuit next suggested the system and principal shown in Fig. 123.

When the occupant of a room or section required to shut off his coil he closed the cock, *a*, and opened the cock, *b*, still maintaining what may be considered a positive circulation, and simply cutting his coil out of the circuit.

This arrangement, though accomplishing one object—that of

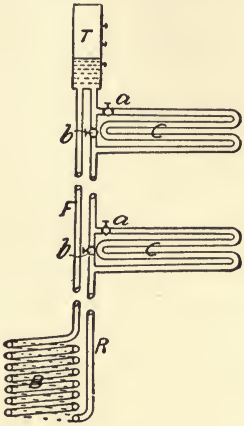


Fig. 123.

shutting off the radiators or heating surface of a room—resulted often in the closing of one valve without opening the other, so that the circulation was entirely stopped, and trouble followed.

To obviate this a three-way cock was substituted at the junc-

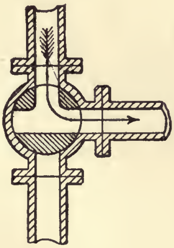


Fig. 124.

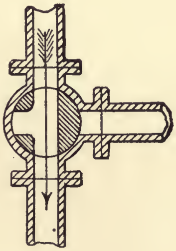


Fig. 125.

tion of the upper pipe of the coil with the flow pipe, so that the act of closing one pipe always opened the other. This cock is shown in Fig. 124 and 125 in detail.

Fig. 124 shows the current going to the coil, and Fig. 125 shows it going through the mains only, the coil being shut off.

All the pipes, of course, are of the same diameter in such an apparatus throughout its whole length.

It was soon found, however that it was unnecessary to have a continuous circuit for the purpose of circulation, and an apparatus on the principle shown in Fig. 126 was the result, with a single valve at *a* on each coil; part of the current going through the coils when the valves were open or partly open, while a main circuit was maintained through the flow pipe, tank and return pipe shown by the dotted lines.

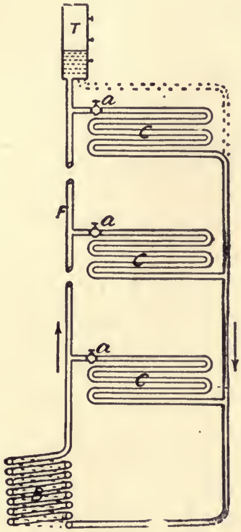


FIG. 126.

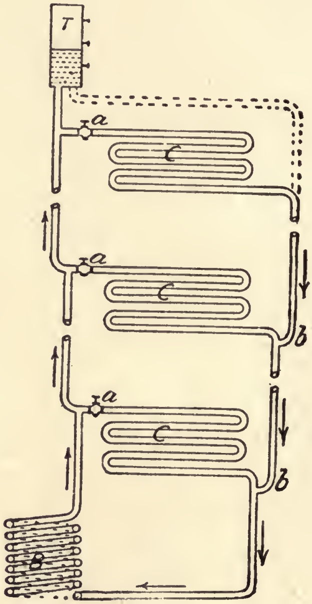


FIG. 127.

The same large uniform diameters, however, were used for some time longer, and the result was the upper coils of a system would be warmer than the lower ones, on account of the greater length of the respective columns of water, and the direct action of the flow of the water past the lower branches. Various devices were tried to get a uniform distribution without regard to the diameter of the pipes, and Fig. 127 shows the general principle used to divide the current.

With a straight rising pipe of uniform diameter the water passed to the upper coil, on the principle shown in Fig. 126, more readily than to the lower ones; the current of the water holding its straight course. The resistance caused by the change of direction at *a a* and *b b*, Fig. 127 by the arrangement of the fittings, diverted and divided this current so that more equable results were obtained in the coils; the extra bends and turns favoring the lower coils by dividing the currents at *a a*, and retarding the upper coils currents at *b* and *b*.

The proper proportioning of the diameters of the pipe for the different levels, of course, would obviate the difficulty, but as there were very few sizes of the pipe used at the time, and those principally cast iron, this was not practicable.

Pipes of a very large diameter throughout would result in carrying sufficient water through the circuits, so that the differences of temperature at different points would be inconsiderable and there would be no necessity for the arrangement shown in Fig. 126; but they would have to be so very large they could not be tolerated in ordinary buildings. It is ancient history, however, to be repeating this to the trade now, and it is only referred to in a cursory manner as a preface to the present practice.

From the crude apparatus of forty and more years ago, and the idea that " the power of the boiler " was necessary for circulation, we have developed modern types of various common-sense forms, and demonstrated that the pipes of a hot-water apparatus can be branched with as much impunity as the pipes of a steam apparatus, provided strict attention is paid to relative diameters and parts, and that the power or difference of weight between the legs of the syphons formed within the branch or radiators is sufficient to keep the water circulating irrespective of the direct power from the boiler to the main circuit; in other words, it was seen that when an apparatus was designed to give equal resistance to the flow of the water at all points, all radiators would act alike, and give very nearly equal temperatures at all points. Previous to this nothing but the coil principle was applied to the radiators, as the general idea prevailed that the continuity of the current could not, or at least should not be broken.

Changes in types of radiators for hot water were made cautiously, however, at first. They passed from the flat or wall coil class, Fig. 35 and 36 into the box coil, Fig. 129; thence to wrought iron vertical tube radiators, connected top and bottom with chambers, and lately into cast iron loops of almost as many various forms as there are of steam radiators, each maker of steam radiators being anxious to supply the hot-water trade as well.

The box coil radiator has been largely used for indirect work, and though it is fast disappearing for direct radiation, for indirect radiation it is still used, and modifications of it that are made of cast iron have a prominent place in present hot water heating practice.

Indirect Radiators.

The box-coil shown in Fig. 128 is the one used in the State, War and Navy Department building for indirect radiation. They are made of cast iron pipe three inches in diameter, with

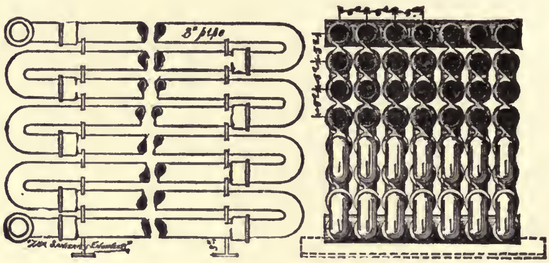


Fig. 128.

bell and spigot ends, the spigot end being a bend, and the sections are connected to make a box-coil with cast iron headers. The pipes are set with 5 inch centers in both directions, and the joints are made with hemp ropeyarn saturated with lead paint, driven into place with a hand tool. They are suspended with the coil-chamber on T-irons built into the walls.

Rust joints may be used if desired, and when once set without splitting the hubs make a more desirable joint, as they are as permanent as the pipe. They require care and judgment, however, in the making, as the rust swells and splits the hubs if not properly prepared and used.

These coils are usually set in brick chambers as shown in Fig. 129, which is introduced here as being typical of all brick settings for indirect work.

The chambers are built of brick with 8-inch walls, and run to the ceiling of the cellar. The valves are ordinary gate-valves, and one is used on both flow and return pipe, the object of the second valve being to permit of shutting off the coil for repairs without interrupting the remainder of the apparatus.

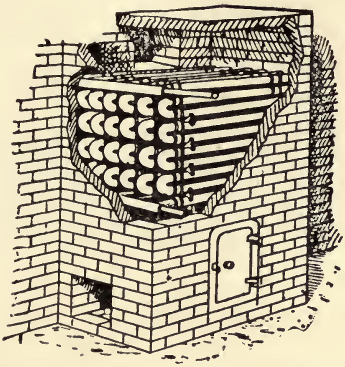


FIG. 129.

An advantage of large diameter coils is their low resistance to the flow of the water, and their capacity to retain heat after the fire goes out on account of the large amount of water they contain.

The wrought iron box coil, made of pipe and cast iron fittings,

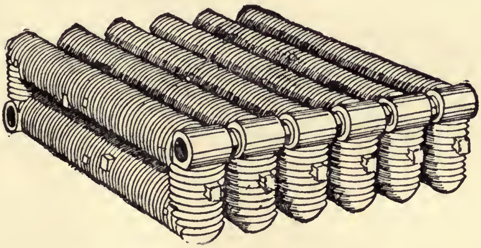


FIG. 130.

is too well known to all persons interested in the construction of warming plants to require anything more than a mere allusion to here. It would be better, however, when using them for hot water purposes to make them larger in diameter than the conventional 1-inch pipe, as it lessens the resistance to the flow of the water through them, and makes them less likely to be frozen should the fire go out.

Figs. 130 to 135 show a class of indirect radiators that may be said to be modifications of a box-coil. They are made of cast iron, and are usually two pipes high by any required number in width, and the heating surfaces are increased by flanges or fins called extended surface. These projections or fins interlock so as to compel the air to be diverted from one to the other in its upward passage between them.

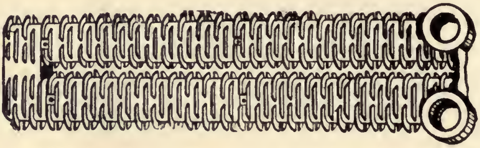


FIG. 131.

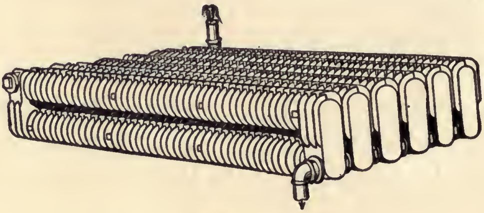


FIG. 132.

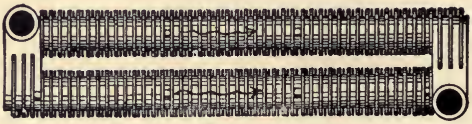


FIG. 133.

Fig. 130 shows the "Clogston" cast-iron box radiator made in Boston, and considerably used in the New England States. There are two modifications of it—one with centre connections and one with end connections; the latter being shown in the illustration as being better adapted to hot-water heating.

It is connected with *R* and *L* nipples between the sections, as plainly shown in the illustration, and set in any manner suitable to a box-coil for indirect radiations. The ribs or flanges which form the extended surface run in an unbroken ring about the pipe.

Fig. 131 is a section of the "Climax," made by the A. A. Griffing Iron Co. of Jersey City. The sections are made into a box-coil by 2-inch right and left nipples, and the radiator is set and boxed in the usual manner. The boxing, etc., is applicable to all radiators alike, therefore, it is unnecessary to

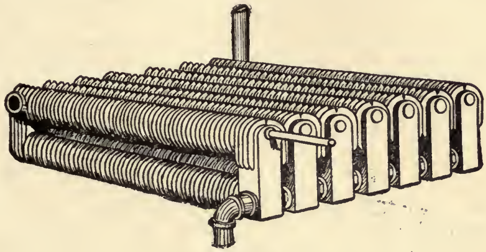


Fig. 134.

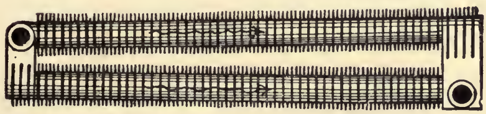


Fig. 135.

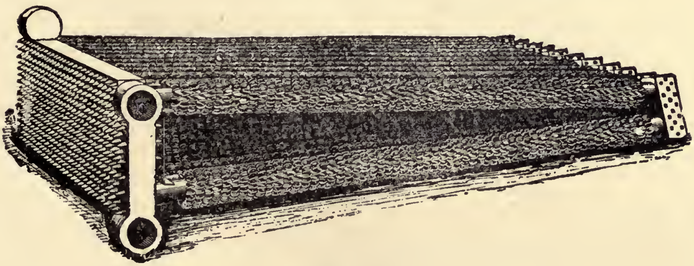


Fig. 136.

show more than a radiator, or a section thereof, in the examples of this class.

Fig. 132 shows the "Eclipse" indirect hot-water radiator Fig. 133 is a side view of a single section of the same. It differs very little from the "Clogston" except in the arrangement of the fins of flanges. In this radiator they run but half way round the section, and interlock when the sections are connected side by side. The sections are connected at opposite ends by right and left nipples, as will be seen in the illustration Fig. 133.

Fig. 134 shows the "Excelsior" indirect radiator. It and the Eclipse are almost identical in appearance, and the method of joining the sections is the same.

Fig. 136 shows another class of extended surface. It is known as the "Compound Coil," on account of it being formed by winding a helical coil of No. 14 square iron wire about the wrought-iron pipe of a plain coil. The headers and return bends are covered with "pin" extended surface, and the mode

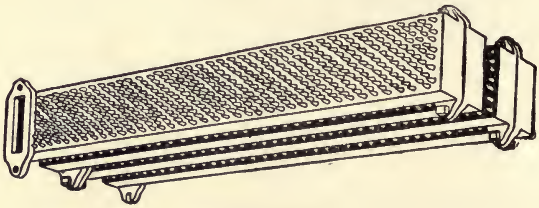


FIG. 137.

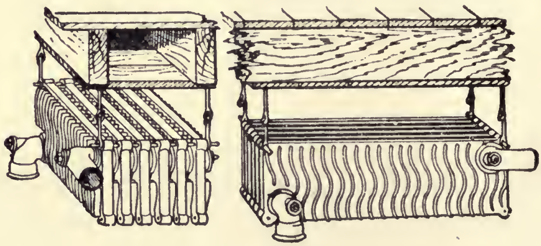


FIG. 138.

of boxing is similar to any box-coil. It was early made by the Gold Car Heating Co. of New York.

Fig. 137 shows the "pin" hot-water radiator. It is known as the "Utica" pattern, on account of being connected at the ends of the sections so as to give a continuous passage to the water from inlet to outlet.

Fig. 138 shows an early type of extended surface hot-water radiator made by the Morris Tasker Co. of Philadelphia. It is called their "Ribbed Radiator for Hot Water." It is held together with long bolts, and paper or rubber gaskets are used in the joints. It answers for very low pressure work.

CHAPTER XXII.

DIRECT RADIATORS AND HOT-WATER HEATING.

Wrought-Iron Radiators for Direct Radiation—Cast-Iron Radiators with Bases—Cast-Iron Sectional Radiators.

The impetus lately given to the hot-water business in the United States is, no doubt, largely due to the invention of modern types of upright radiators that differ nothing in appearance from modern steam radiators.

The use of direct box-coils for hot-water heating were undesirable in any furnished room or residence, and when they were covered with cast-iron fretwork screens with marble tops, etc., they became repositories for dust, etc., and were neither conducive to health or cleanliness, and in public buildings they became sarcophagii—which they so closely resemble—for ancient tobacco and general filth.

Flat coils, when used as direct hot-water radiators, were not objectionable so far as cleanliness was concerned, but they were never considered ornamental. Their capacity with regard to surface being limited—without using large and objectionable diameters—and the wall space they occupied made their use in furnished rooms very rare; and unless in small bed-rooms or bath-rooms, they are not much used in residences by American architects.

The advent of the vertical tube or loop hot-water radiator, however, did away with this objection, and placed hot-water radiators on the same footing as steam radiators, so far as their general appearance is concerned; and with most types of vertical radiators at the present time there is no difference between those used for hot water and those used for steam, that is apparent to the casual observer, who is not an expert.

There is no doubt many ideas have been conceived from time to time, and some of them put in limited operation, wherein the present types have been anticipated; and in the order of the production of many of the present radiators I may not be quite clear, as they are all the production of the last few years, with a few exceptions, and therefore if the order in which they are mentioned or shown here is not the order in which they were first introduced to the public, the individuals who had the honor of producing them will know that it was through a lack of data on the subject that they are not so presented.

Quite early in the history of vertical tube wrought-iron radiators Messrs. Bartlett, Hayward & Co., of Baltimore, made the hot-water radiator shown in Fig. 139.

The "top" or entablature is a hollow cast-iron casing into which wrought-iron tubes are screwed, the same as into the base of a steam radiator. The free ends of these pipes, however, are left open, and are passed through corresponding holes

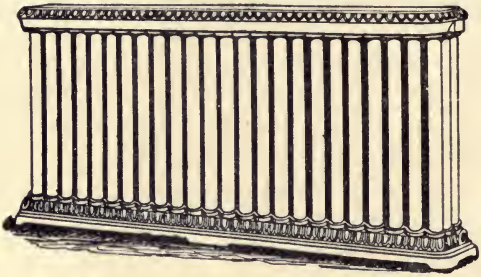


FIG. 139.

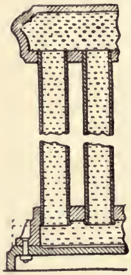


FIG. 140.

in the upper side of a radiator base and there expanded, somewhat like a boiler tube. The bottom of this base is then attached with screws and a joint made on a copper or other suitable gasket; and the detail, Fig. 140, shows this construction plainly.

Water can be admitted to the base at one end and passed out at the other; and so long as the air is drawn from the radiator at its uppermost point, so as to allow it to fill properly with water, it is found that the temperature at any point varies so little that it is not necessary to supply it at the top; an idea that was prevalent some few years ago.

To the A. A Griffing Iron Co., I believe belongs the credit of joining cast-iron loops of the Bundy pattern with a hollow top casting, and making the first cast-iron modern loop hot-water radiator. Had he considered the matter solely in the light of previous workshop practice, he would perhaps not have undertaken it, as such a method of joining loops for steam purposes had always proved a failure, on account of the difficulty of keeping the joints tight, through the trouble from differential expansion of the pipes due to sudden differences of temperature when letting on steam.

They, however, found that for hot-water work the changes of temperature were not sufficiently sudden to strain the metals beyond their elastic limits; and this is so clearly defined now that all makers join their hot-water loops with rigid connections at the upper end as well as at the lower end.

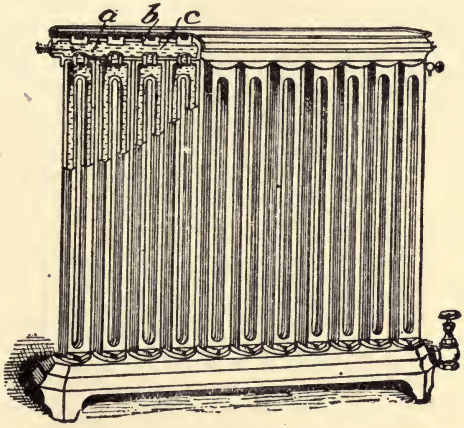


FIG. 141.

Fig. 141 clearly shows the construction of the "Bundy" hot-water radiator. The loops are screwed into the base the same as in the steam radiator. The cap, or top, *a*, however, is cast hollow, with a series of tapped openings, *b* and *c*, through it. The upper opening, *b*, is sufficiently large to permit the passage of short brass nipples that are shown joining the head of the loops with the holes, *c c*. The holes, *c c*, and the holes in the heads of the loops are tapped at one operation of the tap, so they coincide in taper and thread register. The short threaded taper tube or nipple, which is made of brass with a square hole in it for the wrench, is then forced into the hole, *c*, and into the head of the loop; when the hole, *b*, is plugged with a hollow plug, after which an entablature of fretwork is put over the whole to cover the plugs and give an ornamental finish.

Fig. 142 shows the radiator as it was first constructed, with a partition at *a*. It was first thought necessary to introduce this barrier to the current of the water, so as to turn it into the head of the radiator and prevent its passing through the radiator from inlet to outlet.

This was to carry out the old idea that a continuous current was necessary for circulation. It was soon discovered, however, that the circulation was better when the division *a* was broken through. The resistance to the passage of the water, caused by forcing it upwards through the end tubes of the

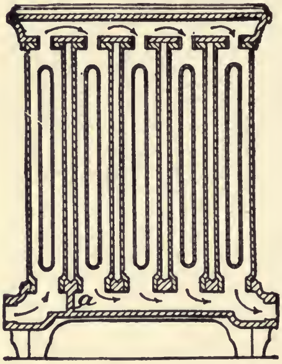


Fig. 142.

radiator and their nipples, as seen in Fig. 142 by the arrows, before it could get over into the remaining tubes, was so great that to get relief for the circulation the workmen punched out the division, *a*, and the improvement was manifest. The hand when passed over the tubes then indicated that the water being allowed to take its own easy course, according to its weight, flowed upwards through the first two or three tubes (or sets of tubes when the radiator was more than one tube wide) and passed along in the cap, circulating downwards in the remaining tubes. At present they are made without the partition and the water diffuses according to its temperature; the colder particles falling to the base and passing out by the return-pipe.

The second prominent cast-iron vertical loop radiator for hot water to appear was the "Union Radiator," the invention of John R. Reed, shown in Fig. 143, and made by the H. B. Smith Company, of Westfield, Mass.

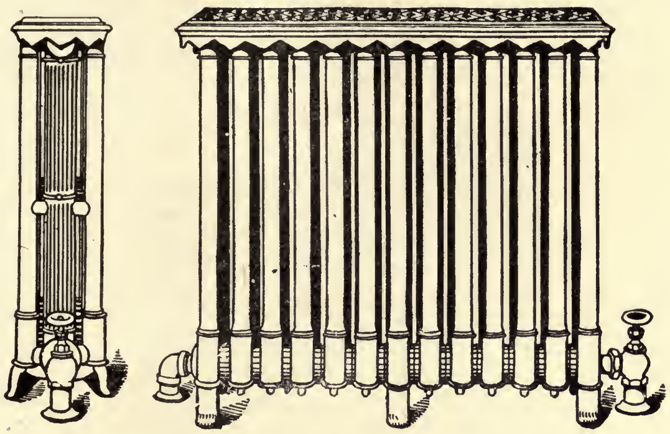


FIG. 143.

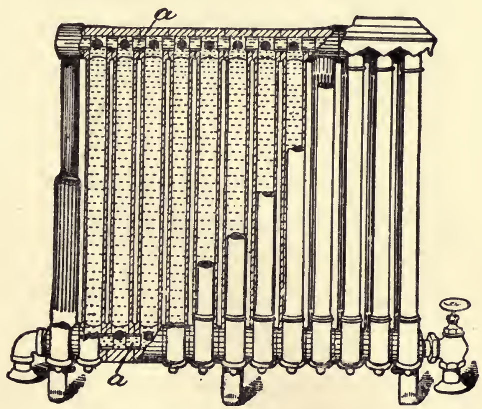


FIG. 144.

This radiator is made up of three-column sections as shown to the left of Fig. 143. The sections are joined to each other at the top and bottom by taper nipples of soft iron, and they are pressed together by special machinery.

Fig. 144 shows the radiator broken away so as to present a section through the centre columns, showing the nipples, *a a*. The holes in the sections which receive the nipples are reamed with a special machine so as to secure uniformity of diameter and taper, and also a fixed distance between the centres of the holes. If the holes are not absolutely true it matters not with the soft iron nipples as they take a permanent though somewhat elastic set to accommodate themselves to slight inequalities. This method of connecting was also a new de-

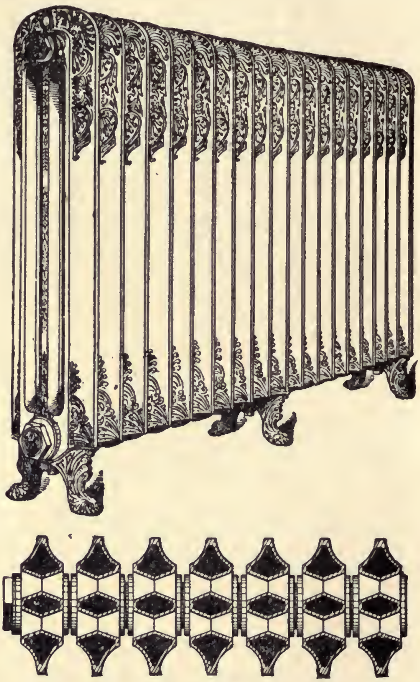


FIG. 145.

parture from old ideas that were based on steam practice. Constant use has demonstrated its practicability and overcome the prejudice to it for hot-water work.

Short rods are used top and bottom, in such a manner as to be unobserved, their purpose being to prevent a disturbance in the joints when handling. In short radiators they are run from end to end, but in long ones they "break joints;" so the difference of expansion between the warm cast-iron and the comparatively cold wrought-iron rods is inconsiderable and not sufficient to overcome the elasticity of the metals.

In general appearance they resemble steam radiators, and in some cases I believe they are used in combination apparatus for both purposes. They have the advantage of having no base, and an open fretwork entablature is set over the top to give an appropriate finish.

Fig. 145 and 146 show respectively the "Bundy Elite" and the "Triumph" radiators, made by the A. A. Griffing Iron Company.

The "Triumph" is comparatively an old pattern as designed for steam. As hot-water radiators, with upper connec-

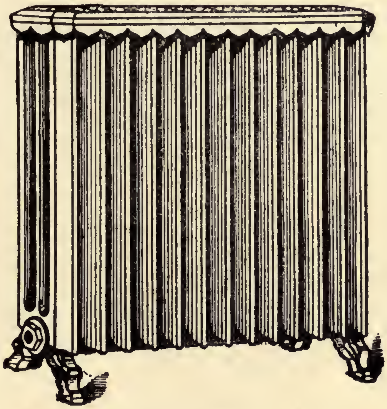


FIG. 146.

tions, they are both, however, recent productions. The "Triumph" is plain, with cast-iron fretwork cap, and resembles the "Union" radiator in all but design and the manner of joining the sections. The "Bundy Elite" is ornamented in relief, and belongs to the more recent class of hot-water radiators, being without base or entablature.

In these radiators the lower connection is made by screwing the sections of the radiator round and round on 2-inch taper nipples, allowing them to become tight on the taper of the threads just before the faces come together. The upper joints are made with special vulcanized fibrous packings, pressed together by a long bolt through the water-space and finished at the outer ends with ornamental nuts. The method of joining the "Triumph." is the same as that used in the "Elite."

In the radiators of the class of the "Union," "Triumph," and "Elite," in which there are three columns to a section, the course of the circulation is supposed to be upwards through the centre passage, and downwards in the outer columns. This would be the natural course for the water to take, and in cases where the writer had an opportunity to test the matter, this is the course the water took; and at the sections near the inlet its course was well defined just after turning the hot water into the radiator.

Fig. 147 shows the "Eclipse" hot-water radiator. It is

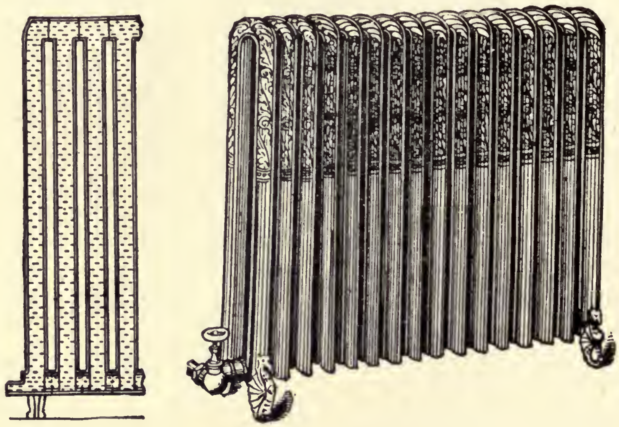


FIG. 147.

made of cast iron and is without base or entablature. The sections or loops have two columns, but in other respects it resembles the last class of radiators. The method of joining the sections is the same, the lower ends being joined with 2-inch threaded nipples. and at the top with faced joints held together with bolts.

Fig. 148 shows the "Ideal" hot-water radiator made by the American Radiator Co. of America.

In almost every respect, except ornamentation and the method of connecting the sections, it is the same as the last radiator (Fig. 147). It differs, however, from all others of its class in the manner of making the joints between the sections.

A special 2-inch right and left handed malleable iron nipple is used both at top and bottom of sections. In the use of a right and left nipple there is nothing new, but in this case the novelty consists in disguising the fact of there being nipples between the sections by making them appear as part of the general design, and not materially increasing the distance between the centres of the sections.

Ordinarily a nipple requires sufficient length between the threads to allow of its being grasped with a wrench or tongs. In this case the threads on opposite ends of the nipples come within one-quarter of an inch of each other, and a flange pro-

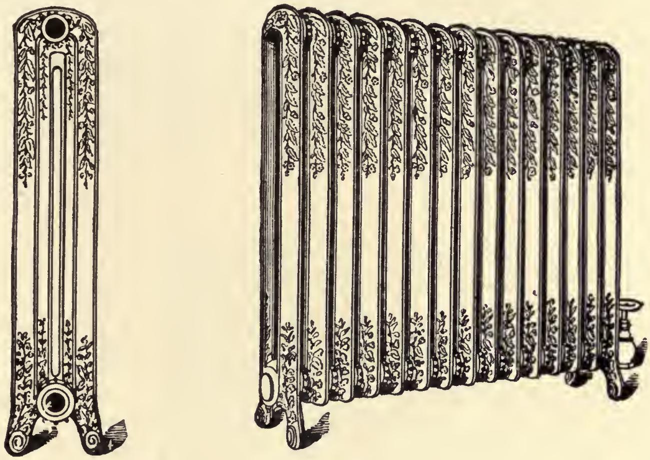


FIG. 148.

jects and overhangs the threads, as shown in Fig. 149. On the left, three sections are shown, two of which are cut away, top and bottom, to show the right and left nipples, *a a*. One element or section is shown complete to give an idea of the appearance of the nipples when the radiator is finished. A special wrench is used to screw the nipples into place and the sections are drawn together parallel.

The radiator shown in Fig. 150 is called the "Perfection," and is made by the American Radiator Co. It is of the same class as the two foregoing, its only material difference being in the manner of joining the sections. Right and left-handed nipples are used without shoulders, and the method of screwing them together is with a special tool from the inside through openings left in the last section that is added to the radiator. The final openings at the top are then plugged and the lower ones are used for the inlet and outlet pipes.

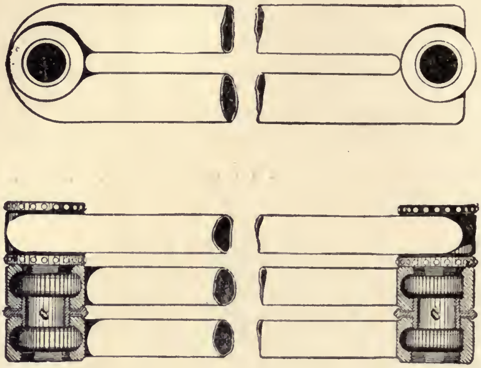


FIG. 149.

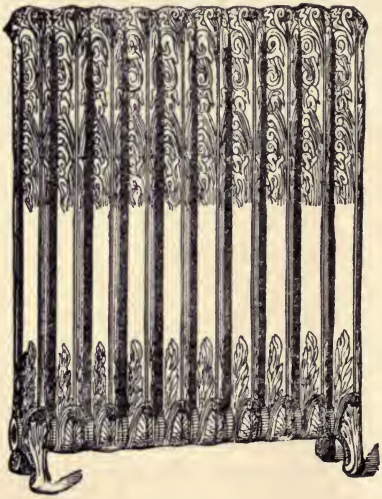


FIG. 150.

Fig. 151 shows the "Whittier" extended-surface cast-iron radiator. It is made by the H. B. Smith Company, and is much used in the Eastern States for either steam or hot-water. It is a comparatively old radiator, being patented in 1868.

It is what is known as a positive radiator—that is, the circulation is continuous; the same as in a coil, which is fully shown by the arrows in Fig. 152. It is usually three sections high, as shown in cut, and one section is joined to another with a $2\frac{1}{2}$ screwed nipple, as seen at *a a*, Fig. 151. The opposite points at *b b* are keyed together by a double dovetailed key, as shown at *b′*.

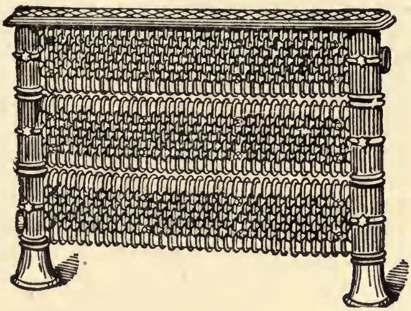


FIG. 151.

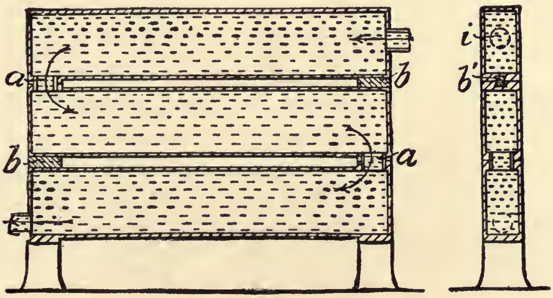


FIG. 152.

These radiators have a low resistance, and will circulate until the water falls below the inlet *i*.

Fig. 153 shows a horizontal hot-water radiator made by Messrs. Bartlett, Hayward & Co. It is made of wrought-iron pipes, screwed into a hollow casting, with return bends on the opposite end of each pair of pipes. Over the bends is placed a hollow casting of the same general appearance as the opposite one.

Fig. 154 shows the detail of the construction of this radiator. The water enters the upper pipe and returns by the lower one, diffusing within the loops by presumably entering the upper pipe and returning by the lower one.

In a general way the radiators from Figs. 141 to 150 inclusive, belong to the same class. Both upper and lower connections form a water-way. The upper connection also forms a

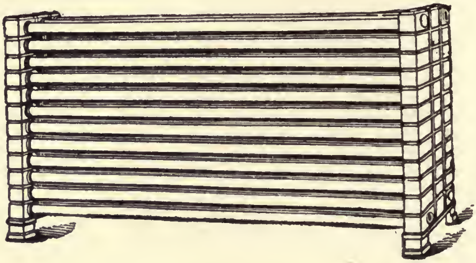


Fig. 153.

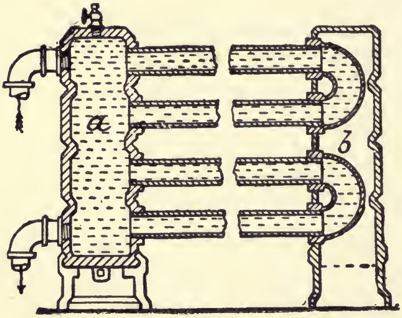


Fig. 154.

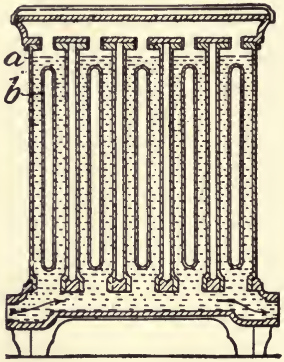


Fig. 155.

passage for the egress of the air to a single point, which is a necessity of all hot-water radiators.

The general idea prevailed not long since that hot-water radiators should be supplied at the upper connection, so the flow of the water would be downwards from this point, Now, however, it is known to be unnecessary, as the water will rise to the head as rapidly within the first few tubes of the radiator as it will in an outside connection. It has also been found that when the air has been neglected and not drawn off regularly in this class of radiators that a circulation will go on from inlet to outlet, and that the efficiency of the heater is not entirely destroyed.

The writer has found that as long as the water remains above the level, *a*, Fig. 155, a circulation will go on by passing up on one side of the loop and down on the other, some little condition favoring one side; while the main circulation passes through the base.

I also found that through months of neglect to draw the air from the head of the radiator the water fell below the top of the loop to a position about at *b*, Fig. 155. Even then the water in the sides of the loops did not become cold, but that a circulation or diffusion went on in each side of loop sufficient to keep the water to all appearances about as hot as in the base.

This applies to all this class of radiators, and though their efficiency must be impaired when they are so neglected, it is still a point in their favor over coil radiators, which latter will stop circulating the moment the air collects to any considerable degree in the upper header or pipes.

The internal resistance to the flow of the water through radiators with a base is small, and I have therefore not considered it necessary to take it into account in designing the mains of an apparatus. In the radiators whose water-way at the bottom is small, however, the resistance may become great, and therefore in all radiators joined with nipples their diameters should be as great as possible, especially in long radiators.

CHAPTER XXIII.

NOTES ON RUNNING MAIN PIPES.

Air Traps in Pipes—Their Effect on the Flow of the Water—Top Connections from Main Flow Pipes—Bottom and Side Connections from Flow Pipes—System of Piping for High Buildings—Valves on Radiators—Main Circuits of Uniform Diameter Throughout.

The most important thing in relation to running the pipes of an apparatus is to guard against the lodgment of air within them at points that may be called " air-traps."

When running pipes for steam, " water traps " are to be avoided, and by a water-trap is meant a sag or downward deflection of the pipe from its perfect alignment.

Air-traps are upward deflections of the flow or return-pipes of a hot-water apparatus from their perfect alignment, and they may be classed under the heads of accidental and necessary.

In a horizontal pipe, or one that is nearly horizontal, such as go to make up the mains of an apparatus, but with pitch sufficient in some directions to carry the air to some particular point of egress, the pipes should always be straight and perfect in alignment when viewed from the side. This is absolutely necessary, as the least irregularity or bend of sufficient magnitude to hold air will impair the circulation in a measure far beyond what any one is likely to suppose who has not had practical experience in the matter.

Let *a b*, Fig. 156, represent the level line of a floor, and *c d* a flow or return pipe hung thereto, with considerable downward pitch in the direction of the arrow. Should this pipe have a bend or trap in it at *e* equal to the diameter of the pipe as shown, it will entirely stop the circulation, either by preventing it at the commencement, by not being able to expel the air, or by the air accumulating thereat in a short time, even if it has been expelled, although the end of the pipe *c* is higher than the top of the trap *e*.

Should the bend of trap *e* be only half the diameter of the pipe as shown in Fig. 157, then just half the pipe will be shut off with air as effectually as though we closed it with a valve, and consequently only half the water will pass at this point that the diameter of the pipe would warrant, and therefore only half the work will be done and the temperature of the water in the radiators cooled or lowered twice as many degrees as it would if the pipe was straight.

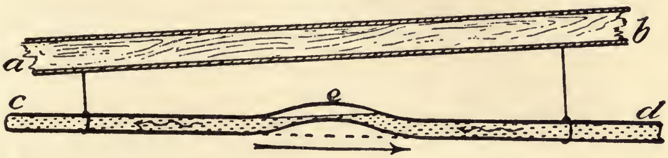


FIG. 156.

Many imagine the pressure should expel this air, but this is erroneous as it has no more possibility of doing so than pressure has of expelling the air from an air chamber on the side of a pipe as shown in Fig. 158. It will compress the air somewhat, but the air that is liberated from the water being under the same pressure, passes into the trap or chamber by difference of gravity and remains there, displacing an equal bulk of water.

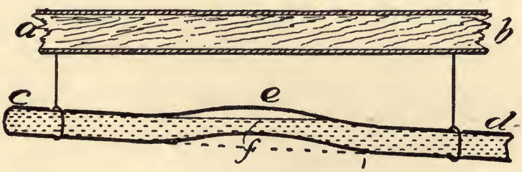


FIG. 157.

With an open ended pipe the passage of the water under considerable head would push the air before it, but in the circuits of an apparatus this cannot follow.

When going upwards within buildings with lines of rising pipe every line or radiator helps to take air from the boiler or mains, and consequently air-vents must be used on the heads of the lines or on the radiators where they will do the most good, so that for ordinary pipe work for direct radiation it is hardly necessary to more than advise the fitter to run straight pipes and pitch them so the air will be safely carried to the point of exit. Therefore, it is probably nearly always proper to take the rising lines and radiator connections from the top of the main as shown in Fig. 159.

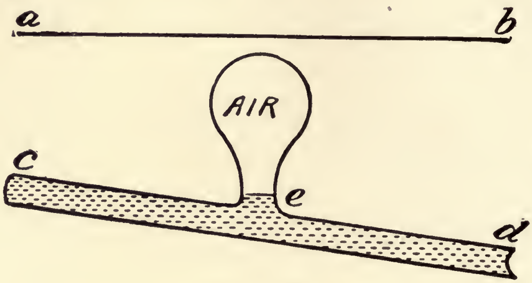


FIG. 158.

It is a good plan to use the top outlet, *a*, of the *tee* one size larger than the pipe, *b*, so as to have a reducing elbow at *c*. It favors the water entering the rising-line or connection as it assists the change of direction of the proportion of water that should pass into the branch, by lessening the obstruction presented to it by the ends of the pipes, etc.

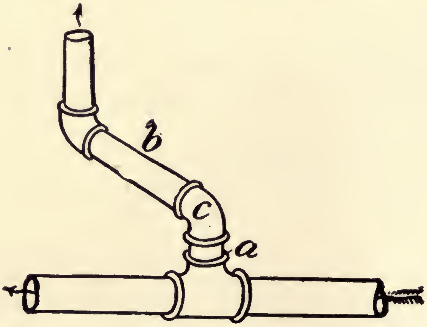


FIG. 159.

There is no particular objection to a side connection, except that under such condition the air must be carried further along the main, or that the convenience of a swinging joint is not obtained.

Care must be taken in making connections for indirect radiators, however. The indirect radiators are usually in places that are inconvenient to enter to attend to air-cocks, and the penalty of the neglect of so doing is apt to be the freezing of the coils or radiators, not to take into consideration the interruption to the supply of warm air.

If a line of main pipe is near the ceiling, then the coils are apt to be below the main, in which case of course the air from the main cannot find egress through the coils, no matter how they are piped, and the connection shown by the dotted lines (Fig. 160) must be strictly avoided, and either a bottom connection, as shown, or a side connection used, with the upward pitch from the coils towards the main as shown by the straight arrows, the waved arrows showing the direction of the flow of the water.

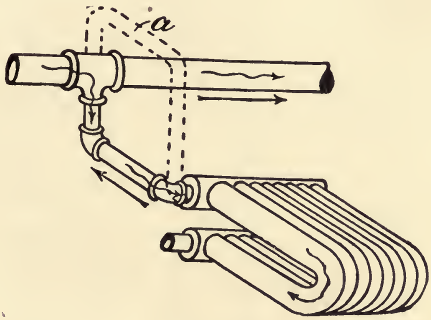


FIG. 160.

If indirect radiators are higher than the main flow pipe, it makes an exceedingly unfortunate arrangement, as in such a case the air will go to the indirect radiators or coils, and there is nothing to be done except careful attention to the operation of hand vents at the coils, or the use of reliable automatic air-vents.

When the air is carried to the end of a flow main, as it properly should in the case of indirect work—unless it is let escape into rising lines—the highest end of the main should have a chamber on it for the collection of the air, and on this chamber an air-vent should be placed; or if desirable and practicable a small open pipe may be run upwards in the building until it is above the top of the expansion tank.

For direct radiation at the present time the flow mains are usually run through the basements or cellars.

When direct and indirect radiation are combined it is almost necessary that they should be so run as to reach the indirect work without showing pipes in the rooms above the basements.

For indirect radiation alone, however, the flow-pipes may be carried to the top of the house and run in the attic, or at the ceiling of the upper story, and for high buildings this system

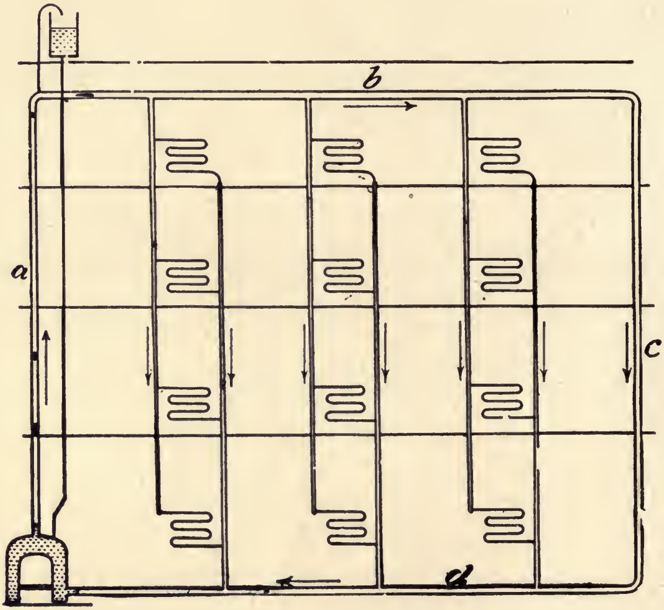


FIG. 161.

appears to have decided advantages over the basement or cellar system.

Fig. 161 shows the scheme of pipes involved in such an apparatus.

The air is relieved at the highest point through an open pipe which bends over the edges of the tank, and beyond this the fall of every piece of pipe and its direction is with the downward flow of the water; so that the darts and arrows show not only the downward pitch of the pipes, but the direction of the flow of the water, in all except the main rising pipe *a*.

The circuit formed by the main pipes, *a*, *b*, *c* and *d*, would be best if of a uniform diameter and proportioned to pass nearly as much water through it—when all the radiators are closed—as is required for all the radiators when they are in use.

If this circulation is maintained, it accomplishes two things: (1) it provides a relief to the boiler when many of the radiators are closed. as they must be expected to be in office buildings; and (2) it always maintains a hot-water supply ever ready to flow into the risers and radiators when the latter are turned on. In fact, with this circulation going on, the conditions are almost as good as though the water for a single rising line was drawn direct from the head of the boiler.

With apparatus as they are ordinarily constructed, with mains in the cellar and rising lines starting therefrom, there is no circulation unless through the rising lines and radiators; and should only a single radiator on a line be opened, there would probably not be sufficient water pass through the circuit and the line to make the heater of any practical value; as the quantity might be too small to counteract the cooling effect of the surface of the riser and circuit.

This brings us to the question of the advisability of using valves in all cases on hot-water radiators.

In small apparatus in private houses under one management valves may be either used or omitted with perfect safety. If they are used the owner soon finds it is much easier to control the heat of the house by attending to the fire than by using the valves on the radiators, and consequently the valves, as a general thing, are always wide open, unless in the case of some particular room where heat is not required, or where a modified temperature is desired, where they can be choked down until the circulation is reduced to the desired quantity, or until it is entirely cut off.

In office buildings, where there are persons of different temperaments who have no control of the firing, valves must be used to allow each person to adjust the heat to his own liking. It is in cases of this kind that main circuits, independent of the radiators, are most required. They give vent to the main circulation of the apparatus and maintain heat at distant points, although the greater part of the radiators may be closed.

A small hole through the disk of every valve can also be provided, and consequently a feeble circulation maintained at all times through every radiator, which will accomplish about the same purpose; and in fact, it is good practice to do this in all cases, as it prevents trouble at the boiler and lets the air pass forward at all times, when it is disengaged in quantities.

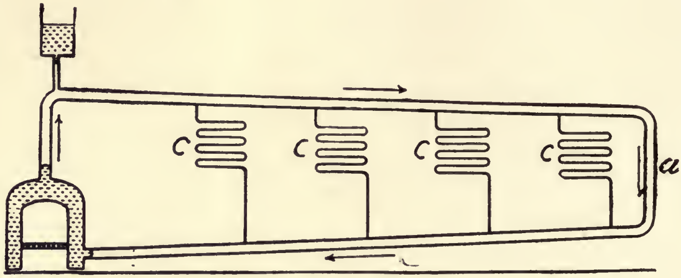


FIG. 162.

In the case of the flow-pipe being in the cellar, and consequently when it is below the radiators, there is some question as to whether these main circulating pipes are practicable. They are practical and proper in indirect work, where the main is above the coil and the return below, as seen in Fig. 162 at *a*;

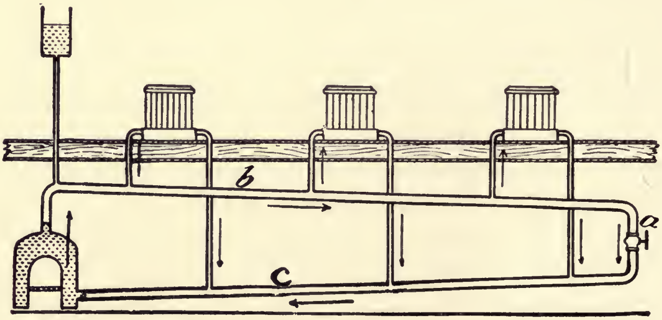


FIG. 163.

In the case shown in Fig. 163 the connection between the flow and return main is usually advantageous, although in an exceptional case it may cause the circulation to start through a radiator in the wrong direction. It is probably well, therefore, to use a gate valve at *a*. If the return main is carried near the ceiling of the basement instead of at the floor (Fig. 163), and if a connection is made between the flow and return main, it is always desirable to place a gate valve at *a*. For if there is no gate valve, it is possible at times for the temperatuie of the watei in the flow and return main to nearly equalize. The head that will cause the flow through first floor radiators will then, practically, be due only to the height of the radiator above the main instead of to the height of the radiator above the boiler.

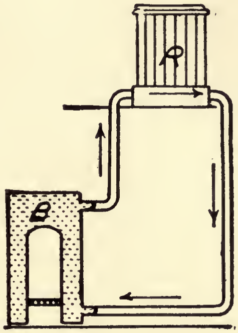


Fig. 164.

When we make a large diameter main circuit with the return main near the basement floor, taking flow from the upper pipe and returning to the lower one, our radiators are in almost the same relation to the boiler they would be in if we took a single flow pipe from its top and returned to near its bottom, as in Fig. 164. Therefore the more rapidly the circulation goes on through the flow and return mains, the hotter the water will reach the radiators.

CHAPTER XXIV.

EXPANSION TANKS.

Expansion Tanks—Open Tanks—Closed Tanks—The Danger of Closed Tanks—Safety Valves on Closed Tanks—Table of Size of Tanks to be Used with Apparatus—Diagram Showing the Expansion ot Water—Table of the Temperatures and Pressures of Steam and Water—Diagram of Temperatures and Pressures of Water.

The question of the position of an expansion tank on an apparatus is one of importance, and requires to be considered in its different aspects.

The ease with which sketches and diagrams are now reproduced by photo-engraving and other inexpensive processes puts it within the power of a writer to appeal to his readers—especially the purely practical ones—in a manner that is eminently more comprehensive than pages of description. It places him in almost the same relation to the reader as a lecturer or teacher occupies who makes use of the chalk and blackboard, a few crude lines often conveying more information to the observer by way of the eye than pages of type or hours of description, which require an extra mental effort to form the picture in the mind's eye.

I will therefore introduce diagrams of the ordinary methods of using tanks, as they occur to me, and refer to them briefly, pointing out their good points and their objectionable ones, and explaining why compromises must frequently be made in the selection of their positions, and how they are attached, etc.

The commonest position for the expansion tank is at the highest point of the flow pipe, as in Fig. 165.

This method is often seen in greenhouses, and is probably the most simple and effective when a single boiler is used with temperature less than 212 degrees.

The air can fly to the tank and escape from the water, and if all the pipes that lead away from the tank, to supply or form the heating surface, begin to fall from this point, no air can lodge within them, and should steam form either by strong firing or the closing of the circuits or radiator valves, no other damage can follow than the escape of the steam from the top of the tank, which in all probability would be discovered before sufficient water could be evaporated from the apparatus to permit of the burning or other injury to the boiler.

To prevent damage within the house by the escaping vapor, an escape pipe, *a*, can be run from the upper part of the tank to the outside of the house, or where overflow pipes are used the pressure or vapor can escape through them.

By this method the temperature of the water can never go above 212° fahr., except that just within the boiler it may

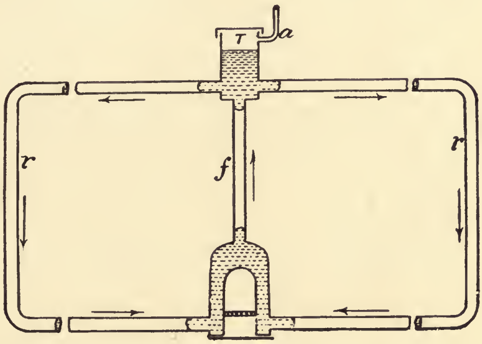


FIG. 165.

slightly advance beyond this point on account of the head of water that is above it in many cases, but as this hot water rushes upwards in the flow-pipe and the pressure becomes less, some of it bursts into steam and is lost by escaping at the tank, unless it becomes sufficiently cooled in its passage through the pipe so as to be below 212° fahr. when it reaches the tank.

To utilize this heat, or rather as it may appear to some to be cooling the steam within the water, and to allow them to carry somewhat higher temperatures, the tank is sometimes placed at the further end of the coils or circuits, which must then be the highest part of the apparatus, so that the water, though warmed above 212 degrees at the boiler, may be so far cooled by passing through the pipes that it will not give off steam when it reaches the tank.

Fig. 166 shows how this is usually accomplished. The excess of heat above 212 degrees is given off through the sides of the pipe, *f*, before the water reaches the tank, *T*; therefore no steam is liberated and the water returns through the pipe, *r*, to the boiler.

For equal perpendicular heights the apparatus shown in Fig. 165 will circulate more rapidly than the one shown in Fig. 166, other things being the same, as with the tank placed so far from the boiler the cooling done by the pipe, *f*, makes the rising column so dense there is but a small preponderance of density or power in favor of the pipe, *r*. Whereas in Fig. 165 the water reaches the tank without cooling perceptibly and all but a small part of the cooling is done in the pipes, *r r*, so that the difference of density between the rising and falling columns is at a maximum instead of at the minimum, as in Fig. 166.

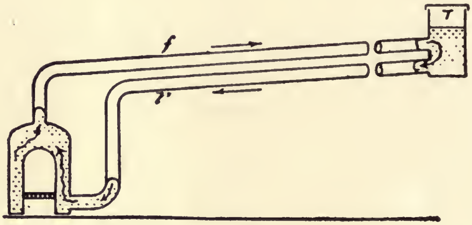


Fig. 166.

Therefore, to gain a little in the question of the temperature of the heating surface, much is lost in motive power, and larger pipe would have to be used to have an equal quantity of water pass around the circuit in the same time, so that from a purely philosophical point of view, the tank, as in Fig. 165, is in a better position than in Fig. 166.

The third position for the tank is to place it on the boiler as shown in Fig. 167. In this case the tank simply takes care of the expansion of the water and does not assist the drawing away of the air from anything but the boiler. Consequently an air vent must be put at the highest part of the pipes as at *a*. I do not consider this as good a position as that shown in the Fig. 165. The objections to it are: If the steam is formed in quantities sufficient to make a pressure at *a*, an amount of water will be forced out of the boiler through the pipe, *b*, and the tank and all the water in the apparatus may be forced out and down to the level of the line, *c*, at the head of the boiler if the fires are very strong, the steam taking the place of the water. The tank in this position, however, acts as a safety-valve, but it would be equally advantageous as such if it con-

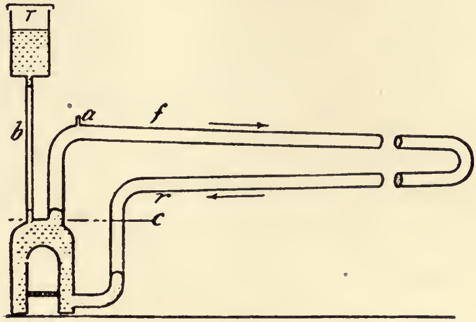


FIG. 167.

nected with the pipe at *a* instead of with the boiler; in which position the tank will also take care of the air—provided no valve is used in the main pipe between it and the boiler.

The fourth position is, as shown in Fig. 168, with the tank pipe, *b*, attached to the bottom of the boiler.

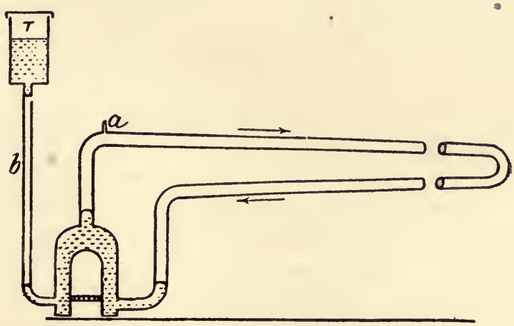


FIG. 168.

When in this position an air vent is also required at *a* for the purpose of taking care of the air which enters the main, but with the tank as shown in Fig. 168 it becomes possible to drive every drop of the water out of the boiler, if steam is formed in sufficient quantity.

Of course, when a tank pipe joins a return pipe it is subject to the same objections as when it joins the lower part of the boiler, and the foregoing remarks apply to it.

The tank question is complicated when more than one boiler is used if either of the boilers can be shut off from the apparatus by valves.

There are two sufficient reasons why more than one boiler is used in an apparatus. The *first* is, when one boiler has not sufficient capacity for the whole apparatus, and consequently one or more must be used, in which case there is no great necessity for stop valves between the boilers and it is probably better to omit them. The *second* is, when it is desirable to have a spare or extra boiler for emergencies, in which case, of course, it is necessary to shut it off from the apparatus when not in use, and valves must then be used.

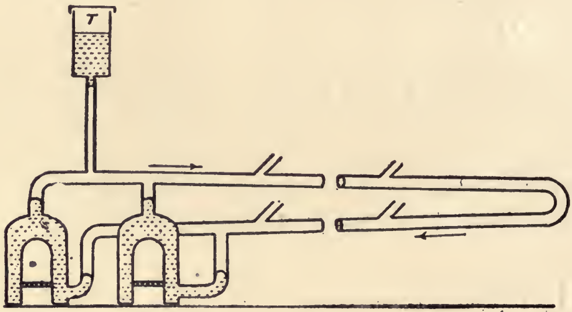


FIG. 169.

In the first of these cases of which a simple illustration is shown in Fig. 169, the tank is best at the highest point, as in Fig. 165. It acts as an air valve and an escape for pressure and steam, as the latter can go very little above 212° fahr., without giving trouble with an open tank.

All that has been said of tanks in connection with a single boiler applies also to two boilers connected without valves (as in Fig. 169) and therefore requires no further illustrations; but should valves be introduced into Fig. 169, as shown in Fig. 170, at *V V V V*, it then requires only a little forgetfulness on the part of the operator to cause the destruction of a boiler.

Should the boiler, *B*, be cut out of the circuit by having both valves closed, then the water will be shut up within it, and should a fire be accidentally or otherwise started within it, it would be ruptured by the expansion of the water, and, of course, destroyed. If it were only partly filled with water and the valves tightly closed, then steam would be formed and as disastrous an explosion from over pressure would follow as with a steam boiler, as it is analogous to one without a safety valve.

Of course, if the object of having more than one boiler is simply to proportion the boiler surface and grate to the requirements of the weather, then a single valve may be introduced into either the flow or the return pipe, as shown in Fig. 171, but never into both, when the tank may be placed as shown in Fig. 169, as the expansion of the water can then find its way into the pipes of the apparatus through the pipe and is without

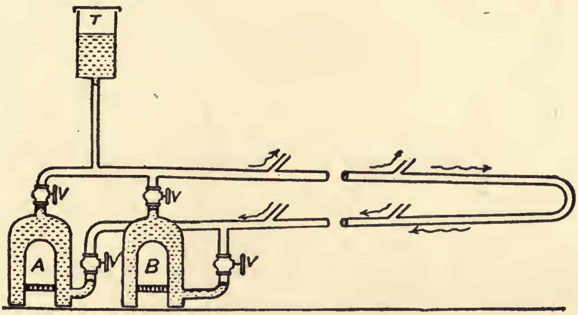


FIG. 170.

a valve, and the most that could follow through a blunder of management would be of little inconvenience, and perhaps the interruption of the apparatus for a short time.

The question sometimes arises as to whether it is better to put a single valve of this kind into the flow or the return pipe. I favor the return pipe, as by that means only the increment of the expansion of the water can then be forced from the boiler; whereas if the valve is in the upper pipe the boiler may be forced empty simply by the formation of steam.

Valves are sometimes used with a hole bored through the disk to prevent the bursting of the boiler; in which case an upper and lower valve may be used, the upper one having the hole. This stops the circulation into the boiler, but it does not admit of cleaning or repairing without tight valves.

The question now arises as to how tanks should be applied in two or more boilers with tight valves, as in the State, War and Navy Department building, elsewhere referred to, and others.

Boilers may be piped as shown in Fig. 172 with tight stop valves, so that a single tank takes away the air and takes care of the increment of expansion, in which case the boilers are connected to a single tank by pipes, *a* and *a*, at the highest points of the mains, the valve in the main being beyond the junction. By this arrangement the boiler that is not in use is not affected, and any change of temperature allows the water to pass either in or out of the boiler through the pipe, *a*. Should it be necessary to shut off a boiler absolutely then valves must be used

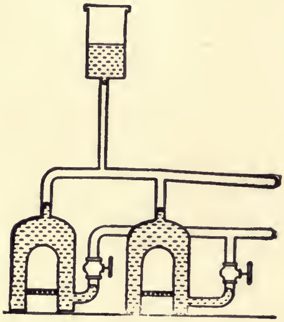


Fig. 171.

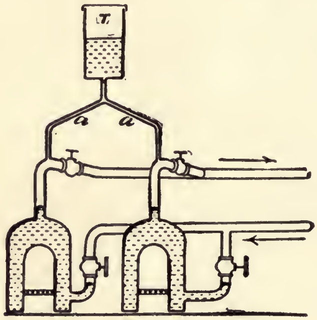


Fig. 172

on the pipes, *a a*, and trouble may follow by neglecting them; so that it would be better not to use the valves, but to have a means of disconnecting the pipes, *a a*, from the boiler that is not in use.

A tank to each boiler, however, as in Fig. 173, is the only positively safe manner for the inexperienced ordinary user, if valves must be used in the flow pipes.

Of course when there is more than one boiler with valves on both pipes, as in Figs. 172 and 173, then tanks cannot or should not be used, on the pipes of the apparatus at the further ends of the lines or at any point outside the valves.

I presume I have said sufficient on this subject so that any intelligent man can form other combinations and consider their respective operations.

The prime use of a tank is to provide for the expansion of the water; its secondary use is to take away the air from the apparatus and to let off steam when it is formed. The air, however, may be taken away by air-vents in any suitable position, and in any kind of an extensive apparatus—not greenhouse work—it would be almost impossible to take care of all the air by the use of the tank.

There is one method, however, of using the tank whereby the air may be taken from the heads of the rising lines or from the principal divisions of a house, and where box-coils are used for radiators, or any form of radiators used wherein the water enters at the uppermost point, provided all the pipes of the division have an upward inclination to one point it can be

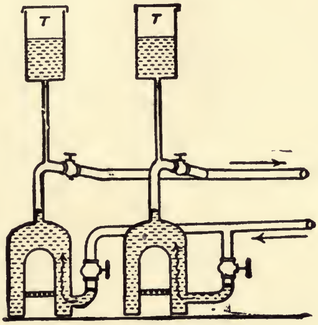


Fig. 173.

used to good advantage, and will prevent the trouble of attending to the air-vents. The principle is shown in Fig. 174 and it simply consists of small-vent pipes, *a a a a*, or a system of them, rising from the heads of the lines or the highest point of the divisions to above the level of the tank. It is a good and safe method also to carry the end of this pipe over the tank so that a rush of confined air or steam will not discharge the water where it can become a nuisance or where it will be lost to the apparatus.

Pipes run in this manner should not have too small a diameter as the resistance to the bubbles of air is considerable, and therefore ½-inch pipe is probably as small as should be used unless to make a very short connection.

The pipes should also be carefully run so the alignment and pitch of the pipe will be upwards towards the tank. A slight trap of one-half the diameter of the pipe will make the whole abortive, and very little horizontal pipe should be used if possible, but if it is unavoidable, the diameter should be increased. If a pipe must be used in a nearly horizontal position, give it all the pitch possible, and see that its alignment is straight, etc. Fig. 175 shows the method of using the tank in the U. S. Barracks, David's Island, New York Harbor, erected under the direction of Capt. George H. Cook, U. S. A.

The pipe, *a*, starts from the highest part of the flow-pipe

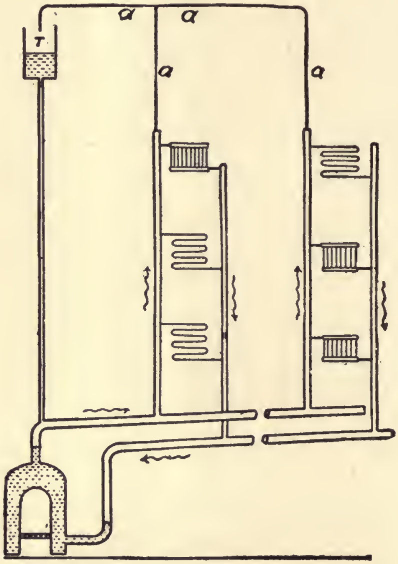


FIG. 174.

inside the valves, so the closing of the latter will not affect the contraction or expansion of the water in the boiler, or the rise or fall of the water within the tank, or cut off the water supply. At the same time the pipes, *b* and *b*, act both as expansion and air pipes from the main circuits.

Should the pipe, *a*, Fig. 175, be extended past the flow pipe to join the return-pipe, *R*, instead of the flow-pipe, *F*, the closing of both set of valves might prove disastrous should a fire be burning, as the water would be thrown out of the boiler through the tank should steam form; as it is shown, it cannot.

Capacity of Expansion-Tanks.

In proportioning an expansion-tank for an apparatus it must be borne in mind that its capacity between its cold-water level line, and its overflow-pipe level must be something in excess of the increment of expansion due to all the water in the apparatus.

For instance, in Fig. 176, the cold-water level line is at *a*, the point at which the apparatus must be filled to before the fire is started. At this point, of course, a ball-cock should be placed when one is used. The line, *b*, is the level of the overflow-pipe at which an apparatus overflows through the failure of the ball-cock to close, or through the undue expansion of the water or the accidental omission to close the feed-water valve when the apparatus is full, should one be used.

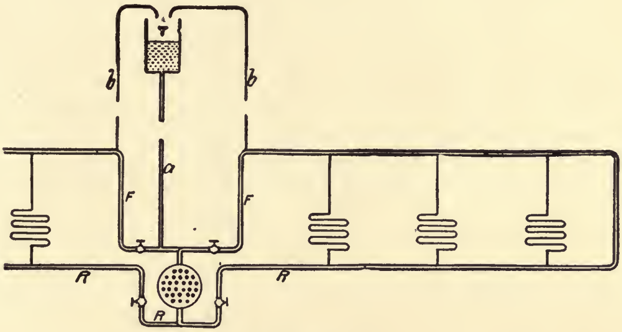


Fig. 175.

This range between *a* and *b* requires to be not only sufficient to provide for the increment of expansion, but also to allow some factor for safety beyond this point, say not less than 10 per cent. of the calculated expansion.

In an apparatus that is open to the atmosphere and run at temperatures not exceeding 212° fahr., it is usual to provide a tank that has a capacity between the points, *a* and *b*, equal to $\frac{1}{20}$ the whole capacity of the apparatus. This provides for the expansion of the water from maximum density (40. —) to 212° fahr., and is found thus: Cold water to fill the apparatus = say 100 gallons, or any other suitable quantity. Volume of water at 40° fahr. = 1. Volume of the same weight of water at 212° = 1.043, the increase being 4.3 per cent., or just under $\frac{1}{23}$ of the original bulk. The proportion, therefore, of $\frac{1}{20}$, the capacity of the apparatus, forms an ample tank for the ordinary conditions of house warming.

Referring to Fig. 176, it is proper to say here that it is better that all pipes which run between boilers and tanks, such as the pipe, *e*, should be branched near the tank, so the direct branch, *d*, passes over the top of the tank and the branch, *c*, enters its bottom. This allows the air, vapor or steam to rise and go over into the tank without agitating or lifting the water in the tank, as it would if obliged to pass through the pipe, *c*, causing a waste through the overflow, or throwing the water out of the tank.

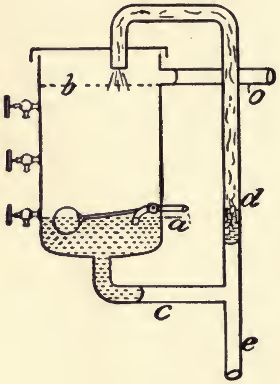


FIG. 176.

TANK FOR HIGH PRESSURES.

With high-pressure apparatus, however, more ample tanks must be provided, or disaster will follow. When proportioning a tank for a high pressure apparatus, it must be remembered there must not only be the spare room necessary to hold the increment of the expansion of the water, but it is also necessary there should be room in the tank (which is, of course, a tight one), above the water when the latter is expanded to its utmost, sufficient to hold all the air there was originally in the tank, without its being compressed to a dangerously high pressure.

There is an occasional experiment now with some fitters who have not carefully considered this question to close the ordinary tank—proportioned by the $\frac{1}{20}$ rule—that always ends in the destruction of the weakest part of the apparatus, generally the boiler. No boiler that I know of can stand such usage unless it happens to be a welded coil, and then it is the tank or some weaker part of the apparatus that gives way.

To see this in its proper light, we have to consider an ordinary apparatus with an expansion tank one-twentieth of the whole capacity, or sufficient to take care of the increment of the expansion of water from 40° to 212° fahr. If we close this tank so the air cannot escape, the accompanying diagram, Fig.

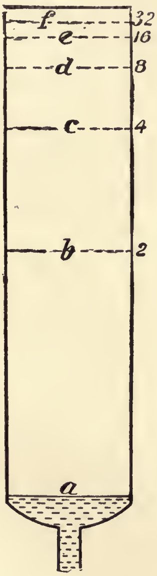


FIG. 177.

177, will show the additional increment of pressure caused by the expansion of the water and the compression of the air.

When the surface of the water is at *a* the water in the apparatus is cold, say with a temperature of 40° fahr. When it is warmed to about 155 degrees, it rises until it reaches the position, *b*, or half way up, and has compressed the air above it until it has a pressure of two atmospheres (by which must be understood the pressure of the atmosphere and 15 pounds additional). At a temperature of about 185 degrees it is at *c*, and the pressure of the air is *four* atmospheres, or 45 pounds gauge pressure; at 200 degrees, or thereabouts, it reaches *d*, and the pressure is *eight* atmospheres, and at *e*, *sixteen* atmospheres, and at *f*, *thirty-two* atmospheres, or 480 pounds pressure per square inch (465 pounds above atmosphere), and, as yet, the water has not reached a temperature of 212° fahr. This is sufficient to account for the bursting and leakage of some hot-water boilers and the escape of the water from the apparatus.

With a tank of twice the capacity, of course, the danger is very much lessened, as then one extra atmosphere only can be added to the pressure caused by the water-head, for a range of temperature between 40 degrees and 212 degrees. But the practice generally of closing a tank should be condemned for house warming, as a mistake in the amount of water let into the apparatus will upset all calculations; and where high temperature is an absolute necessity, the designing of such an apparatus should be entrusted to one thoroughly conversant with the subject.

It is almost impossible to estimate the pressures that can be obtained with a closed tank. With steam the temperatures and pressures always bear a fixed relation to each other—when in the presence of water—so that knowing the one, the other can always be found. With water in a closed non-elastic vessel, however, and subjected to heat, the pressure may become enormous, although the temperature is comparatively low. Should water, at a temperature of three or four hundred degrees, burst its envelope, a large part of it will instantly fly into steam, and the damage that will follow will be just as disastrous as though a steam boiler blew up with steam at a pressure corresponding to the temperature we have supposed for the water.

It is evidently not necessary to compress air for the purpose of keeping a pressure on the water until it—the water— reaches 212 degrees. It is then necessary to advance pressure on the surface of the water in the same or a slightly greater ratio than the pressure of steam advances with its temperature (see Table XI), otherwise part of the water will be converted into steam. To proportion an apparatus for high-pressure hot-water, in which the pressure can be kept just ahead of the temperature in this relative manner would be next to impossible. It might be done for some constant temperature of the water, but would be practically impossible with varying temperatures, therefore, the only safe way to arrange for a high pressure apparatus is to provide a tank sufficiently large to take care of the increment of the water with some space above it, in which air can be compressed or steam allowed to form, but with a safety valve arranged on it to let off the excess of pressure whether of air or steam.

It is immaterial whether air or steam rests on the surface of the water in the tank for the purpose of keeping the pressure on the water, and the circulation goes on just as well with the one as with the other; therefore, the idea of the absolutely closed

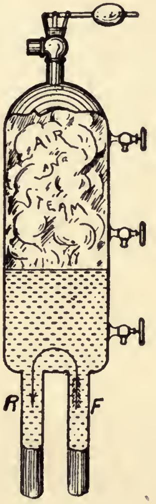


FIG. 178.

tank should be abandoned as dangerous in *all* cases, and a tank with a well-made safety valve used instead. Fig. 178 shows a tank with safety valve arranged for pressure above atmosphere and temperature above 212 degrees—high pressure.

As such apparatus are generally small, the tank may be made of wrought-iron pipe with welded ends, or it may be of cast iron and always with rounded ends.

The following table, No. XI, shows the increase of volume of water for each one hundred degrees of temperature between 40° fahr.—its greatest density—and 600 degrees; water at 40 degrees being unity.

TABLE XI.

Temperature	Bulk of volume	Safe proportion for tank
40°	1.0000	....
100°	1.0075	....
200°	1.0380	$\frac{1}{24}$
300°	1.0860	$\frac{1}{10}$
400°	1.1480	$\frac{1}{6}$
500°	1.2230	$\frac{1}{4}$
600°	1.3100	$\frac{1}{3}$
1	2	3

The third column gives the least safe proportion of the total cubic contents of the rest of the apparatus that it is necessary to provide in the expansion tank, for the temperatures given in the first column. For temperatures up to the boiling point the tank should be open, and for higher temperatures it should be provided with an efficient safety valve. The relative capacity of that part of the tank between *a* and *b*, Fig. 176, should be proportioned to the decimal portion of the amounts in column 2; the capacity of the rest of the apparatus being taken as unity.

The accompanying diagram, Fig. 179, shows the whole matter in a graphic manner. The dark shading—forming the wedge—to the right of the perpendicular line, *a b*, shows the increase of volume of water as the temperature is advanced between 40° and 600° fahr. The light shading to the left of line, *a b*, shows the constant relative volume at maximum density so that the proportion of increase for any temperature, and consequently the least capacity of the tank, is the horizontal distance between the perpendicular line, *a b*, and the ordinates of the curved line, *a c*, compared with a horizontal line through the light shading on the left. The increase of volume for temperature intermediate to those shown at the left of the diagram can be approximated by the assistance of the other ordinates of the curve, *a c*. The total volume of the water for any temperature is proportional to the distance from the perpendicular at the left of the diagram to the curve, *a c*, measured on a horizontal line corresponding to the given temperature.

I wish to add, before leaving the question of tanks, that unless the water in an apparatus is to be heated above the temperature of 212° fahr., nothing can be gained by using a closed tank. The circulation will be no faster thereby, and for house apparatus for simple warming purposes, this practice of closed tanks should not be tolerated, as it makes an apparatus, which is otherwise absolutely safe, *dangerous*, and liable to burst and scald people.

Let me also add that if a closed tank is not sufficiently large to take care of the increment of expansion, under all conditions,

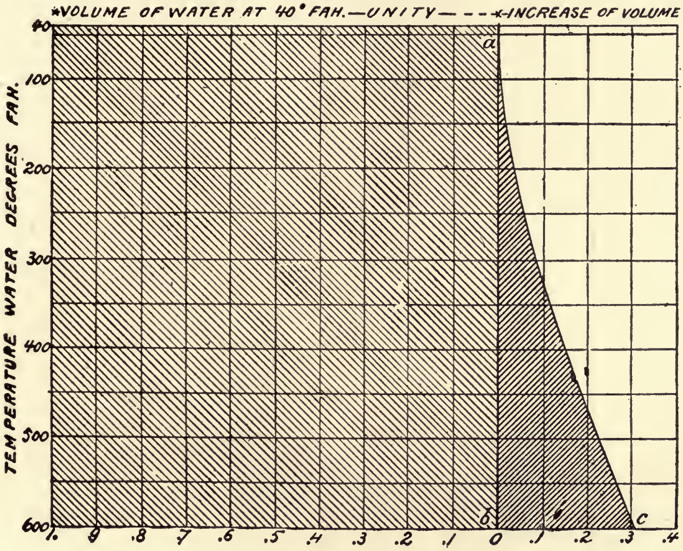


FIG. 179.

something is sure to burst, as the expansion of the water is practically irresistible, and enormous pressures that are sure to rupture any boiler or radiator, will be obtained, and the only safeguard lies in the use of a safety valve, with a tank not only sufficiently large to take care of the increase of volume, but also to hold air enough to allow for its compression within reasonable limits.

It may happen also that a closed apparatus is started with too much water in it, in which case the expansion will fill the remaining part of the tank no matter how large it is relatively;

TABLE XII.—REGNAULT'S TABLE

(From Prof. Charles A. Smith's work "Boiler Practice," with interpolations, and with fractions omitted.)

Temp. of water or steam degrees fahr.	Pressure per sq. in. above atmosphere	Temp. of water or steam degrees fahr.	Pressure per sq. in. above atmosphere	Temp. of water or steam degrees fahr.	Pressure per sq. in. above atmosphere
212	0	307	60	397	225
215	1	312	65	400	233
219	2	316	70	401	235
222	3	320	75	404	245
225	4	324	80	408	255
227	5	328	85	411	265
230	6	331	90	414	275
233	7	334	95	417	285
235	8	338	100	430	335
237	9	341	105	445	385
239	10	344	110	457	435
242	11	347	115	467	485*
244	12	350	120	487	585
246	13	353	125	500	670
248	14	355	130	504	685
250	15	358	135	519	785
252	16	361	140	534	885
254	17	363	145	547	985
256	18	366	150	....	....
257	19	368	155	....	....
259	20	371	160	....	....
262	22	373	165	....	....
266	24	375	170	....	....
269	26	377	175	....	....
272	28	380	180	....	....
274	30	382	185	....	....
281	35	384	190	....	....
287	40	386	195	....	....
293	45	388	200	....	....
298	50	390	205	....	....
300	51	393	210	....	....
303	55	394	215	....	....

* Temperatures above 485 pounds are calculated, the others are experimental.

and, therefore, a safety valve becomes necessary to let off this superabundance of water, and the only chance of guarding against accident is to provide a reliable safety valve in every case where the tank is not an open one.

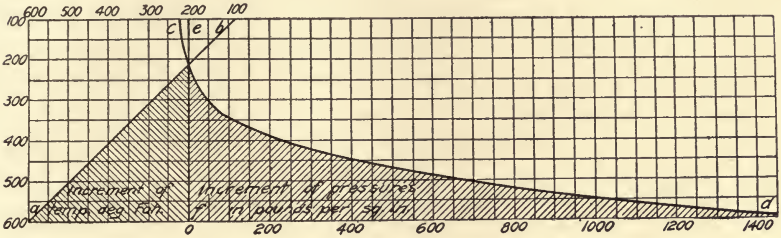


FIG. 180.

Attention must be drawn to the rapidity with which pressures increase with the temperatures.

Up to 212 degrees we may say we have no pressure. This is not absolutely correct, as we are under the pressure of our own atmosphere. The power to burst vessels or cylinders, however, commences at atmosphere, and counts therefrom; therefore, up to a temperature of 212 degrees in an open apparatus the walls are not strained by the addition of heat. Beyond this point, however, to secure any given increment of temperature we must also have an increment of pressure, and consequently must have either a closed tank in which to compress air or form steam, or be under a head of water equivalent to the pressure we desire.

Up to a temperature of 300° fahr. the necessary pressures cannot be said to be very dangerous, as with a properly proportioned and operated tank they will not exceed 51 pounds per square inch, as will be seen by Table XII.

Beyond this, however, the pressure advances very rapidly; so that at a temperature of 400 degrees the pressure is 233 pounds per square inch, requiring an advance of 182 pounds per square inch for an increase of 100 degrees of temperature; while at 500 degrees it is about 670 pounds per square inch, requiring an increment of 437 pounds per square inch for an advance of 100 degrees of temperature.

The following diagram (Fig. 180), based on the above table, I have constructed to illustrate graphically the natural increase of pressures due to the advance of temperatures of water or steam.

The line, *e f*, is the zero of pressures in this case—atmosphere. The ordinates of the curved line, *c d*, to the right of the perpendicular line, *e f*, show the increments of pressures per square inch above atmosphere, corresponding to the increments of temperatures shown on the left by the line, *a b*, so that the horizontal lines measured each way through the shading, from the line, *e f*, show the relative increments of both temperatures and pressures.

It is probably well to remark here that horizontal ordinates of the line, *e d*, also represent the pressures of steam corresponding to the temperatures of steam or water, as shown by the corresponding ordinates of the line, *a b*.

CHAPTER XXV.

VALVES FOR HOT-WATER APPARATUS.

Gate Valves—Butterfly Valves—Angle Valves—Angle Cocks.

The valves to be used in a hot-water apparatus should receive some little consideration in this book.

It is not very important as to what they are composed of so long as they will not corrode and become inoperative.

The most essential thing in the matter of valves for an apparatus is to select those that cause the least resistance to the flow of the water. Therefore, it is probable that gate valves are the best that are to be obtained in open market.

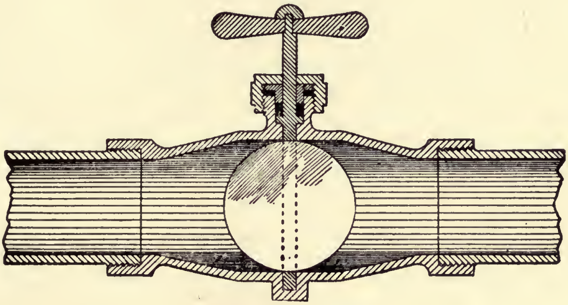


Fig. 181.

Nothing but a gate valve should be tolerated in the main pipes of an apparatus unless it is a butterfly valve of good design and thin, wedge-shaped disk, that will offer little resistance to the flow of the water.

A well-designed butterfly valve for this purpose should swell in the body, Fig. 181, so the area about the disk should be greater than the area of the pipe. By so doing the injury caused to the flow of the water by the obstruction of the disk and spindle will be compensated for.

When absolutely tight valves are necessary about boilers, etc., so that a circuit or other part of the apparatus can be shut off for repairs or alteration, there is then nothing better than a merchantable gate valve.

When an interruption of the current only is required a butterfly valve may be used.

It would be well in the construction of either gate or butterfly valves for hot-water apparatus to have a hole in the disk with a screw plug in it, so the fitter can have the means of making a "pass-by" through the disk without taking the valve to a machine shop; and it also allows him the opportunity of being able to close the aperture with a plug when he thinks it necessary. Gate valves with single disks are more suitable for hot

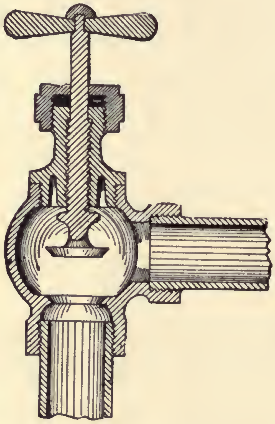


FIG. 182.

water than those with a double disk especially if they are to have a pass-by through the disk.

The gate valve is too well known to require an illustration here. Fig. 181, however, shows a common form of butterfly valve with swelled body.

Globe valves should never be used in a hot-water apparatus on account of the obstruction they offer to the passage of the water. Angle valves are not much better, still they are about the only thing obtainable for radiators or coils. Gate or butterfly valves can be used for radiators where appearance is not considered. In the formation of a neat connection, however, they cannot be used, therefore the ordinary angle valve is used instead.

Angle valves, in which the disk will rise against the " nut " —sometimes called the " bonnet " of the valve—are better than ordinary steam angle valves, as the disk is withdrawn from the centre of the current of water when they are wide open.

Fig. 182 shows the manner in which the disk hinders the flow of the water in an ordinary angle valve, by being stopped in the middle of the globe, and Fig. 183 shows the improvement for hot water, when the disk is run further up. It requires a longer stem with more thread on it, in the latter valve. The pitch of the thread can be quickened however, so the same number of revolutions will open it to the fullest extent that it is necessary to give to an ordinary steam valve.

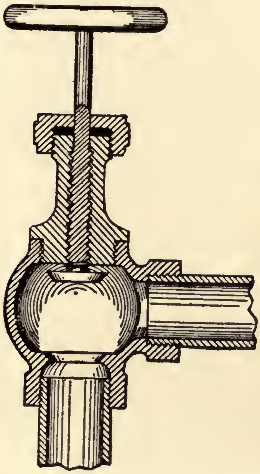


Fig. 183.

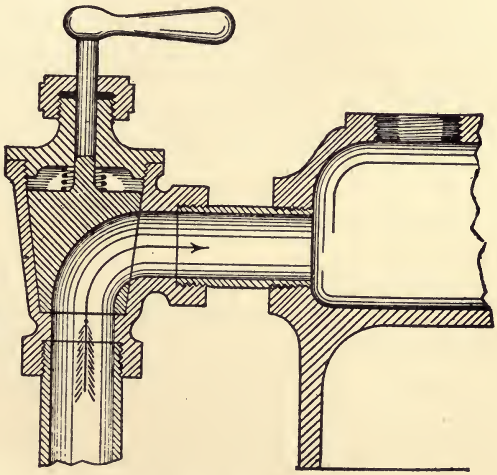


Fig. 184.

As it is not necessary to have that degree of tightness—called in the workshop " fit "—between the parts of hot-water valves that there is required for steam valves, as the difference of pressure between the sides is so inconsiderable, a valve like that shown in Fig. 184 can be used to advantage on the inlet to radiators.

It is in a measure a plug cock of special design with the inlet at the bottom, and when the plug is in the position shown it offers a very low resistance to the flow of the water, much less than an elbow and probably not over one-tenth what a common angle valve will offer, as there are no abrupt shoulders, and the radius of the bend is comparatively long, giving a resistance of probably less than twenty diameters of the pipe.

A slight change of the plug from the position shown will present abrupt corners to the flow of the water, and materially check its flow when required. Less than one-quarter of a turn will entirely shut off the passage of the water. The taper of the plug should be such that it will not jamb in the barrel, and a helical spring of brass wire is sufficient to keep it in its place against the slight pressure of the water, even when the valve is closed.

CHAPTER XXVI.

AIR VENTS.

Air-Vents for Hot-Water Apparatus—Scollay's Automatic Air-Vent for Hot-Water Radiators, etc.

The air-vent most in use for hot-water radiators, etc., is a simple compression wheel air-cock of small dimensions, similar to that shown in Fig. 185.

They are made in various ways, but generally the small angle-valve type is preferred. They may have metal handles of the lever or the T-pattern, though the wooden wheel handles are to be preferred when they are well made, the wood being a non-conductor of heat. They are usually polished, and plated

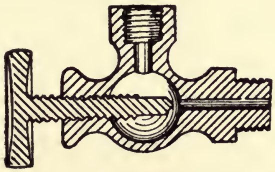


FIG. 185.

throughout in either silver or nickel, the latter being the most serviceable, as it will keep its color better.

When children have access to the air-valves of a radiator the valves can be provided with short spindles that are squared for the reception of a small socket wrench or key.

With regard to the use of air valves all that is necessary to say is that they should be used at the very highest point of the radiator, and that usually when they are used at the end of a radiator there is a considerable air pocket above them by the fact of the tap-hole being in almost every case from one-half to one inch below the inside of the top of the casting.

The first automatic air-valve for hot water that I am acquainted with was the one made by Mr. John A. Scollay, a hot-water engineer of Brooklyn, N. Y. It is shown in Fig. 186. Its general appearance being that of a small brass cylinder, with a small perforated cap on the upper end, the lower end being provided with a threaded tail-piece by which to attach it to the highest point of the radiator or air chamber. The detail is a vertical section, through its centre. The outer case, *a*, is made of brass and within it is a float, *e*. To the upper side of the float there is attached a small valve, *d*, which forms a seat against an adjustable tube, *b*, which fits into the head of the cylinder. A small guide stem top and bottom keeps the

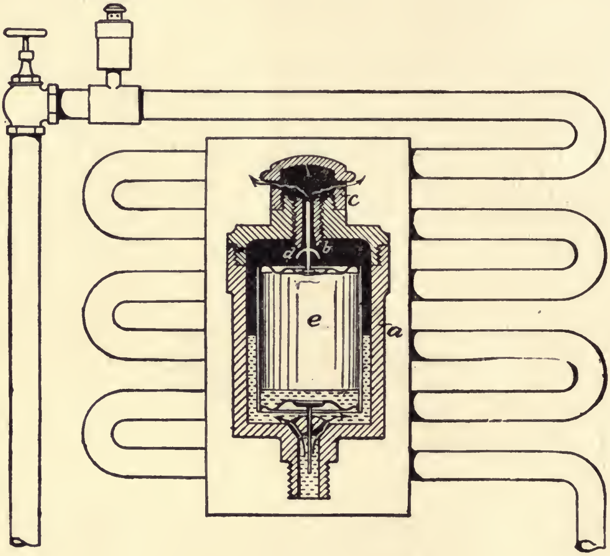


FIG. 186.

float in a central position. Its operation, which is plainly suggested by the diagram, Fig. 186, is: Should air be disengaged from the water it will pass into the case, *a*, displacing the water therein, when, of course, the valve drops away from its seat by gravitation, letting the air escape through the holes in the side of the cap. The return of the water into the cylinder after the air escapes buoys up the float, bringing the valve to its seat again and closing the point of egress.

The valves are also made to close under the effect of heat as well as floatation. The ends of the float, *e*, are concentrically corrugated, so that they can move in the direction of the axis of the cylinder under internal pressure. When a quantity of alcohol, therefore, is placed within the float and the latter properly closed the expansion of the vapor of alcohol will thrust the valve to its seat if steam or hot vapor is formed sufficient to boil the alcohol.

Instead of perforations in the cap for the liberation of the air after it passes the valves a small pipe is sometimes attached to the head of the cylinder below the cap, with suitable passages so the air or vapor or accidental leakage of water can be carried to a place where it can do no damage, in the manner usual to automatic air valves on steam apparatus.

For indirect radiators, when set in such relation to the main flow-pipe (as shown in Fig. 160 by the dotted lines) that the air will not escape backward through the inlet pipe to the main flow pipe, automatic valves are almost indispensably necessary and at all points in any apparatus that they are troublesome to reach or that are likely to be neglected they can be used to advantage.

Automatic vents depending on the principle of expansion alone are not reliable for hot-water purposes and the float principle is the only one that I have any knowledge of that is reliable, other than the open pipe carried higher than the tank, which, of course, is always reliable in low-pressure work when of sufficiently large diameter and untrapped. Practical reasons, that are unnecessary to explain, are likely, however, to be interposed to the promiscuous running of these open-air pipes, and, of course, they cannot be used in high-pressure work.

CHAPTER XXVII.

AUTOMATIC REGULATORS.

Automatic Door and Damper Regulators—The Nason Regulator—The Hawkins Regulator—The Open-Tank Regulator—The Tasker Regulator—The Haynes Regulator—The Blake Regulator.

The question of the automatic regulation of doors and dampers of hot-water apparatus is one that requires some consideration.

Mr. Joseph Nason, of New York, gave the subject considerable attention twenty or twenty-five years ago, and at that time devised a very simple practicable apparatus, which is shown in Figs. 187 and 188.

His first practical use of the apparatus was in the residence of Mr. William A. Perry, M. Am. Soc. M. E., and of the firm of Henry R. Worthington, New York, in the year 1868, at Bay Ridge, L. I., in which house it is in working operation at the present time.

Fig. 188 shows it in principle as applied to the chimney damper of Mr. Perry's house, and Fig. 187 is a detail showing the method of compounding the levers, etc., and attaching it to the main pipe of the apparatus.

Every pipe of an apparatus is subject to some change of length when subjected to a change of temperature. The expansion of wrought iron is not great, however, being about the $\frac{1}{150000}$ of its length for each degree fahrenheit that it is warmed —nevertheless, this is ample if the pipe has any considerable length, and it was this expansion or change of length that was taken advantage of by Mr. Nason, who conceived the idea of utilizing the expansion and contraction of any convenient run of main pipe or large branch of the same near the boiler, the longer it might happen to be, within certain practicable limits, the better for the purpose, and I believe he did not consider

25 feet as too great a length, though he was satisfied to do with less, 10 feet or thereabouts, when he could not obtain a more favorable run of pipe.

His principle was to fix the clamp, *A*, on the Fig. 187, main pipe at some convenient point from the boiler, and also to clamp the part of the apparatus, *B*, to the pipe close to the boiler.

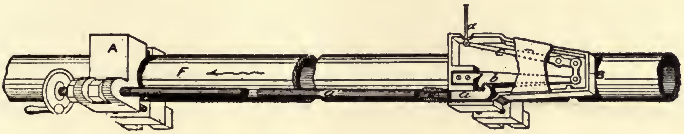


FIG. 187.

Within the box or casing, *B*, there is arranged a system of compound levers as shown, the multiplication of the movement between the hook *a* and the damper-rod, *d*, being 200—in other words, the levers are so pivoted that a movement by expansion of the $\frac{1}{200}$ part of an inch in the direction of the arrow at *F* on

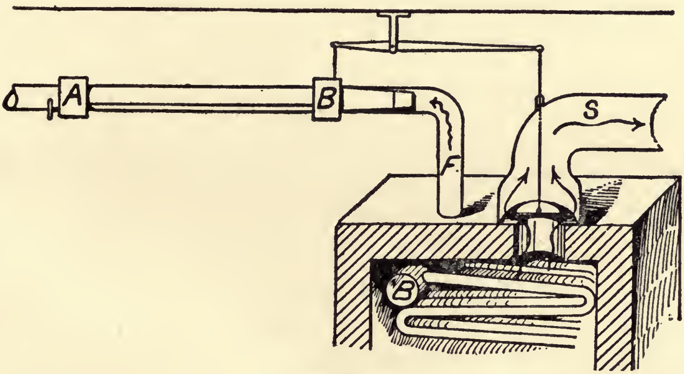


FIG. 188.

the main pipe will move the rod, *d*, and the end of the lever, *c*, in an upward direction one inch.

The steel hook, *a*, is connected by a rod, *a*″, to the clamp, *A*. This rod being two inches from the flow-pipe is not materially affected by any change of temperature in the water, therefore when the main pipe elongates, the tendency is to put a tensile strain on the rod and hook, which latter engaging with the lever, *b*, gives motion to the remaining moving parts.

The necessity for a considerable distance between *A* and *B* becomes plainer, when we consider that it is necessary to operate doors or dampers on small changes of temperature. If we desire to adjust an apparatus to keep the temperature of the water at 180° fahr., it is plain the temperature must advance a little beyond this to close the damper and also fall somewhat below it to open it again, therefore the best we can hope to do is to keep it as near 180 degrees as we can and control our damper by the smallest difference of temperature possible, so that we should be satisfied if we can prevent the water from advancing above 183 degrees or going below 177 degrees, giving us a range of temperature of six degrees.

If we control, therefore, with a change of six degrees, and our pipe between the clamps is 25 feet long, the change of length is $\frac{6}{150000}$ parts of the whole length, and in the case of a 25-foot pipe, it is the $\frac{1}{1000}$ part of a foot or the $\frac{1}{83}$ of an inch, which in a decimal fraction is .012 of an inch.

Now as the multiplication is 200 times we have

$$.012'' \times 200 = 2.4 \text{ inches}$$

as the movement at the rod, *d*, for a change of six degrees when the clamps are 25 feet apart on the pipe.

In the above apparatus, it will be noticed, the principle involved is to take advantage of the difference of two iron rods, or more particularly a rod and a pipe, one of them only being subject to a sudden change of temperature and length. The apparatus must be kept from sudden draughts of cold air and both pipe and rod should be covered with non-conducting materials, if the most satisfactory results are to be expected. They should not be wrapped in the same envelope, however, as the change of temperature in the pipe should not affect the rod. An adjusting screw is attached to the end of the rod at the clamp, *A*, so the tension on the rod may be regulated.

Carleton W. Nason, M. Am. Soc. M. E., the President of the Nason Manufacturing Company, New York, some years ago, suggested to the writer the advantage there might be in subjecting two strips of metal of as widely different coefficients of expansion as possible to uniform changes of temperature, and proposed the thermostat shown in Fig. 189.

He suggested making a hollow cone of brass and another of iron and slipping the brass within the iron one, in which position to rivet them closely in a spiral manner. They were then to be cut in a lathe, between the spiral of rivets, so that when completed they formed a tapered spiral coil.

This coil is enclosed within a case, *A* (Fig. 189), and fastened

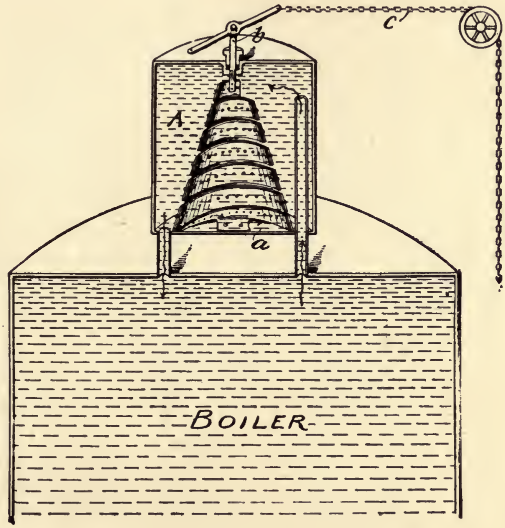


FIG. 189.

to the bottom plate, *a*. To the apex of the coil is attached a spindle, *b*, which passes through a stuffing box at the top of the case, as shown. Upon the end of this spindle is a cross lever with chain and pulley, the former connecting with the door or damper in the usual manner.

The brass coil of the conical spring being within the iron one and having a greater coefficient of expansion, unwinds the coil under an advance of temperature, turning the spindle and giving motion to the lever. In like manner a fall of temperature contracts the coil reversing the motion of the lever. A counterweight should be used to balance the weight of the door or damper so as to lessen the work of the spring.

Mr. John T. Hawkins, M. Am. Soc. M. E., and President of the Campbell Printing Press Company, read a paper at the Nashville meeting of the American Society of Mechanical Engineers in May, 1888, on the subject of "Automatic Regulation for Hot-Water Heating-Apparatus," in which he describes a thermostat involving the same principle as the foregoing for automatically opening and closing the doors and dampers of a hot-water boiler.

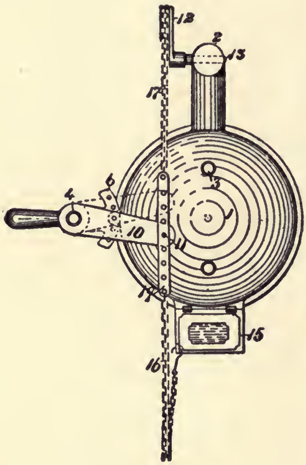


Fig. 190.

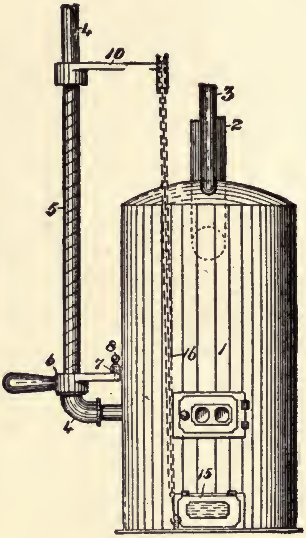


Fig. 191.—Damper Regulator for Hot-Water Boilers.

Quoting from the transactions of the American Society of Mechanical Engineers, he says:

"Figs. 190, 191 and 192 show respectively a plan view and a front and side elevation of the apparatus as attached to a hot-water system. 1 is the heater; 2, the flue leading to chimney; 3, pipe leading from the top of the heater to a radiator; 4, a return-pipe from the radiator, delivering the cooled water into the lower part of the heater. Surrounding pipe 4 is a helical-coil thermostat, constituted of two strips of dissimilar metals, having widely different coefficients of expansion, as brass and iron, riveted, soldered, or brazed together. This helical thermostat fits over the pipe, 4, easily, with the more expansible metal on the inside, and the less expansible on the outside, exposed to the temperature of the surrounding air. The lower end of the helix is secured to a lever, 6, having in one arm an arc of pin-holes, the outer arm constituting the handles. A lug, 7, is attached to the heater, having the single hole meeting the arc of holes in the lever, 5. A pin, 8, may be placed in either of the holes in the arc, and thus the lever, 6, be rigidly held in either position determined by the given hole used.

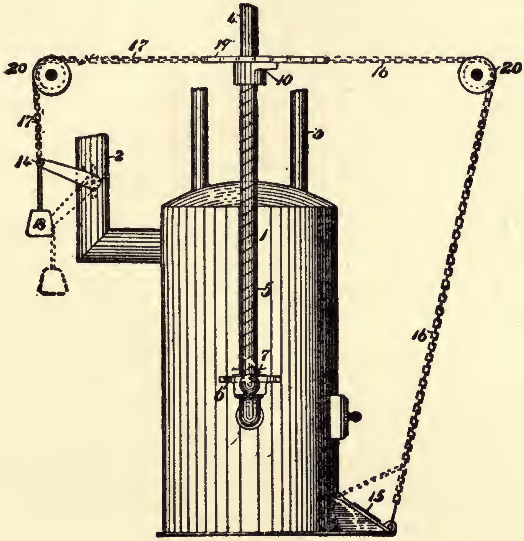


FIG. 192.

"To the upper end of the helix is secured a lever, 10, having at its free end a pin, 11. 13 is a damper of the flue-pipe; and 12 a lever secured to its axis. 15 is the ash-pit or inlet damper. 19 is a strip of metal containing a series of holes fitting the pin, 11. 16 is a chain passing over one of the leading pulleys, 20, with one end connecting to the strip, 19, and the other to the inlet damper, 15. 17 is a similar chain passing over another leading pulley, 20, and connecting the other end of the strip, 19, with the free end of the damper lever, 12. 18 is a weight suspended from the lever, 12, to counterbalance the weight of the damper, 15, and the surplus vertical chain leading from it.

"In this construction it will be obvious that the expansible helix, having the more expansible metal exposed to the fluctuations of the temperature of the pipe within it, while the less expansible one is in contact with the surrounding air, and therefore only partially heated by conduction from the inner one, will undergo a considerably greater straightening or unwinding for a given elevation of temperature of the pipe within it than if it were merely immersed wholly in the medium whose variation of temperature was to operate upon it, as with the ordinary thermostat; and that, the lower end of the helix being fixed, and the helix being of considerable length, such a straightening or unwinding by elevation, or coiling up by reduction of temperature of the pipe, will cause the upper lever, 10, to move through a considerable arc for a small variation in temperature of the pipe within it, and that the force exerted to move the lever, 10, will be a very positive one. The pin holes in the plate, 19, serve merely to regulate the relative position of the dampers, 13 and 15, and the lever, arc 6. The same, however, may be accomplished by hooking the chains directly to the lever, 10, and taking them up or letting them out, as may be required. The adjustment of the position of the lever, 6, will determine the temperature of the pipe, 4, at which the dampers, 13 and 15, will become closed or remain in any desired position of partial opening; and, in any given weather, it will be only necessary to put the pin, 8, in such hole of the arc of lever, 6, as will keep the water returned down the pipe, 4, and consequently that circulating through the radiator, at the required temperature. This adjustment decides what temperature the apartment will be maintained at, the apparatus thereafter automatically maintaining that temperature. * * *

"The helical thermostat is shown as surrounding a return pipe, but it will be equally efficient, and is generally most desirable, if placed upon an ascending or delivery pipe, the only difference being that in one case the regulation is made to conform to the fluctuations of the temperature of the water passing from the heater to the radiator, and in the other case to those of the water, returned from the radiator to the heater."

Occasionally engineers endeavor to control the doors and dampers of an apparatus by the height of the water in the expansion tank. As the water in the apparatus warms and cools it flows and ebbs in the tank, so that a float suspended therein, as shown in Fig. 193, will rise and fall with the water and control the doors by the intervention of the chain over pulleys. It seems a simple and positive method, but for some reason it has not received the recognition it would appear to deserve. Like almost everything else of the kind, it has a weak point, which in this case is the trouble to keep the desired level of water in the expansion tank, as evaporation and leakage interferes and disarranges the adjustment.

A ball-cock in the tank does not help matters, as it will not

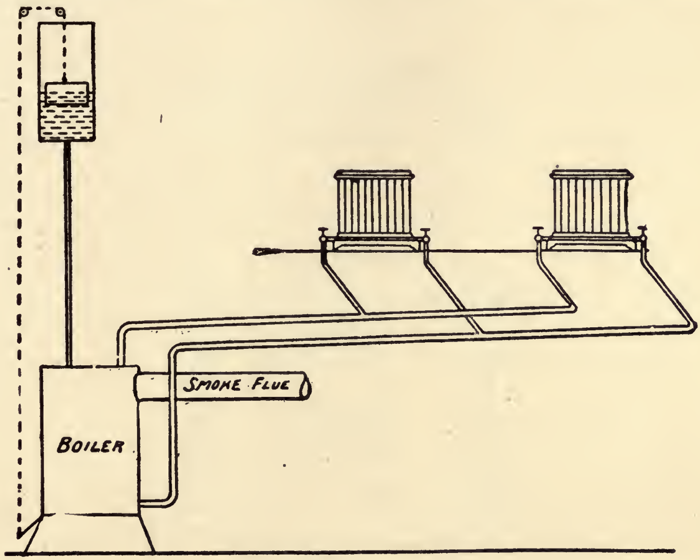


FIG. 193.

come into operation until the lowest cold-water level is reached, so that it is necessary for some one to watch the level of the water constantly. In the hands of one who will look after the careful regulation of the height of the water it should give good results as it can be made very positive.

The Pascal Iron Works of Philadelphia used this principle to control their hot-water furnace before 1870, as I find the apparatus as shown in Fig. 194 in one of their books bearing that date. In the illustration, *a*, is the expansion tank, or any open tank on the same level with it. Through its bottom extends a tube of equal height with the tank. Within this tank is an annular float, a rod from its centre extending through the tube and connecting with the "break draught" door, *c*, which door is in turn connected with a cold-air door, *d*, above the fire and a draught door, *e*.

As the float is elevated it first opens the door, *c*, and closes the draught door, *e*, shutting off the air from the fire. Should this not be sufficient its further rise opens the door, *c*, to a greater extent. If the expansion of the water is still con-

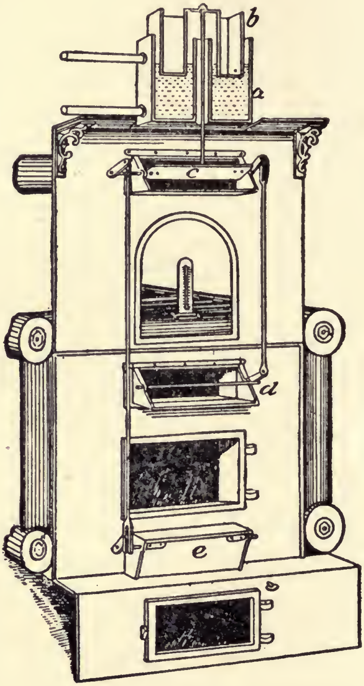


Fig. 194.

tinued, by the heat of a heavy fire, then the door, *d*, is brought into action by the further movement of the crank and stud on the right of the door, *c*, working in the slot at the end of the rod.

Mr. E. A. Haynes, of the firm of Haynes & Kidder, Franklyn Falls, N. H., used the expansion of water in a different manner to control the doors, etc., of an apparatus. The principle involved was to take advantage of the expansion of water or any other liquid when confined within a tight vessel, but with an elastic top that will rise and fall with the expansion and contraction of the liquid.

Fig. 195 shows the apparatus in section. An outer casing of cast iron, *C*, of any suitable shape or dimension is connected with the boiler by the flow-pipe, *C′*, and the return-pipe, C^2. This case is connected the same as any radiator or heater, so the water of the boiler can readily and properly flow through it, and it is usually placed a foot or so above the head of the boiler.

Within the case, *C*, is a smaller chamber, *D*, with a pipe, *d*, extending from its upper end, and passing through the top of

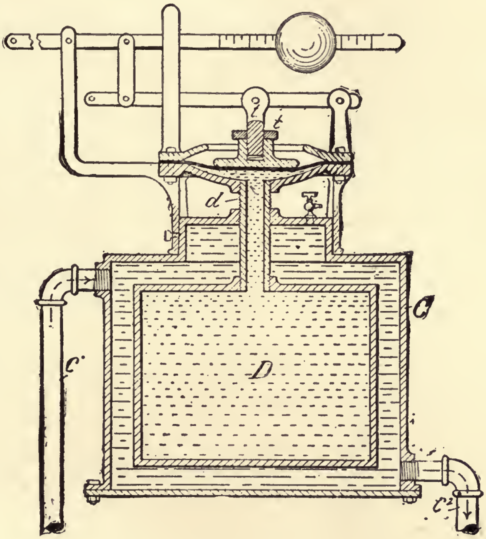


FIG. 195.

the outer case. On the end of this pipe is screwed an ordinary regulator bowl with rubber diaphragm, and in all other respects the apparatus is the same as a steam regulating bowl, with levers, chains, etc.

When the water in the outer chamber, *C*, becomes warm it heats the water in the inner chamber, *D*, and expands it, driving the excess through the pipe into the bowl beneath the rubber diaphragm, and forcing the latter upwards, operating the levers, and consequently the draft or fire-door, or both, as in a steam apparatus.

A pet-cock is used on the outer chamber to draw off the accumulated air. A tube to fill the inner chamber to the desired height is also used, though not shown in the cut. Adjustment is secured by running the stud, *t*, up or down and holding it in place by the jam-nut, *t'*.

A practical difficulty attending this style of regulator is, when the water in the chamber, *D*, becomes hot by contact with the water in the case, *C*, it closes the door or damper. A fall of temperature, however, of the water in *C* is not responded to

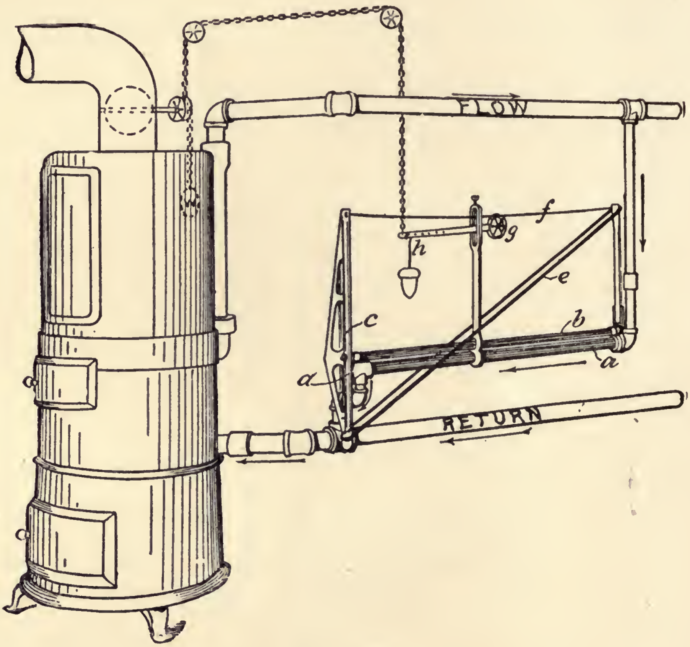


FIG. 196.

quite rapidly enough by the water in *D* on account of the mass of water and the limited heat-transmitting surface, therefore this class of regulator can be made more sensitive by the use of a coil at *D*, or some other receptacle that will have a large surface compared to the amount of water it holds; or, if instead of using the apparatus as shown, the regulating bowl at the top is screwed on a long closed pipe, that is projected directly into the water of the boiler, the regulation will be closer than at present.

The principle involved, however, is a good one, and is deserving of close consideration with regard to its practical development.

Fig. 196 shows the thermostatic regulator invented by Mr. George W. Blake, of New York.

The principle involved is to take advantage of the differential expansion between a brass pipe, *a*, through which the water flows, and an iron rod, *b*, that is kept cool and is protected from undue changes of temperature by being covered with a slip tube, etc. The rod, *b*, is under tension, and the pipe, *a*, under compression, when the temperature of the water is advancing. The upright, *c*, is a beam or truss balanced against a knife edge at *d* on the end of the brass pipe, *a*. Two inches above the knife edge, *d*, the rod, *b*, is fastened to the beam, *c*, in such a manner that the tension of the rod may be adjusted. To the top of the beam, *c*, is attached a flat steel strip or spring, *f*, and to the opposite end of this spring is fastened the link, *e*, the other end of which holds the lower end of the beam, *c*. The upright at the right of the cut, opposite the beam, is simply a support for the end of the stirrup and the spring. The action is as follows: When the brass pipe, *a*, is elongated it thrusts the lower end of the beam from it and forces the upper end to compress the spring, *f*, at one end while the stirrup is drawn against the opposite end of the spring by the outward movement of the lower end of the beam, the resultant action being to compress the spring from each end and deflect it into a bow which presses on the grooved wheel, *g*, depressing it. The depression of the wheel gives a fourfold motion to the other end of the lever at *h*, so that a depression at *g* of two inches, which can be secured by a change of about ten degrees in the water at the pipe, *a*, is sufficient to move the damper chain eight inches.

The damper is weighted to remain open, which may be called its normal position, so that during the contraction of the pipe, *a*, while cooling, the weight, *w*, closes the damper, and the weight, *h*, restores the lever to its normal position and takes up the slack of the apparatus.

Nearly all the attachments that can be made to operate a damper may be used either on the ash-pit or draught-door, or may be employed to open or close cold-air inlets, and when used for the latter purpose are placed in direct circuit with the indirect coils or radiators.

CHAPTER XXVIII.

SPECIAL FITTINGS.

Special Fittings.

The ordinary steam and gas elbows and tees for wrought-iron pipe are not well adapted for hot-water fitting. A reference to pages 42 to 45 will show the great loss of head, and consequently flow, of water due to common elbows with short radii and rough ends.

The long-bend water fittings, shown in Figs. 197, 198, 199 and 200, are a great improvement over the common fittings for this class of work. These fittings were early made by the Walworth Manufacturing Co. and by the Providence Steam and Gas Pipe Co. A number of special fittings used in plumbing

Fig. 197.

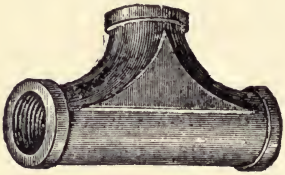


Fig. 198.

are also admirably adapted to hot water work. The Durham House Drainage Co. were among the first to introduce these special fittings.

A group of them are selected and shown on page 271, Fig. 201. They suggest their own fitness for hot-water work.

A special feature of this class of fittings is shown in Fig. 202. They are so formed on the inside that the alignment of the inside diameter of the pipe and the fittings agree at the joints, so there is no considerable shoulder one way or the other, and if care is taken in the use of standard taps and dies, the end of the pipe can be screwed so near the bottom of the thread of the fitting that a very small space only will be left at these

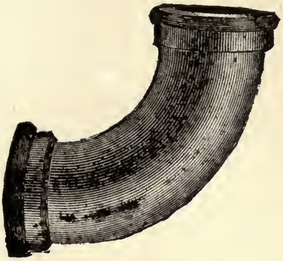


FIG. 199.

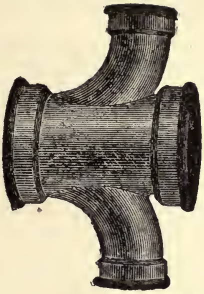


FIG. 200.

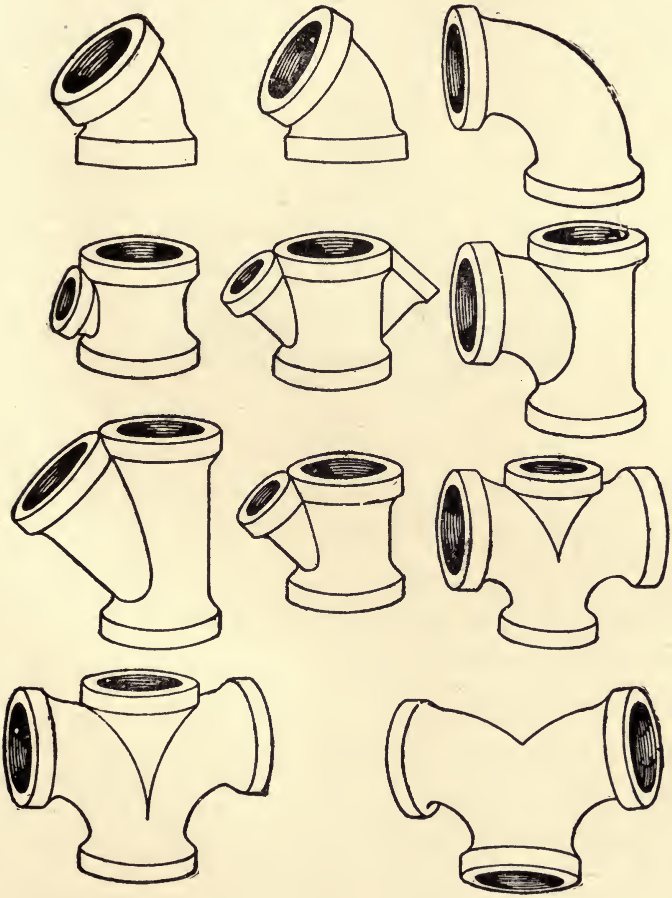


FIG. 201.

points of juncture. In the cut the pipe is shown fully screwed to the bottom of the recess of the fitting. This, of course, is well known to operative mechanics to be what is sometimes called a "practical" impossibility, without an immense loss of time and labor—meaning that ordinarily it would not be properly done, not that it could not be properly done, but that the chances would be against its being so, as it would be necessary to have the proper degree of tension on the threads, just at the moment of bottoming. It is possible, however, to make a proper degree of tightness on the threads when the pipe is within one-quarter of an inch or thereabouts of the bottom, and not lose more time than is ordinarily consumed with common fittings. From the practical side of the question, also this

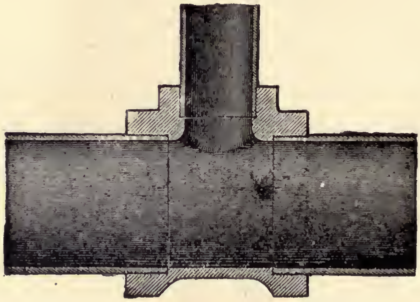


FIG. 202.

space is an advantage, for should pipes be fitted to bottom tightly and then be unscrewed for any purpose, it is difficult to secure a tight joint in the thread on the second screwing, and dependence would have to be placed on the pressure at the end of the pipe, which would not be reliable, and would be impracticable for these reasons.

The small space of one-quarter of an inch in large diameter pipes, with a depth no greater than the pipe is thick, is not a serious matter, and the gain caused by maintaining a constant diameter, and the avoidance of abrupt shoulders is great.

A special eccentric fitting is shown on page 141. Fittings of this class that are eccentric on both the "run" and the branch, are sometimes used.

Eccentric fittings can also be formed by using eccentric bushings on the ordinary unreduced tees. They, however, do not form as good an alignment at the top of the pipe as the special eccentric fitting, for the reason that some appreciable thickness must intervene between the outside and inside diameter of the bushing at its thinnest side.

CHAPTER XXIX.

TESTING HOT-WATER RADIATORS.

The Manner of Preparing the Radiators—Where to Place Thermometers on Them—How to Conduct Comparative Tests—Specific Heat of Metals—Units of Heat in the Iron and the Hot Water it Contains—Units of Heat Given Off by the Radiators—Table of Specific Heat of Metals, etc.—Table of the Weight of a Cubic Foot of Water at Different Temperatures —Diagram Showing the Weight of a Cubic Foot of Water at Various Temperatures.

I am often asked by practical men the best method for testing the comparative value of hot-water radiators.

In my judgment, the subject admits of but a single reply, and that is: There is but one method of testing the efficiency of a radiator for hot-water heating that will be accepted by a scientific investigation.

Many practical men hang thermometers at a fixed distance above the radiators that are to be compared, and note the rise of the mercury. This may be a slight guide in a general way as tending to indicate the temperature at which the air leaves the radiator, but as to how much of the rise of temperature is due to radiation, and how much to the warm current is difficult to determine, and therefore such tests have no value.

Take a radiator without a top and let the thermometer be exactly over a tube, and then both the direct radiation and the centre of the warm current of air will act on it. Let the top of the same tube be flat, and the influence of direct radiation against the bulb will be greater than with a pointed top, the distance of the thermometer from the top of the tube being the same. Take radiators with fretwork tops, and in like manner a hot current from a favorable round hole in the top of one may impinge on the bulb, while in another the thermometer may be over a solid or close part of the fretwork through which the air comes poorly, and by which direct radiation is almost entirely shut off.

Again, take radiators made without tops, or box or flat coils, and try and compare them with radiators with marble tops, or with each other. How can it be accomplished in this manner when everything is so dissimilar?

Aside from all this, it is impossible to get anything like quantitative analyses by such a method, and it would be no surprise to me if it were found that a radiator apparently doing the highest duty was really the lowest in efficiency, when tried by a method that measured and accounted for the units of heat given off in a certain time.

When dealing with steam radiators the water of condensation can be collected and weighed, and the work or duty that is done computed with great accuracy in the hands of a competent person. When dealing with hot-water radiators close approximations to the truth can be obtained (1) by knowing the weight of iron in the radiator and its specific heat; (2) by knowing the number of pounds of water the radiator contains, and (3) by noting the number of degrees the whole radiator and contents will cool in a given time, counting from the moment the passage of hot water is interrupted on its way through the radiator.

Presumably the proper way to appeal to practical men in this matter is to go through an example with them, describing in detail, as we progress, the *modus operandi*:

(1) Let us assume, therefore, that we have a radiator of 100 square feet of surface, and that we desire to measure its efficiency under conditions of ordinary practice.

(2) Assume that the water enters the radiator at 205 degrees and leaves it at 195° fahr., so as to have its *mean* temperature while passing through the radiator 200° fahr.

(3) Assume the temperature of the room in which the experiment is to be conducted to be 60 degrees, and that this temperature is kept constant during the experiment, or that the room is so large that the heat imparted by the radiator is not sufficient to materially change its temperature; or, if this cannot be done on account of the room being small, then the temperature of the room at the commencement and end

of the trial must be taken and a mean or average struck; but, if possible, select a room where the temperature can be kept uniform.

The radiator or radiators should be placed in positions exactly alike and as near to the conditions of ordinary use and practice as possible, though for comparative tests, if they are arranged on broad platforms near the centre of the room, and as far distant from each other as convenient or possible, it will be better than if they are against walls. They must also be so far from each other that the radiation of one cannot materially influence the other, and for this reason if a screen of white cloth is placed midway between them (but in such a

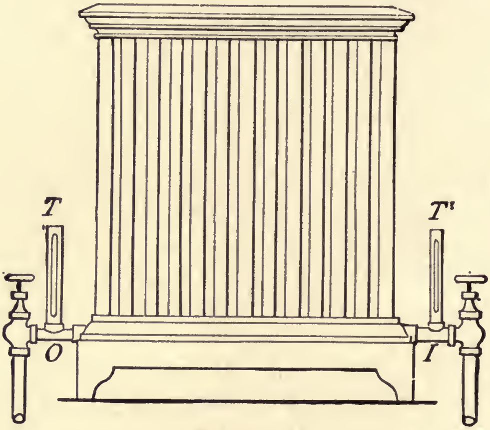


Fig. 203.

manner that it will not prevent the air from coming freely in contact with the radiators) it will be of advantage as tending to make the test more equable, and as preventing error by more nearly eliminating the possibility of one radiator conflicting with the other. Positions, of course, should be transposed and the tests made over again when comparing rival radiators to find how closely the second test agreed with the results of the first trial, and to judge whether the difference found to exist between the radiators was not due to some local cause rather than to the kind and form of the radiating surface.

Taking the radiator then of 100 square feet, as at first assumed, we should screw both nipples into it and put one valve on it, after which it should be weighed carefully and the weight noted, which weight we will assume to be 450 pounds. We will also assume it is made of cast iron, so as to determine its specific heat hereafter, as the specific heats of cast and wrought iron are somewhat different.

The reason for weighing but one valve is that on the supposition that when the valve on each end of the radiator is closed and the current of water interrupted, as it will be hereafter, but one-half of each valve will enter into the weight of

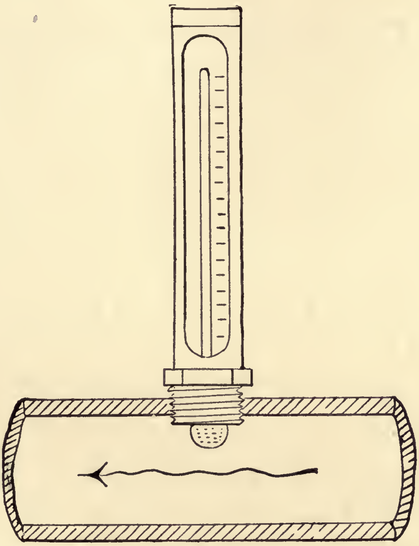


Fig. 204.

the radiator that is cooling, the water being divided by the disk of each valve.

Having found the weight of the metal of the radiator we should then fill it with cold water at a temperature of say 40° fahr., or whatever we can obtain and note the temperature, taking care that all the air is out of the radiator. Then weigh the radiator and the water, and by deducting one weight from the other we have the exact number of pounds of water the radiator will contain at 40° fahr., which we will assume to be 300 pounds.

We then connect the radiator as shown in Fig. 203 with thermometers *T T* at inlet and outlet, let into the nipples as shown in Fig. 204.

The radiator is then connected and filled, the air being expelled, and the water allowed to warm and circulate. After being in operation a sufficient time to leave no doubt but that the iron is as hot as the water, or as nearly so as it will ever become, the temperatures as shown by the thermometers at the inlet, *I*, and at the outlet, *O*, should be taken and noted, the valves being instantly and simultaneously closed and the time noted.

Previously we had assumed the water to be 205 degrees at inlet and 195 degrees at outlet, so the mean temperature of the water at the moment of closing the valves will be 200° fahr.

We now wait and note the cooling of the water that has been thus shut up within the radiator, and we know the iron of the radiator is cooling in the same ratio, so that we have 450 pounds of cast iron, and something less than 300 pounds of water cooling and giving off heat.

At the end of say 45 minutes we find that the water, etc., has cooled to a mean temperature of 150° fahr. That is, we find that since the water was shut off it has equalized in temperature between the ends of the radiator, and that the thermometers now show a temperature of about 151 degrees and 149 degrees, respectively, or they may be closer; but what is most necessary to observe is that when the reading of the thermometers added together and divided by 2 gives an answer of 150 degrees or any other suitable temperature, the experiment can be stopped and the lapse of time noted.

I said there would be somewhat less than 300 pounds of water in the radiator at the moment of closing the valves, although we found it took 300 pounds to fill it at the commencement of the experiment. This is due to the fact that water at 200 degrees occupies more space than water at 40 degrees, the volume in the former case being 1.039, and the specific gravity .9622, while in the latter case it is 1.000, and the specific gravity 1.000, or if we desire to represent the matter more plainly to a practical man, we may say that the weight of a cubic foot of water at 40° fahr. is 62.4 pounds, whereas at 200°

fahr. it is 60 pounds, and that the 300 pounds of water at 40 degrees increases in weight in the ratio of 62.4 and 60. for this particular difference of temperature. Therefore we have

$$\frac{300 \text{ lbs.} \times 60}{62.4} = 288.46$$

pounds as the weight of water that was in the radiator when the valves were closed.

We have also, however, 450 pounds of cast iron to cool, and we are at liberty here to figure the units of heat in 450 pounds of cast iron cooled 50 degrees and proceed accordingly; but if we are to make a number of experiments with any particular heater, it is better that we should reduce the iron to the equivalent of water, and add it to the 288.46 pounds already obtained, and figure the whole as so much water.

The specific heat of cast iron is .1298 (according to Regnault) where water is unity. Therefore 450 pounds of cast iron multiplied by .1298, and divided by 1. = its equivalent in water, which is

$$\frac{450 \text{ pounds} \times .1298}{1} = 58.41 \text{ pounds.}$$

Add together then the actual pounds of water in the radiator (288.46 pounds), the equivalent in water of the iron which forms the radiator (58.40 pounds), and we have 346.86 pounds as the total equivalent of the radiator and its water when reduced to the common value of water in its capacity to store heat.

We have accordingly 346.86 pounds of water cooled from a mean temperature of 200 degrees to a mean temperature of 150 degrees, which of course is 50 degrees. Therefore 346.86 pounds × 50 degrees = 17343. heat units as the sum total of the heat given off by the radiator for 45 minutes.

To use this for standard comparison (as with other radiators or other conditions the time and amount of heat abstracted from the water will in all probability be different) we had better find the units of heat given off per square foot of surface, per degree difference of temperature between the air of the room and the temperature of the radiator.

The temperature of the air of the room we assumed or found to be 60 degrees. The temperature of the water in the radiator at the commencement of the test was 200 and at the finish 150 degrees. So that we have

$$\frac{200° + 150°}{2} = 175°$$

as the mean temperature of the radiator during the trial.

The temperature of the room being 60 degrees, we then have $175° - 60° = 115°$ as the difference between the radiator and the air of the room.

Divide this difference (115 degrees) into the total heat (17343 heat units), and we have 150.8087 as the units of heat given off in forty-five minutes by the whole radiator (100 square feet) for each degree that the radiator is warmer than the air.

Divide 150.808 heat units by 100 square feet and we have 1.50808 as the units of heat given off by a single square foot of surface for each degree that the radiator is warmer than the air, the time being still forty-five minutes.

If, therefore, the radiator gives off 1.50808 heat units per degree of difference of temperature between the radiator and the air for forty-five minutes, it gives off 2.011 heat units for an hour, as thus obtained

$$\frac{1.50808 \times 60 \text{ inches}}{45''} = 2.01077 \text{ heat units.}$$

As I remarked at the commencement, this result is a close approximation to the truth. Errors in mercurial thermometers and the expansion of the iron envelope of the water are likely to cause slight differences, however, and therefore from the point of scientific research the result is not perfect. For comparative purposes, however, with the same instruments well compared and the differences noted, pretty accurate work can be accomplished in the hands of an experienced person, and the errors confined to within one or two per cent.

The following is a table of the specific heat of metals and other substances likely to be used for radiators or experimental purposes, which will prove useful in making tests:

TABLE XIII.—SPECIFIC HEAT OF METALS, ETC.

Cast iron	.1298*	Regnault
Wrought iron	.1138	"
Zinc	.0955	"
Copper	.0950	"
Tin	.0569	"
Glass	.1937	"
Water	1.0000	"

* These numbers are very close approximations to the truth, however, and will do for our purpose.

Tables by other authorities may show slightly different results.

The weight of a unit of water at different temperatures is also of importance in these calculations as was shown before. I therefore append a table of the weights of a cubic foot of water at different temperatures, advancing by ten degrees from 40° to 500° fahr.

TABLE XIV.—TABLE OF THE WEIGHTS OF A CUBIC FOOT OF WATER AT VARIOUS TEMPERATURES.

Temperature of water	Pounds per cubic foot	Temperature of water	Pounds per cubic foot
40	62.408	200	60.096
50	62.380	210	59.866
60	62.332	212	59.824
70	62.264	220	59.620
80	62.170	230	59.37
90	62.062	240	59.12
100	61.944	250	58.86
110	61.808	275	58.17
120	61.660	300	57.44
130	61.502	325	56.70
140	61.334	350	55.94
150	61.148	375	55.14
160	60.958	400	54.32
170	60.768	450	52.67
180	60.544	500	51.02
190	60.324	...	.....

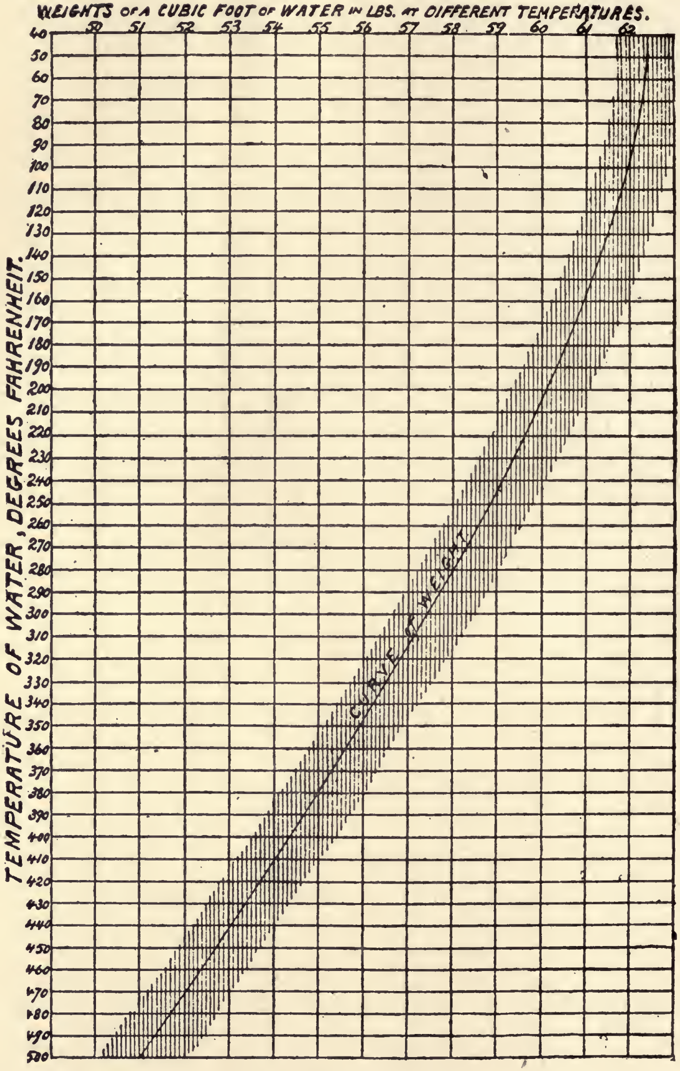

WEIGHTS OF A CUBIC FOOT OF WATER IN LBS. AT DIFFERENT TEMPERATURES.
50 51 52 53 54 55 56 57 58 59 60 61 62
TEMPERATURE OF WATER, DEGREES FAHRENHEIT.
40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400 410 420 430 440 450 460 470 480 490 500
CURVE OF WEIGHT

FIG. 205.

The weight of any fixed bulk of water must vary as the weight of a cubic foot of the same varies at different temperatures. Therefore, knowing the number of pounds of water that will fill any space or radiator at some stated temperature, the number of pounds weight of water which the same space will hold at a different temperature can be found by multiplying the original weight by the number opposite the new temperature and dividing by the number opposite the original temperature in the table.

Example: Assume a box filled with water at 80° fahr. to weigh 300 pounds, what will it weigh when filled with water at 275° fahr.? Opposite 80 degrees is 62.17 and opposite 275 degrees is 58.17.

Therefore,

$$\frac{300 \text{ pounds} \times 58.17}{62.17} = 280.07 \text{ pounds.}$$

The accompanying diagram (Fig. 205) shows the curve of the weight of a cubic foot of water for different temperatures from 40° to 500° fahr.

By the aid of the decimal lines close approximations can be made in the matter of weights per cubic foot in the case of temperatures not found in the table. Thus for a temperature of 245 degrees the weight is very nearly 59 pounds, as can be seen by observing where the curve crosses the 59 pound line, though the intersection shows the weight to be rather less than 59 pounds.

CHAPTER XXX.

POSITION OF THERMOMETERS ON HOT-WATER APPARATUS.

The attachment of a thermometer to a pipe appears such a simple matter at first thought, that one who has not considered it carefully is likely to imagine it is a waste of words to dwell on it.

The object of using a thermometer on a hot-water pipe is to find the temperature of the water within the pipe, and to record this temperature with anything like accuracy the thermometer must be properly located.

The bulb of a thermometer should dip into the moving current of the water in a flow or return pipe, if reasonable accuracy is required. It must also offer little or no resistance to the flow of the water, especially in pipes of small diameter.

The ordinary bulb has not sufficient magnitude of itself to offer any considerable resistance to the passage of the water, unless in a very small pipe. The brass casing which covers it and protects it from fracture, however, is about an inch in diameter—three-quarters of an inch, pipe measure, or 1.05 inches actual—and this offers resistance when screwed through the side of a pipe. Therefore, in pipe of 2 inches in diameter, or less, the effect on the water of passing it directly through a pipe must not be overlooked.

The thermometer shown on page 277 in the chapter on Testing Hot-Water Radiators is a special one, in which the bulb is not protected, but in the regular commercial thermometers for hot water the safety tube passes below the bulb, as shown in section in Fig. 206 at *a*.

To avoid presenting an obstruction to the flow of the water, and also because it is more convenient to the fitter, a *tee* is often used in the pipe and the thermometer is screwed into it, as shown in Fig. 207.

This presents no material obstruction to the flow of the water, but it forms an air pocket, and in a short time the ball of the thermometer is not surrounded by water but by air, and the true temperature of the water is not recorded.

It sometimes happens the fitter will use an upper corner of the flow pipe, say just above the boiler, and insert a T instead

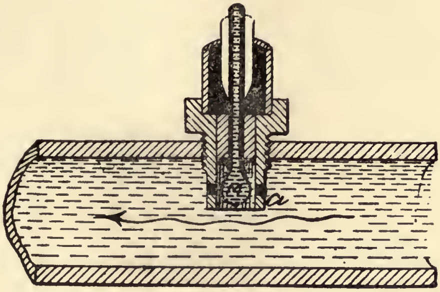


FIG. 206.

of an elbow, as shown in Fig. 208. He probably has not a tee that is reduced on "the run," and he therefore uses a bushing or perhaps two of them and puts his thermometer in this improvised arrangement, with the result of having a deeper air

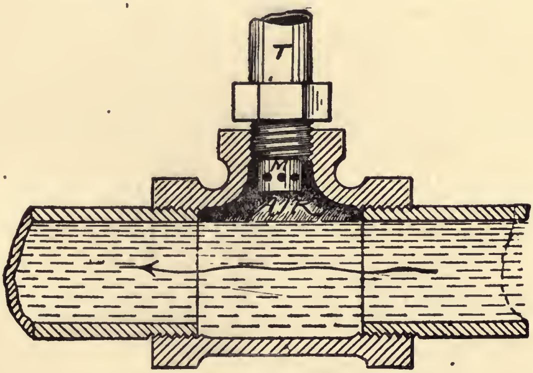


FIG. 207.

pocket than before and a greater difference existing between the actual temperature of the water and what the thermometer shows, than with the arrangement shown in Fig 207.

Should he only conceive the idea of putting a valve between the thermometer, *T*, Figs. 208, and the bushing, *B*, using two nipples, one above and the other below the valve, for the purpose of getting at the thermometer without drawing the water from the apparatus he has a still deeper air pocket, and the

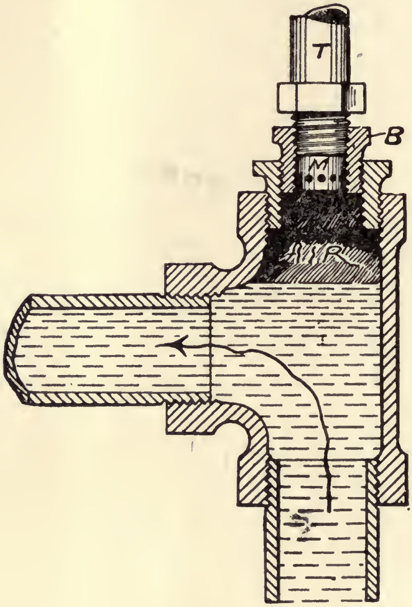


FIG. 208.

thermometer will be indicating something. far from the temperature of the water.

The remedy is to either put the bulb in the water through the side of the pipe as in Fig. 206, or to use a tee as in Fig. 207,

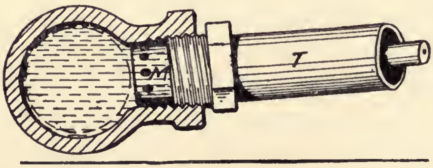


FIG. 209.

and place it on its side, or nearly so, as shown in Fig. 209, in which position the air cannot be collected or held by the *tee*.

If a thermometer must be so placed on an apparatus that it can be cut off with valves, then it is better to place it in a small shunt circuit, with a valve on each side of it, as in Fig. 210 at *T*, and carry the bulb well down.

Sufficient water will pass through this circuit to give a close approximation to the true temperature of the water in the main pipe.

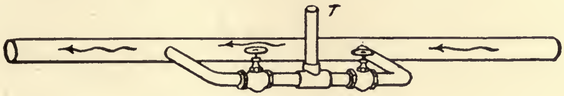


Fig. 210.

It is sometimes desirable to know the temperature of the water in an apparatus at distant points and in places where a permanent thermometer is not required. In such cases the writer has found that when an ordinary glass thermometer,

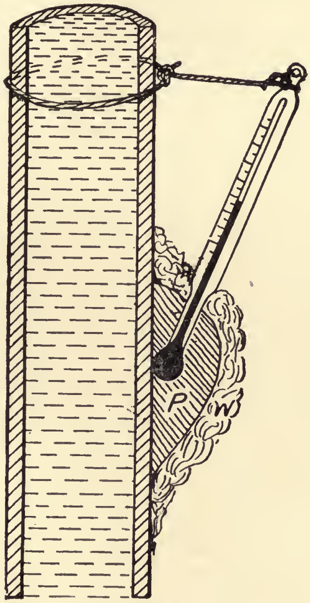


Fig. 211.

but without a metal case—such as is used for testing the temperature of liquids—is placed against a pipe as shown in Fig. 211, and a ball of soft putty pressed over the bulb, so as to make a close contact with the pipe, the thermometer will register within one degree of the actual temperature of the water within the pipe.

The putty heats rapidly and the oil, etc., of which it is made conducts the heat to the bulb. Over the putty I place cotton waste. so as to reduce the cooling action of the air to a minimum. One point of the bulb also comes in direct contact with the iron of the pipe, and while the putty is fresh good results can be otbained.

When comparing the temperatures of radiators in a new apparatus this method will be found convenient, as it saves time and expense, and for comparative purposes is presumably as good as any other.

CHAPTER XXXI.

FORCED HOT-WATER CIRCULATION.

A forced circulation of hot water is sometimes resorted to when conditions make it impossible to obtain a satisfactory circulation in the ordinary way.

It may be that the radiators are at a lower level than the boiler, in which case the cooling of the water in the radiators will not tend to promote a circulation. It may be that the radiators are so far distant from the boiler or heater that it would be necessary to use very large flow and return pipes, should we depend for the circulating force only upon the difference in temperature between the water in the flow and return pipes and upon the elevation of the radiating surfaces above the boiler.

Forced hot water circulating systems have been used when it has been desired to heat a group of buildings from some central source. In certain cities also, particularly in Ohio, underground hot water systems have been installed to furnish heat for a number of private residences.

Exhaust steam is often used to heat the water which is circulated between the power house and the various buildings. One of the advantages claimed for this method of heating is, that heat from the exhaust steam may be taken up by the water, when exhaust steam is available and that this heat may be given out by the various radiators after the supply of exhaust steam itself ceases. In this way it may be possible to distribute the heating effects of the exhaust steam over periods during which no exhaust steam is available for heating, or it may be possible to store up some of the heat of the exhaust steam during periods in which the exhaust steam is in excess of what would normally be required by the heating system, and then to utilize this stored-up heat during periods in which the exhaust steam is less than what would normally be required by the heating system.

It is also claimed that it is possible to reduce the back pressure on an engine over what is possible if exhaust steam at or near atmospheric pressure is circulated within the various radiators. When we consider the back pressure on an engine in connection with a heating system, we should consider it under two different conditions, viz.:

a. When we are able to utilize all of the exhaust steam in heating.

b. When we are not able to utilize all of the exhaust steam in heating.

In the first case (where we are able to utilize all of the exhaust steam advantageously in heating), it makes very little difference in steam economy whether or not we have a small back pressure on the engine. In other words, our total economy is not appreciably affected, whether the engine runs with a very small back pressure and we use the exhaust steam plus a certain amount of live steam in order to do our heating, or whether the engine runs with a somewhat larger back pressure (requiring therefor more steam per horse power) and we use the exhaust steam now available plus a smaller amount of live steam than heretofore.

In the second case (when we are not able to utilize all of the exhaust steam in the heating apparatus), it is of course desirable to reduce the back pressure on the engine. There are, however, two conditions to be considered viz.:

a. When the excess of exhaust steam must be exhausted into the atmosphere.

b. When the excess of exhaust steam can be condensed in a surface or jet condenser.

In the first case (when the excess of exhaust steam must be exhausted into the atmosphere) it will be necessary to carry an engine back pressure slightly above the atmosphere and as the ordinary heating apparatus can usually be operated at a pressure very little above the atmosphere, we are not likely to show much of a reduction in engine back pressure.

If, however, the heat must be carried to buildings located at a great distance from the power house, it may be that a considerable reduction in engine back pressure may be secured by the forced circulation of warm water in place of the exhaust steam.

In the second case when a surface or jet condenser is used to condense the exhaust steam, which is not required in the heating apparatus, it may be possible to operate the engine at times with a back pressure below the atmosphere. The surface or jet condenser necessitates the use of dry and wet vacuum pumps, etc., and it is often considered that it is not worth while to install this apparatus.

The forced hot-water heating system will of course give us the same possibility of easy temperature control by mean of the ordinary radiator valve, which the ordinary gravity hot water heating system possesses.

The fact also that a hot-water heating system can be run at a temperature below that of exhaust steam at atmospheric pressure may result in a saving due to the smaller loss by radiation from the mains.

In designing a forced hot-water heating system, there are certain points which should be borne in mind. It is desirable in the first place to properly provide for the air within the system. The main pipes should, if possible, pitch so that air will tend to pass in the direction in which the water flows. For it will be found that with the high water velocities that may be used in a forced hot-water system, the water within the pipes will tend to carry the air along with it, even though the pitch of the pipes would tend to carry the air in an opposite direction. It is best, therefore, to pitch the main pipes so that they rise slightly in the direction in which the water flows. This of course is true of both the flow and the return pipes. Where there is a drop in the main or a point at which air would tend to collect, small air relief traps are often used. These traps consist simply of a small tank or receptacle with a valve controlled by a float. They are so arranged that the float falls, when air collects, and the falling of the float opens a valve which allows the escape of the air, with a subsequent lifting of the water level in the tank to some predetermined point. It is a good idea to carry the overflow or discharge pipe from this tank down to a sink or other appropriate waste. The pipe should terminate with an open end above the sink the intention being to carry water from the tank where it will do no harm in case the valve operated by the float does not close tightly and yet to arrange this overflow pipe so that if water escapes, it will be noticed and the leaky valve repaired.

Where radiators can be connected so that air from the same will pass back into the mains, radiator air valves or cocks may not be essential. In other cases air valves or cocks must of course be provided.

The mains in a forced hot water heating system should be arranged if possible, so that all radiators supplied by one set of mains will have approximately equal tendencies to circulate. By this means we may avoid the use of a large number of choke valves. We can then place a choke valve in the return line of each group of mains and if we have a thermometer to show the temperature of the water in each return pipe, it is usually easy to adjust the choke valves so as to obtain the desired drop in temperature in each group of radiators.

A method of piping which is sometimes resorted to, and which may be made to work very well in a forced hot water circulating system, is to connect a series of radiators (both inlet and outlet connections) to a single main. If the radiators stand at a sufficient height above the main, and if we circulate the water through the main, so as to keep the water in the main itself hot, the cooling of the water within each radiator, together with the elevation above the main, will be enough to maintain the circulation through the radiator. The return water from each radiator will, of course, mingle with the hot water which goes to supply each succeeding radiator and the hot water flowing into each radiator will be slightly cooler than that which was furnished to the radiator ahead. It is not difficult, however, to maintain a circulation sufficiently rapid in the main hot water pipe so that there will be only a small difference between the temperature of the water furnished to the first radiator and that furnished to the last radiator in the series. In this arrangement one might ask, what there is to cause a circulation through an individual radiator in one direction rather than in the other. There seems to be no apparent reason why the water should start to circulate in either direction, if both connections are taken from the heating main in a similar manner. Nevertheless so difficult is it for the conditions to be exactly the same in the case of both connections that the water will start to circulate almost immediately either in one direction or in the other. When the circulation begins, we have a difference in the temperature of the water in the two connections, which will of course maintain the circulation.

A centrifugal pump is often used to produce the circulation in a forced hot water system. The reason for this is, that, while the difference in pressure that the pump must produce should remain about constant, the quantity of water to be pumped may vary greatly. It is possible to obtain satisfactory results also with a piston or plunger pump. A by-pass around the pump may be provided through which the excess of water may pass, when the pressure produced by the pump runs above some fixed limit or the pump may be controlled automatically (as house pumps are often controlled) so as to maintain a fixed pressure upon its discharge *side*.

CHAPTER XXXII.

MISCELLANEOUS MATTER, TABLES, ETC.

House of Notre Dame—Table of Contents of Pipes—Table of the Coefficients of Expansion of Water.

On page 141 allusion was made to the system of piping used in the House of Notre Dame, Toronto, pointing out its impracticability for very large buildings.

This building has probably less than 200,000 cubic feet of space, and yet it requires twenty separate circuits of main pipes, all starting from and returning to the boilers, to secure the necessary circulation of the water for about fifty radiators. The system has its advocates, however, and in the present instance the work is well arranged and forms a good guide to any one desirous of using two or more boilers with such a system. I, therefore, give it in full as it appeared in *The Engineering and Building Record*, April 21, 1888, from a correspondent while investigating the methods of warming buildings by hot water in Canada.

HOT-WATER BOILERS AND FLOW-PIPES IN THE HOUSE OF NOTRE DAME, TORONTO, ONTARIO.

He writes: "The extraordinary small space occupied by the boilers in this building compared to the space required for steam boilers for the same sized building surprised me. The actual floor-space of the two boilers was only 7 feet 3 inches by 4 feet. This, of course, did not include the fire-room and the space taken up by the connections. The latter, however, take up a great deal more room than the boilers, although they occupy much less space than any steam boilers that would be suitable for such a building. I was unable to find the amount of heating surface in the building on account of the difficulty of going through the rooms, but I was enabled to make sketches and measurements of the boilers and the pipes, which you will see in Figs. 212 and 213.

"As all the valves on the flow-pipes were tagged and numbered, and the rooms they controlled marked on them, I by this means approximated the surface as given hereafter.

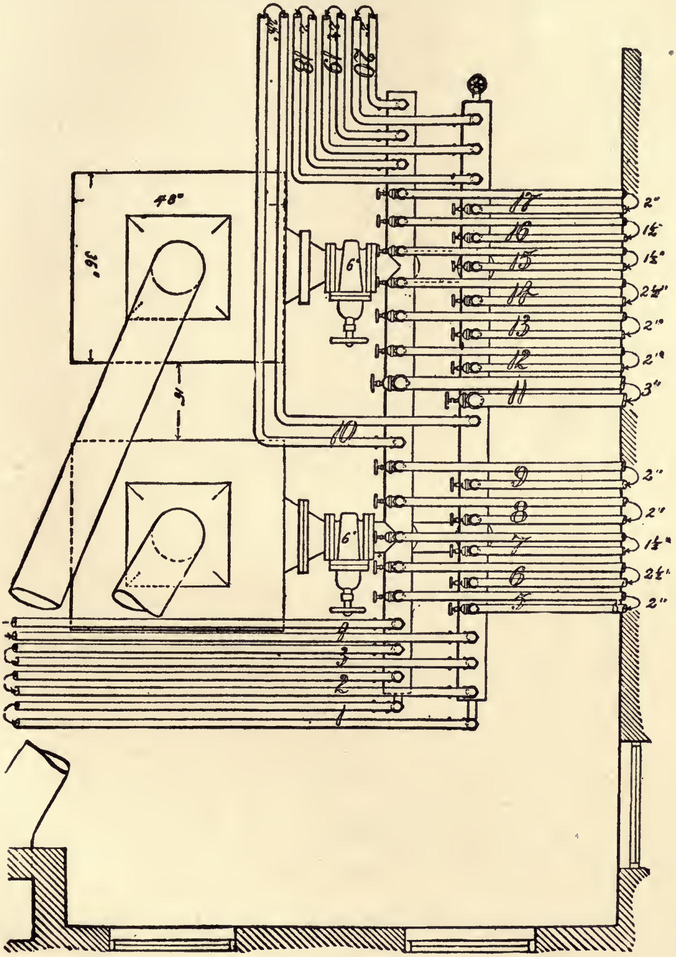


FIG. 212.

"It will be noticed a 6-inch valve controls the main flow and return pipe of each boiler. To each valve is joined a header or manifold, and from these manifolds the flow and return pipe for each subdivision of the house is taken in pipes ranging from 3 inches to 1½ inches in diameter, as will be seen by reference to Fig. 212. Each couple or circuit is numbered from 1 to 20, inclusive, and the size of the pipes, with the rooms of the building they supply, 1 an approximate estimate of the surface is given in the following list by one who is accustomed to heating apparatus.

"Circuit No. 1.—Size, 2½ inches; rooms supplied are chapel, practice-room and bath-room; square foot surface probably not under 400 feet.

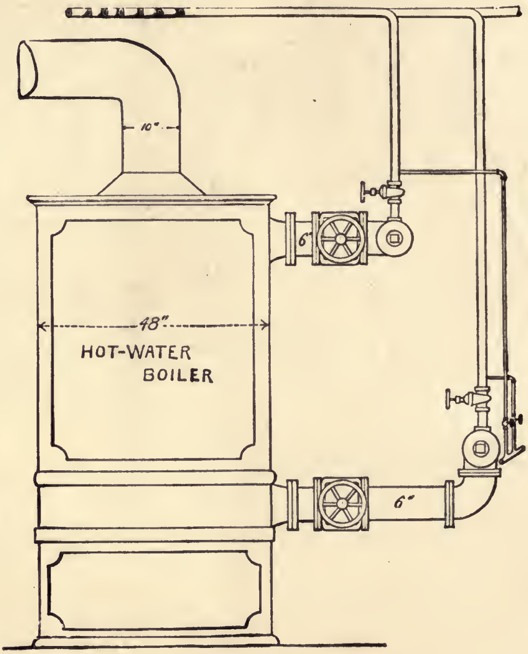


Fig. 213.

"Circuit No. 2.—Size, 2 inches; large bath-rooms; surface, 150 square feet.

"Circuit No. 3.—Size, 1½ inches; bath-room; surface, 75 square feet.

"Circuit No. 4.—Size, 1½ inches; two coils in chapel; surface, 100 square feet.

"Circuit No. 5.—Size, 2 inches; coil, south-west corner sitting-room, first floor; 120 square feet.

"Circuit No. 6.—Sitting-room, second floor, and girls' dormitory; size, 2½ inches; 250 square feet.

"Circuit No. 7.—Size, 1½ inches; breakfast-room; and room C 100 square feet.

"Circuit No. 8.—Size, 2 inchcs; rooms 2 and 4 and water-closet; 150 square feet.

"Circuit No. 9.—Size, 2 inches; room A and parlor; 200 square feet.

"Circuit No. 10.—Size, 2½ inches; reception-room and two vestibules; 300 to 400 square feet.

"Circuit No. 11.—Size, 3 inches; top floor and new hall; 400 or 500 square feet.

"Circuit No. 12.—Size, 2 inches; rooms 29, 30, 31, and corridor; 150 square feet.

"Circuit No. 13.—Size, 2 inches; rooms 6, 7, and 8; 150 square feet.

"Circuit No. 14.—Size, 2½ inches; corridor 1 and room D; 200 square feet.

"Circuit No. 15.—Size, 1½ inches; corridor 2 and room 14; wall coil, 120 square feet.

"Circuit No. 16.—Size, 1½ inches; top floor; wall coil, 100 square feet.

"Circuit No. 17.—Size, 2 inches; back hall and office; 150 square feet.

"Circuit No. 18.—Size, 2 inches; north wing; library and reading-room; 150 to 200 square feet.

"Circuit No. 19.—Size, 2½ inches; north wing, first floor; 300 to 400 square feet.

"Circuit No. 20.—Size, 2 inches; corridor, north wing, closets, etc.; 150 square feet.

"The total surface in this building cannot be much short of 3700 square feet, and a room 12 by 12 feet is certainly more than ample for the plant, so far as boilers and valves are concerned.

"The necessity for so many small pipes or circuits I cannot see the philosophy of. Still it is the result of practice here, and men who have tried a branched system instead say they cannot get as good results and are not as sure of the results they will obtain as with the system shown here.

"The heat from these mains is, as a general thing, not lost.

It warms the halls and rooms of the basement and their influence is felt through the whole house, and correspondingly less surface is required in many of the upper parts of the building.

TABLE XV.—CONTENTS OF STANDARD WROUGHT-IRON PIPES.

Nominal internal diameter of pipe	Length of pipe containing one cubic foot*	Cubic feet in one foot length of standard pipe	Weight of water in one foot of pipe, pounds
¾-in.	270.00	....	.25
1-in.	166.90	.006	.37
1¼-in.	96.25	.010	.647
1½-in.	70.66	.014	.881
2-in .	42.91	.023	1.45
2½-in.	30.10	.032	2.07
3-in.	19.50	.051	3.20
3½-in.	14.57	.069	4.28
4-in.	11.31	.088	5.50
4½-in.	9.02	.111	6.92
5-in.	7.20	.138	8.63
6-in.	4.98	.197	12.25
7-in.	3.72	.27	16.87
8-in.	2.88	.34	21.616
9-in.	2.29	.44	27.25
10-in.	1.82	.55	34.50
11-in.	1.51	.660	41.50
12-in.	1.27	.785	49.00
13-in.	1.04	.957	59.85
14-in.	.903	1.107	68.93
15-in.	.77	1.300	82.20
16-in.	.68	1.47	91.70
17-in.	.61	1.56	102.05
1st col.	2d col.	3d col.	4th col.

* A pipe seldom contains less water than the quantity given in the table. It may, however, contain somewhat more, for when pipe has not the full thickness, and its outside diameter remains of standard size, the internal diameter must be greater than the nominal.

"The means of drawing the water from any single circuit is shown in Fig. 213. A pipe of small diameter is joined with the flow and return pipe just above the return stop-valve in each case."

The fuel used in this building was given at *three* tons per week in cold weather.

Contents of Pipes of an Apparatus.

In designing expansion tanks for a hot water apparatus it is not only necessary to be able to ascertain the increment of the expansion of the water due to the greatest rise in temperature, but it is also necessary to be able to give some correct estimate of the amount of water it contains; or, in other words, the cubic contents of the apparatus, which of course consist of boiler, pipes and radiators or coils of all descriptions.

In estimating boilers it is either necessary to take the maker's rating of their cubic contents or figure it out for yourself, according to the mensuration of solids if you have any doubt as to the correctness of their figures.

The above also applies to all radiators of any class whatsoever not made of merchantable pipe.

The water contained in the mains and pipes of an apparatus, however, and by radiators made of ordinary wrought-iron pipe can best be estimated by the quantities of water given in the standard table of wrought-iron pipe used by all the manufacturers in the United States and from which I take the second column in Table XV; the remaining columns (3d and 4th) are calculated.

Coefficients of the Expansion of Water.

Different formulæ for the expansion of water give slightly different results, and as a consequence tables to be found in popular hand-books seldom agree.

The difference, however, is not great, and the result as a whole simply goes to prove that the separate investigators arrived at results practically the same, as shown by the following Table (No. XVI):

TABLE XVI.

Temperature of water	Coefficients of the Expansion of Water from Various Sources.				
	From Haswell's tables by Dalton's method. Water at 72° expands $\frac{1}{.0018}$	From table in Nystrom's Mechanics	Thomas Box's table calculated by Tredgold's rule	From Hood's treatise on Heat; Dr. Young's formula	D. K. Clark by Rankin s formula
39	....	1.0000	....	1.00000	....
40	1.000	1.000002	1.00000	....	....
46	....	....	....	....	1.0000
50	....	1.000254	....	....	1.00015
52	1.00021	1.000353	1.0005123	1.00036	1.00029
60	....	1.000901	....	....	1.00074
62	1.00083	1.001075	1.0014070	....	1.00101
70	....	1.001909	....	1.00198	1.00160
72	1.00180	1.002151	1.002627	....	....
80	....	1.003249	....	....	1.00299
82	1.00312	1.003554	1.004143	1.00371	....
90	....	1.004894	....	....	1.00459
92	1.00477	1.005253	1.005901	....	....
100	....	1.006822	....	1.00718	1.00639
102	1.00672	1.007240	1.007911	....	....
110	....	1.009032	....	....	1.00889
112	1.00880	1.009479	1.010150	1.01001	....
120	....	1.011442	....	....	1.01139
122	1.01116	1.011956	1.01261	....	....
130	....	1.014198	....	1.01490	1.01390
132	1.01367	....	1.01527	....	....
140	....	1.016962	....	....	1.01690
142	1.01638	....	1.01814	1.01835	....
150	....	1.020021	....	....	1.01989
152	1.01934	....	1.02120	....	....
160	....	1.023262	....	1.02441	1.02340
162	1.02245	....	1.02443	....	....
170	....	1.026672	....	....	1.02690
172	1.02575	....	1.02788	1.02856	....
180	....	1.030242	....	....	1.03100
182	1.02916	....	1.03148	....	....
190	....	1.033960	....	1.03501	1.03500
192	1.03265	....	1.03526	....	....
200	....	1.037819	....	....	1.03889
202	1.03634	....	1.03922	1.03939	....
210	....	1.041809	....	....	....
212	1.04012	1.042622	1.04333	1.04306	1.0444

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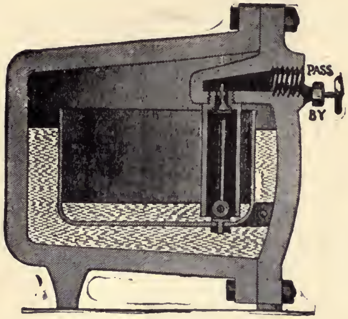

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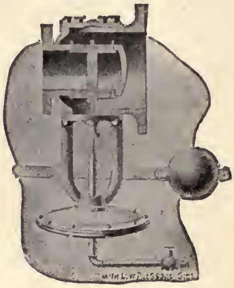

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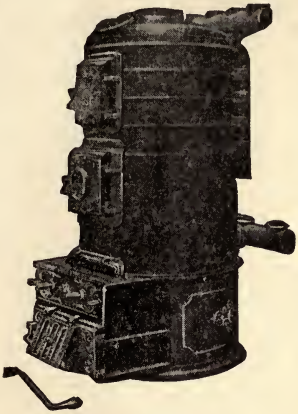

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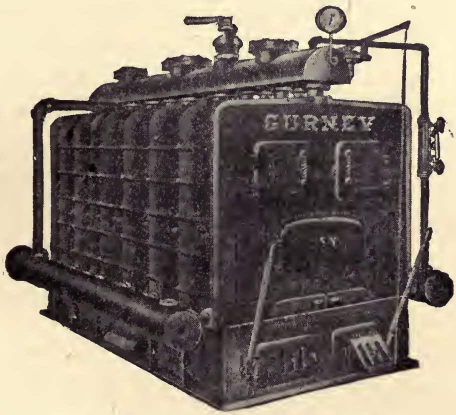

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