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By
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STEAM HEATING

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STEAM-HEATING APPLIANCES

PIPES AND FITTINGS

INTRODUCTION

1. In the erection of steam-heating apparatus, pipes and various fittings having a shape suitable for the requirements are used. The fittings are made of cast iron, brass, malleable iron, and steel castings, tapped or otherwise finished to connect the pipes together. The pipes used in most of the work are plain uncoated wrought iron and mild steel.

2. For connecting pipes to the fittings, screw threads are generally used. These threads have a standard number of threads to the inch for different sizes of iron pipe, and the fittings are tapped with threads to suit the thread of the pipe. The threads are made with a slight taper, the thread in cutting starting with a small groove, increasing in depth until a full thread is cut. They are usually made *right-hand;* that is, the pipe in screwing into the fitting is turned to the right. *Left-hand* threads are also used on pipe and in fittings; in buying pipe, the left-hand thread must be specially ordered, as the regular pipe on the market is threaded only right-hand.

The fittings most commonly used are **elbows**, called **ells**, or **L's**; and **branches**, called **tees**, or **T's**. An ell is used

TABLE I—DIMENSIONS OF STANDARD WROUGHT PIPE

Diameter			Thickness	Circumference		Transverse Areas			Length of Pipe per Square Foot of		Length of Pipe Containing 1 Cubic Foot	Nominal Weight per Foot	Number of Threads per Inch of Screw
Nominal Internal	Actual External	Approximate Internal		External	Internal	External	Internal	Metal	External Surface	Internal Surface			
Inches	Inches	Inches	Inch	Inches	Inches	Square Inches	Square Inches	Square Inches	Feet	Feet	Feet	Pounds	
⅛	.405	.270	.068	1.272	.848	.129	.0573	.0717	9.440	14.150	2,513.000	.241	27
¼	.540	.364	.088	1.696	1.144	.229	.1041	.1249	7.075	10.490	1,383.300	.420	18
⅜	.675	.494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.730	751.200	.559	18
½	.840	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.130	472.400	.837	14
¾	1.050	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270.000	1.115	14
1	1.315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.900	1.668	11½
1¼	1.660	1.380	.140	5.215	4.335	2.164	1.4960	.6680	2.301	2.768	96.250	2.244	11½
1½	1.900	1.611	.145	5.969	5.061	2.835	2.0380	.7970	2.010	2.371	70.660	2.678	11½
2	2.375	2.067	.154	7.461	6.494	4.430	3.3560	1.0740	1.608	1.848	42.910	3.609	11½
2½	2.875	2.468	.204	9.032	7.753	6.492	4.7840	1.7080	1.328	1.547	30.100	5.739	8
3	3.500	3.067	.217	10.996	9.636	9.621	7.3880	2.2430	1.091	1.245	19.500	7.536	8
3½	4.000	3.548	.226	12.566	11.146	12.566	9.8870	2.6790	.955	1.077	14.570	9.001	8
4	4.500	4.026	.237	14.137	12.648	15.904	12.7300	3.1740	.849	.949	11.310	10.665	8
4½	5.000	4.508	.246	15.708	14.162	19.635	15.9610	3.6740	.764	.848	9.020	12.490	8
5	5.563	5.045	.259	17.477	15.849	24.306	19.9900	4.3160	.687	.757	7.200	14.502	8
6	6.625	6.065	.280	20.813	19.054	34.472	28.8880	5.5840	.577	.630	4.980	18.762	8
7	7.625	7.023	.301	23.955	22.063	45.664	38.7380	6.9260	.501	.544	3.720	23.271	8
8	8.625	7.982	.322	27.096	25.076	58.426	50.0400	8.3860	.443	.478	2.880	28.177	8
9	9.625	8.937	.344	30.238	28.076	72.760	62.7300	10.0300	.397	.427	2.290	33.701	8
10	10.750	10.019	.366	33.772	31.477	90.763	78.8390	11.9240	.355	.382	1.820	40.065	8
11	11.750	11.000	.375	36.914	34.558	108.434	95.0330	13.4010	.325	.347	1.510	45.028	8
12	12.750	12.000	.375	40.055	37.700	127.677	113.0980	14.5790	.299	.319	1.270	48.985	8
13	14.000	13.250	.375	43.982	41.626	153.938	137.8870	16.0510	.273	.288	1.040	53.921	8
14	15.000	14.250	.375	47.124	44.768	176.715	159.4850	17.2300	.255	.268	.903	57.893	8
15	16.000	15.430	.285	50.260	48.480	201.060	187.0400	14.0200	.239	.248	.770	62.000	8

to change the direction of a run of a pipe line, and a tee is used to connect a branch line of piping to the main line, or run, of piping, the branch being at right angles to the main line.

STANDARD WROUGHT-IRON AND MILD-STEEL PIPE

3. Standard wrought-iron and mild-steel pipes are made in the sizes and weights shown in Table I. In writing specifications, the words **wrought pipe** are used when the contractor is permitted to use either wrought-iron or steel pipe. The pipe is sold in lengths averaging from about 18 to 20 feet. The small sizes are shipped in bundles convenient for handling. All pipe from ⅛ inch to 1¼ inches nominal diameter is butt-welded, and pipes 1½ inches in diameter and larger are usually lap-welded, although butt-welded pipes can be obtained as large as 3 inches in diameter. The standard weight pipe is usually tested by hydraulic pressure to 300 pounds or more per square inch for the butt-weld sizes, and to 500 pounds pressure or more for the lap-weld sizes. The safe-working pressure for standard pipe is about 100 pounds per square inch; this allows a fair margin of safety to provide for deterioration of the structure of the metal, by expansion and contraction, and for corrosion.

RADIATORS AND COILS

RADIATORS

4. Definitions.—Radiators are metallic bodies so constructed that a large amount of surface is obtained. They are used for warming buildings by emitting heat to the air in the buildings, or to air as it enters buildings. Steam or hot water inside the radiator heats it, which in turn heats the air and other matter surrounding it.

Radiators made of cast iron are known simply as radiators; those made of iron pipe and fittings are called **coils**.

There is a large number of different kinds and styles of radiators manufactured, but they differ chiefly in arrangement and ornamentation. In a general way, they may be classified as *direct radiators*, *indirect radiators*, and *direct-indirect*, or *semidirect*, *radiators*. Nearly all radiators are made of cast-iron sections screwed or bolted together, while nearly all coils are made of wrought-iron or steel pipes screwed into suitable fittings or manifolds.

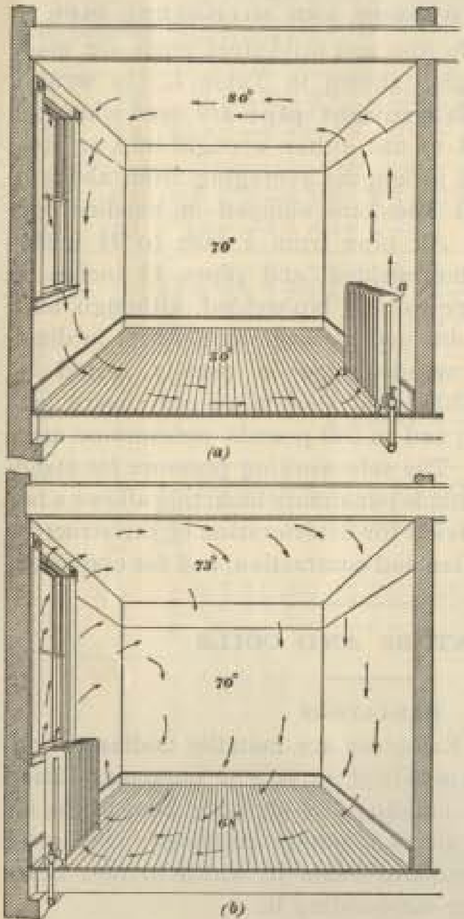

Fig. 1

5. Location of Radiators.—Direct radiators are located inside the rooms or other places to be warmed, and usually stand on the floor. The air in a room that is warmed by direct radiation is therefore reheated and circulated within the room unless special provision is made for changing the air. The proper place to locate a direct radiator is at the coldest place in the room to be warmed. Ordinarily this is under a window at the north or northwest side of the building. Cold winds usually blow in through the crevices of such a window and will make a room uncomfortably cold near the window, even though it is comfortably warm elsewhere. If the radiators are located so that the warm air-currents ascending from them will mix with the incoming cold-air leakage, a nearly uniform temperature can be maintained in the room.

6. Examples of Radiator Location.—Fig. 1 shows two locations for direct radiators in a room, and the air-currents produced by heat from the radiators. In Fig. 1 (*a*), the radiator *a* is shown located against the inner wall. Air cooled by the window *b*, and aided by cold-air leakage, falls to the floor, then flows slowly toward the radiator, where it becomes heated and rises to the ceiling. This produces a circulation in the direction shown by the arrows, the hot air being at the ceiling and the cold air at the floor, while 70° may be obtained in the middle of the room. This is considered bad practice and should be avoided.

In Fig. 1 (*b*), the radiator is shown located under the window. The rising current of warm air, mixing with the cold air falling from the window, not only prevents the cold air from gathering on the floor, but also produces a lower temperature at the ceiling and a higher temperature at the floor. The temperatures marked in these illustrations are not constant; they change with changing conditions.

If a radiator is located in the center of a room the cold air on the floor will travel from all directions toward the radiator, where it will become heated and ascend to the ceiling in the form of a column; the resultant temperatures at floor and ceiling will be similar to those obtained by the system shown in Fig. 1 (*a*).

7. Size of Radiators.—The amount of exterior surface on the radiator designates the size of the radiator. Thus, a 100-square-foot radiator has 100 square feet of outside surface exposed to the air.

The dimensions of the sections of radiators vary with different manufacturers. Cast-iron radiators are constructed of sections that vary in shape, size, and ornamentation according to the manufacturers' ideas. The favorite form of section is a hollow loop, a number of which when connected together at the base, sometimes also at the top, constitute the radiator. Short sections are used for making low radiators; long sections are employed for making high radiators. The standard height of a section is 38 inches above the floor, and manufacturers usually ship radiators of this height if the height is not mentioned in the order. Ordinarily, one section of a two-column loop radiator 38 inches high has 4 square feet of heating surface, that is, outside surface.

There are a number of radiator sections on the market that contain more than 4 feet to a standard section. Some of these have extended surfaces, which form flues, in the heart of the radiators.

TYPES OF DIRECT RADIATORS

8. Operation.—Direct radiators give off heat by radiation to all surfaces that absorb the rays. The concealed, or flue, surfaces, that are masked by adjoining surfaces, give off heat by convection only. Radiators having the greatest exposed surfaces on the outside are usually considered to be best for direct radiators, and those exposing the greater amount of surface to the air passing through them are considered better for indirect heating. A combination of the two is used very advantageously for admitting fresh air for supplying ventilation by **direct-indirect radiation.** The heaters that are placed in casings, where there is no chance of radiant heat being given off, are called **indirect radiators.**

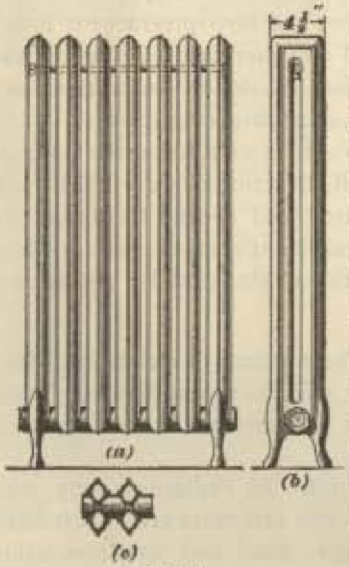

FIG. 2

9. Single-Column Radiators.—A single-column radiator is shown in elevation at (*a*), in end view at (*b*), and in section at (*c*) in Fig. 2. It is called a **single-column radiator** to distinguish it from the regular *two-column radiator* in common use, the chief difference between them being that the single-column radiator is only about 4½ inches wide, while the two-column radiator is about 7½ inches wide.

The single-column radiator, being narrow, is especially suited for use in narrow halls or passages where a wide radiator would be an obstruction. It presents a large amount of exposed surface and is consequently an efficient heater. It is not suited for general use, because the radiator must be long in order that it shall contain a sufficient number of square feet of heating surface.

10. Two-, Three-, and Four-Column Radiators. **Two-column radiators** are similar to the single-column radiators, except that they are wider, and each section consequently has a greater exposed surface. The width is usually about 7½ inches and the spread of the legs about 8½ inches.

Three-column radiators have sections about 10 inches wide, each section having 5 or 6 square feet of surface.

Four-column radiators have sections about 10½ inches wide. Each standard section contains about 8 square feet of surface. Radiators of this class are suitable for places where long radiators cannot be installed, but the surfaces of the inside columns are inefficient unless they are constructed so that a good upward circulation of air is obtained through the radiator. The inside surfaces enclosed by the outer columns do not warm the building by radiation, but by convection; hence, the necessity of large openings between the columns. Ordinarily it is considered advisable to avoid the three-column and four-column radiators as much as possible and use the two-column radiator instead, in which radiator all the heating surface has a high heating efficiency.

11. Flue Radiators.—When the sections of flue radiators are placed together, the front edges nearly, but not quite, touch one another, and a number of flues are formed by vertical ribs cast on each side of the inner sections and on the inner cheek of the end section. The sections are cast in the form of hollow boxes with flat cheeks, and therefore cannot resist a high pressure, even though the cheeks may be tied together by partitions. This form of radiator is more efficient in the low size than in the high size. Flue radiators operate to heat the air by inside flues.

12. Wall Radiators.—Wall radiators are long narrow radiators that are attached to the walls. They extend over a large area, and being placed on the outer walls constitute an excellent mode of distributing radiating surface. Ordinary radiators have the surfaces bunched, and the heat emitted from them is consequently localized, while the heat emitted from wall radiators is more uniformly distributed through the room. Wall radiators are frequently composed of a number of sections connected together in a long line, with radiator nipples at the top and bottom of each section, and supported on suitable brackets, firmly attached to the wall. The steam enters one end through the inlet valve, travels the full length of the radiator, and the water of condensation escapes through the return valve at the other end, the air vent being located at the return end.

These wall radiators can be made up so that the sections will be either vertical or horizontal, according to the length or height of the radiator desired. A wall radiator in common use is known as the *Fowler*. There are three sizes of sections in general use. The **standard size** is 24 inches long, 12½ inches wide, about 3 inches thick, and contains 7 square feet of radiating surface. The **medium size** is 21 inches long, 12½ inches wide, about 3 inches thick, and contains 6 square feet of radiating surface. The **short size** is 17 inches long, 12½ inches wide, about 3 inches thick, and contains 5 square feet of radiating surface. Wall radiators of the type mentioned can be used in place of wrought-pipe coils, and can be fastened to walls and ceilings, with the sections extended or grouped together. The construction of the sections permits a number of combinations. These sections are put together by radiator nipples, which are screwed up from the inside by a long bar with a square end that engages projections inside the nipples.

DIRECT-INDIRECT RADIATORS

13. Direct-indirect radiators, or **semidirect radiators,** as they are very often called, are placed and connected up inside the rooms to be warmed by them in the same manner as direct radiators, except that special connections are made by which fresh air from the outer atmosphere is permitted to flow between the heating surfaces of direct-indirect radiators and enters the rooms warm. Direct-indirect radiators, therefore, have the advantage of ventilating the building as well as warming it by direct radiation. They are usually located against the outer walls, being generally placed underneath windows; the air supply is brought in through the walls. If they are located against the inner walls, special sheet-metal ducts may be used to supply them with fresh air from the outer atmosphere.

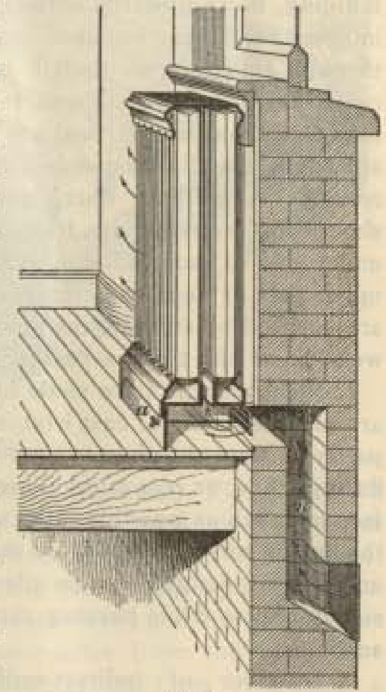

FIG. 3

14. A **prime surface direct-indirect radiator** is shown in Fig. 3. It is a simple two-column Bundy radiator having the base enclosed by plates *a*, which compel the fresh air that comes in through the flue *b* to pass upwards between the hot radiator loops before it can escape into the room. The air is thus warmed as it enters the room.

INDIRECT RADIATORS

15. Construction and Location.—Indirect radiators are located outside of the rooms to be warmed by them; consequently, the heat given off by indirect radiators is not emitted by radiation, but is given off by convection only. Air from the outer atmosphere, or an inside supply from the building, flows upwards between the heating surfaces of the indirect radiators, becomes warmed, and enters the room through registers, so that in buildings warmed by indirect radiators, the only visible parts of the heating installation in the rooms that are warmed are the registers. Indirect radiators are usually suspended from the basement or cellar ceiling. A cold-air duct, generally made of galvanized sheet iron, conveys air from the outer atmosphere to the under side of each radiator, and the hot-air pipe connects the upper part of each radiator to the register. The radiators are encased by suitable casings of galvanized sheet iron or wood lined with tin or asbestos, as the circumstances demand.

Indirect radiators are made in a number of forms. Some are made entirely of cast iron, others partly of cast iron and partly of wrought pipes. Cast-iron radiators generally have flutings, fins, or pins to increase the exterior or heating surface as much as possible, also to cause the air to impinge on the heated surfaces as it flows through the radiator. The pins and fins, or flanges, are so placed that the air must take a zigzag course while passing through the space between the sections.

A number of indirect-radiator sections when joined together are called an **indirect stack.**

16. In many indirect radiators the heating surfaces are extended by means of pins, whence the name **pin radiators** is derived. A common form is shown in Fig. 4. The sections are hollow castings with pins extending from the cheeks, as shown. A horizontal partition or division plate runs through each section from the header end to a point near the return end, to compel the steam to travel the full length of each section before it reaches the return pipe. The sections shown are put together with slip nipples and bolts. Air passes upwards between the pins in a zigzag fashion, and thus becomes warmed before entering the building.

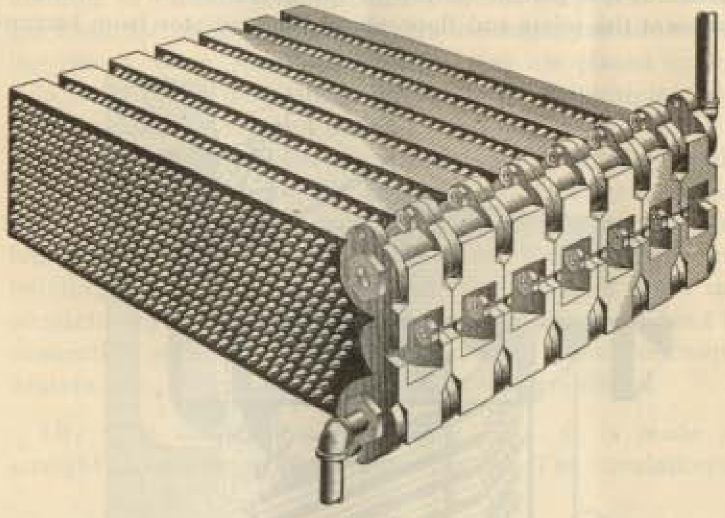

Fig. 4

17. Indirect Radiator Installation.—Fig. 5 shows a Bundy angle indirect radiator connected up against the outer wall; it also shows the sheet-metal casings and air ducts. The stack is suspended from the floor joists by hangers *a*, *a* that support the cast-iron steam base, and by rods *b* that support the loops about one-quarter from the end. The lower end of each rod *b* is bent to the form of a hook, a 2″ or 2½″ × ½″ iron bar *c* being placed in the hooks, as shown. These hangers are secured to the floor joists by lagscrews, or bolts and nuts. The cold-air duct takes its supply from the outer atmosphere through a perforated screen having a shield over it at *d*. The cold air is injected into the casing *e* at a point where the radiator is farthest from the casing, to give an unobstructed inlet. The hot-air duct is built in the brick wall, as shown at *f*, its lower opening being taken from the widest part of the air space above the radiator stack. An ordinary wall register *g* is located in the side wall of the room to be heated, and is provided with louver valves. Air flows through the radiator and into the room, as shown by the arrows. A sheet of corrugated asbestos *h* is placed on top of the galvanized-iron casing to prevent the joists and floor above the radiator from becoming too warm. Steam enters the radiator at the top of the box casting, and the water of condensation escapes through the pipe *i* connected to the bottom of the same casting. The temperature of the room is regulated by opening or closing the register valves. Incidentally, the ventilation of the room is also affected by operating these valves.

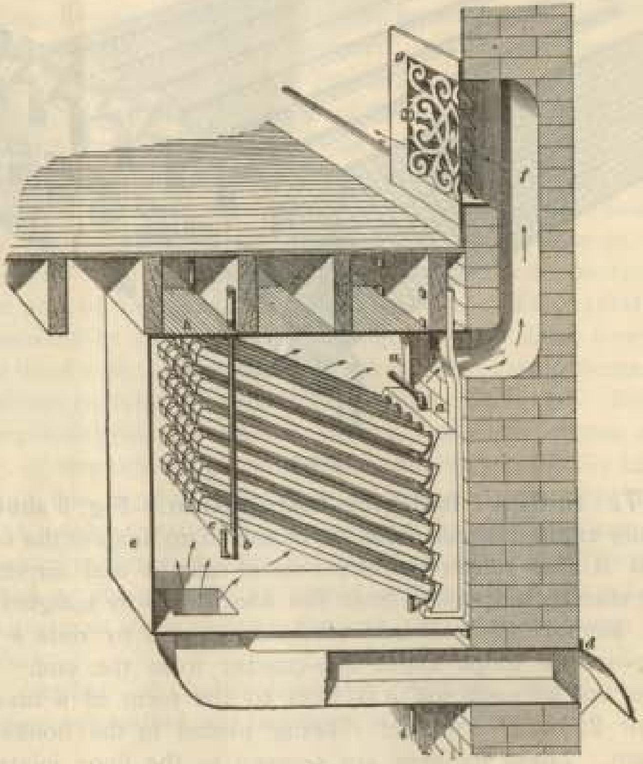

FIG. 5

PIPE COILS

18. Purpose and Construction.—Pipe coils are made of wrought-iron or soft-steel pipe and suitable fittings; they are built in various forms to suit different purposes. Some are used for plate warmers; others are employed for warming rooms, when, for direct heating, they are placed on the side walls or on the ceiling; in the form of multiple coils, they are used for indirect heating.

Coils generally require to be built to suit existing conditions, and consequently are not kept in stock by manufacturers, but are built to order, or built by the steam fitter himself, either in his shop or on the job. Coils for warming buildings are generally constructed from standard pipes and standard cast-iron fittings; for those intended to be used in connection with ice machines, evaporating pans, feedwater heaters, etc., forged fittings are commonly employed.

19. The **continuous flat coil,** Fig. 6, is made of straight pipes connected by return bends. The circulation of the fluid through it is direct and certain, and it is regarded as the most efficient form of radiator in common use.

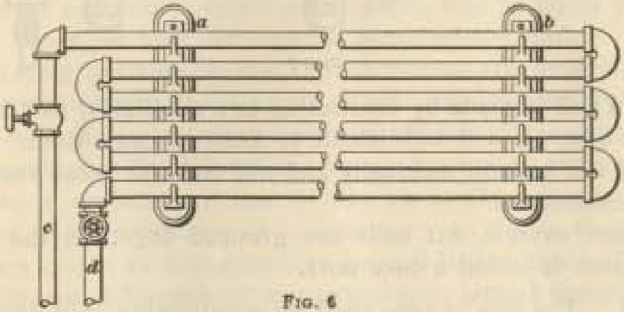

FIG. 6

20. A **miter coil** is shown in Fig. 7, the pipes being connected between two manifolds *a* and *b*. The steam moves forwards simultaneously through all the pipes; its velocity, therefore, will be one-sixth of the rate in a single pipe, as in Fig. 6. The circulation is likely to be uneven, because the fluid entering at *g* will naturally flow by momentum to the end of the manifold, and will enter the pipe *e* in greater quantity than into the pipe *f*. The path through *ec* is shorter than through *fd*, and, the friction being less, the main part of the current will go that way.

It will be noted that all the horizontal pipes are connected to the manifold *a* by means of elbows and vertical pipes. This must always be done, so as to permit the several pipes to expand independently, as their differing temperatures may require. The vertical pipes will bend or yield sufficiently to accommodate the difference in expansion.

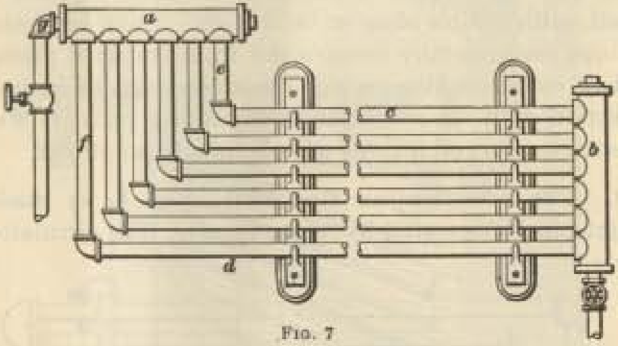

Fig. 7

If a coil is made by connecting two manifolds, parallel to each other, it will be difficult to keep it steam-tight. The pipes will expand unequally and will crack or break some of the connections.

When several flat coils are grouped together, the construction is called a **box coil.**

21. The size of pipe used for constructing coils depends mainly on the pressure of steam to be employed, the length of the coil, and the force of the circulation through it. The sizes in common use are from 1 inch to 2 inches.

Pipe coils must be arranged so that all the water condensed within them may flow easily toward their outlets.

RULES FOR RADIATOR SURFACE

22. General Rules.—The method of computing the amount of radiator surface required for any given service is as follows:

Having ascertained the amount of heat to be supplied, in British thermal units per hour, the difference in temperature between the air to be heated and the heating medium used in the radiators is found. If hot water is used, the temperature considered should be the average of its temperatures at entering and leaving the radiator. The coefficient of heat emission corresponding most nearly to the given difference of temperature and to the kind of radiator to be used should then be multiplied by the difference in temperature, in degrees. The product will be the total emission of heat per hour per square foot of radiation surface that may be expected.

The area of radiator surface required may then be found by dividing the total amount of heat required per hour by the emission from 1 square foot as computed.

For heating by direct radiation, the amount of heat to be supplied per hour, neglecting leakage, will be equal to the heat losses per hour through the windows and walls.

Heating systems in the United States are generally so proportioned that the amount of radiating surface provided will be sufficient to meet the requirements of zero weather, and ordinarily the difference between the temperature of the radiating surface and that of the air in the room is 150°, under which conditions it is customary to figure that each square foot of radiating surface emits 2 British thermal units per degree difference of temperature, or a total emission of 300 British thermal units per hour.

23. Common Approximate Rule.—The rule known to steam fitters and heating contractors as the *Two-Twenty-Two Hundred Rule* (2-20-200) is simple and quickly applied. It is in quite common use for obtaining the approximate size of a direct-steam radiator, and is intended to give an amount of radiation sufficient to comply with the usual specification that the rooms must be heated to 70° during zero weather. For inside protected rooms, the 2-20-200 rule gives results from 10 to 20 per cent. too large, and for rooms very greatly exposed, from 10 to 20 per cent. too small. These facts prove that good judgment should be exercised in applying this rule, making proper allowance for extreme exposures and proper deductions for protected rooms.

Rule.—*To find the amount of radiation, divide the glass surface, in square feet, by 2, the exposed wall surface, in square feet, by 20, and the contents of the room, in cubic feet, by 200; the sum of the quotients is the amount of heating surface required, in square feet.*

Or,

$$S = \frac{A}{2} + \frac{B}{20} + \frac{C}{200}$$

in which S = radiation, in square feet;
A = glass surface, in square feet;
B = exposed wall surface, in square feet;
C = cubic contents, in cubic feet.

EXAMPLE.—How many square feet of common cast-iron standard steam radiation is required to heat a room having 180 square feet of glass surface, 900 square feet of exposed wall surface, and 20,000 cubic feet of space?

SOLUTION.—Applying the formula corresponding to the rule,

$$S = \frac{180}{2} + \frac{900}{20} + \frac{20{,}000}{200} = 235 \text{ sq. ft.} \quad \text{Ans.}$$

24. Rules for Semidirect and Indirect Natural-Draft Radiators.—For semidirect radiators, the amount of radiating surface, as just computed, should be 25 per cent. larger; and for indirect natural-draft radiators, it should be at least 50 per cent. larger than is given by the preceding rule. That is, for semidirect radiators, multiply by 1.25, and for indirect natural-draft radiators, multiply by 1.5.

EXAMPLE.—By the preceding rule, a certain room requires 75 square feet of direct radiation. (*a*) If the radiation is semidirect, how many square feet will be required? (*b*) If the radiation is of the indirect natural-draft type, what should be its extent?

SOLUTION.—(*a*) $75 \times 1.25 = 93.75$ sq. ft. Ans.
(*b*) $75 \times 1.5 = 112.5$ sq. ft. Ans.

HEATING AND POWER BOILERS

HEATING BOILERS

25. Introduction.—The process of making steam consists in transforming water from the liquid to the gaseous condition; this can be accomplished only by the application of heat. In practice, steam is made within a closed vessel whose outer surface is brought in contact with direct rays of heat and the hot gases from some burning fuel, the vessel being known as a **steam generator,** or more commonly as a **steam boiler.** For the sake of brevity the qualifying word *steam* is often dropped, and the vessel is then simply called a **boiler.** The surfaces of the boiler with which the water is in contact on one side and the fire or hot gases of combustion on the other side, are called the **heating surfaces;** such surfaces as are in contact with steam on one side and fire or the hot gases of combustion on the other side are known as **superheating surfaces.** The fuel, which generally is coal, is burned in a suitably enclosed space known as the **fire-pot, firebox,** or **furnace,** and rests on iron bars forming the **grate.** A **draft** by which air is supplied to the burning fuel is created by the chimney or smokestack, which also carries off the waste gases of combustion.

In order to generate steam rapidly and efficiently, it is necessary that the heating surfaces of boilers be arranged to give a good circulation of the contained water. By **circulation** is meant the setting up of a current in the water that will pass over the heating surfaces in a strong uninterrupted flow as long as heat is applied.

26. Classification of Boilers.—Boilers may be classified broadly as *heating boilers* and *power boilers.* **Heating boilers,** as a general rule, are designed simply for low-pressure heating and carry a steam pressure of not over 10 pounds per square inch. **Power boilers,** as implied by the name, are chiefly used to furnish steam for power purposes, and are divided by some into *medium-pressure* *boilers*, which carry pressures not above 100 pounds per square inch, and *high-pressure boilers*, which carry pressures in excess of 100 pounds per square inch.

27. Low-pressure heating boilers are commonly made of cast iron. In the construction of fire-tube and drop water-tube types of heating boilers, however, wrought iron and steel are also used.

Medium-pressure power boilers are chiefly made of wrought-iron or steel plates with wrought-iron or steel tubes, and in some forms of tubes with cast or forged fittings. High-pressure stationary boilers are generally composed of steel tubes fitted into wrought-steel connections and have steam drums of steel plates.

SECTIONAL HEATING BOILERS

28. Low-pressure steam-heating boilers must be made of a material that will transmit heat readily, and the parts must be so arranged as to absorb the greatest possible amount of heat from the hot gases passing over them. It is also important that the parts be so arranged that they can easily be kept clean and in good condition for the transmission of heat. Such boilers must be so designed as to insure safety, not only under the stresses incidental to ordinary work, but also when neglected and partly worn out by long service.

Partly for manufacturing reasons, and partly because facility in handling and shipping, as well as ease of repairing, are thereby secured, cast-iron boilers are built up of sections placed either vertically or horizontally. The sections are united in different ways; some manufacturers use threaded nipples screwed into the sections and drums or manifolds, others use tapered nipples and through bolts. A *through bolt* is a long bolt passing clear through the pieces to be held together, and is supplied with a nut and generally with a washer at its threaded end, a washer being often used under the bolt head.

29. The term **sectional boilers** is applied principally to a class of low-pressure, cast-iron, heating boilers composed of a number of independent sections connected in such a manner that the group will operate as one structure. There are, however, a few forms of water-tube power boilers to which the term sectional boilers may be correctly applied. The sectional construction permits a boiler to be made large or small in capacity by varying the number of sections.

30. The common types of sectional cast-iron boilers differ very little from one another in general outline, the principal difference in construction being found in the form of the sections and methods of connecting them, the disposition of the heating surfaces, and the arrangement of the flues through which the gases of combustion pass to the chimney.

The majority of the boilers especially designed for low-pressure steam heating are built up of vertical and horizontal cast-iron sections in the form of hollow **slabs**, which rest on a cast-iron base containing the grate bars, the sections being bound together by connections with the steam and water headers at the top and sides of the vertical types of sectional boiler, or by means of bolts passing through lugs cast on the section or through the openings of slip nipples in the water leg and steam space of the sections.

RATING OF DOMESTIC HEATING BOILERS

31. The power, that is, the heating capacity, of a house-heating boiler is determined by the character, form, and amount of heating, or fire, surface, the relative amount of grate surface, and the water- and steam-holding capacity of the boiler. The efficiency of such a boiler depends on the proper relations of these factors, and also on the amount and kind of fuel burned in a given time. Although commonly employed as a unit for expressing the relative capacity of power boilers, the horsepower, especially when applied to domestic heating boilers, does not represent a satisfactory unit of rating or standard by which the power or steam-generating capacity of such heaters may be compared. Domestic heating apparatus may be satisfactorily rated by using 1 square foot of direct radiating surface as a unit for determining their relative power, which may be expressed in horsepower, if desired, on the basis that 1 boiler horsepower equals 33,330 British thermal units per hour, absorbed and transmitted from the fuel to the water. With temperature differences such as commonly exist between steam-heated radiators and the air surrounding them, say 150°, 1 square foot of direct radiating surface gives off from 250 to 330 British thermal units per hour, and since the evaporation of 1 pound of water from and at 212° F. into steam at atmospheric pressure requires 966 British thermal units, it is apparent that each square foot of radiation requires practically from $\frac{250}{966}$ to $\frac{330}{966} = \frac{1}{4}$ to $\frac{1}{3}$ pound of steam per hour. On this basis it can be assumed that 1 boiler horsepower is capable of supplying from 100 to 130 square feet of direct radiating surface, including all ordinary losses. In other words, an approximate horsepower rating may be substituted for the radiating surface rating by multiplying the number of horsepower by 100, the direct radiation equivalent of a horsepower; or, by dividing a given amount of radiating surface by 100, the required horsepower of the boiler necessary to supply it with steam may be determined.

32. Low-pressure steam-heating boilers may also be rated according to the amount of their heating surface, allowing from 10 to 18 square feet of heating surface as equivalent to 1 boiler horsepower. On the basis of 10 square feet of heating surface per horsepower (34.5 pounds of water evaporated) an evaporation of 34.5 ÷ 10 = 3.45 pounds of water per square foot of heating surface will be required, while ratings of 15 and 18 square feet of heating surface per horsepower will, respectively, necessitate an evaporation of 34.5 ÷ 15 = 2.3 pounds and 34.5 ÷ 18 = 1.92 pounds per square foot of heating surface. The evaporative efficiency of domestic heating boilers is low, because of the imperfect combustion due to careless firing and poor draft, and also on account of their generally bad management, being in many cases entrusted to servants who understand little, and care less, about the proper way to handle them. Under favorable conditions, however, where the draft is satisfactory and the management good, such heating boilers give results closely approximating those obtained with boilers used for power purposes. The element of size alone does not determine the actual capacity of a heating boiler, which may, under favorable conditions, be greater than its rated capacity, depending on the care and skill with which it is managed and fired.

33. Boiler ratings determined by laboratory tests, which are usually made under the most favorable conditions, and with expert firing, are of comparatively little value as establishing standards of capacity on which it is wise to base the selection of a boiler required to do a given amount of work in house heating. As some catalog ratings would seem to indicate an evaporative efficiency for heating boilers in excess of that claimed for the best types of power boilers, it is a good plan in laying out a steam plant to calculate the probable capacity of the boiler selected according to the grate area and amount of heating surface, as well as radiation to be supplied. The manner of doing this can be best shown by an example.

A boiler having a grate 24 inches by 50 inches is rated by the maker to supply 2,100 square feet of direct radiating surface, and it is desirable to know whether this rating accords with the generally accepted rules by which the capacity of the boiler is approximately determined.

The coal consumption per square foot of grate surface varies in heating boilers between 4 and 8 pounds per hour, averaging about 6 pounds. The amount of heat usefully absorbed by the boiler per pound of fuel may be assumed to be 8,000 British thermal units per hour, and the heat emitted per square foot of radiation may be taken as 300 British thermal units per hour. The grate area is

$$\frac{24 \times 50}{144} = 8.33 \text{ square feet}$$

Then, the number of British thermal units absorbed by the boiler per hour may be estimated to be

$$8.33 \times 6 \times 8{,}000 = 399{,}840 \text{ British thermal units}$$

This heat absorption per hour will supply $399{,}840 \div 300 = 1{,}333$ square feet, nearly, of direct radiation. This conservative estimate is seen to be

$$\frac{2{,}100 - 1{,}333}{2{,}100} = .365 = 36.5 \text{ per cent.}$$

less than the manufacturer's rating.

The apparent discrepancy between the estimated capacity and the manufacturer's rating is due to the assumptions of the manufacturer that the boiler will work under the best conditions, burning about 8 pounds of coal per square foot of grate surface, and that the heat emission is 250 British thermal units per square foot of radiation per hour. Under these assumptions, which it is unsafe to make for the conditions existing ordinarily in domestic heating, the heat transmitted to the water per hour is

$$8.33 \times 8 \times 8{,}000 = 533{,}120 \text{ British thermal units}$$

and the amount of radiation that can be supplied is $533{,}120 \div 250 = 2{,}132$ square feet, or, in round numbers, 2,100 square feet.

GRATE SURFACE

34. Required Area of Grate.—The area of grate surface required in any given case depends on the type of boiler employed, the amount of water to be evaporated, the nature and amount of coal to be burned, and the rate of combustion, which varies from 3 to 20 or more pounds of coal per square foot of grate per hour. The general rule for finding the grate surface is as follows:

Rule.—*To find the grate surface, in square feet, divide the weight of steam, in pounds, required per hour by the product obtained by multiplying the number of pounds of coal burned per square foot of grate per hour by the number of pounds of water evaporated per pound of coal.*

Or, $$G = \frac{W}{CE}$$

in which G = grate surface, in square feet;
W = weight of steam, in pounds per hour;
C = pounds of coal per hour per square foot of grate surface;
E = evaporation, in pounds per pound of coal.

In this rule, no account has been taken of the difference in the number of heat units required to evaporate water from different feedwater temperatures into steam at different pressures. Hence, the rule is only approximate, but close enough for practical work.

TABLE II

AVERAGE EVAPORATION PER POUND OF COAL

Type of Boiler	Coal Burned per Hour per Square Foot of Grate Area			
	6 to 10	10 to 14	14 to 18	18 to 20
	Water Evaporated per Pound of Coal Pounds			
Cylindrical	7.00	6.75	6.50	6.00
Two-flue	7.25	7.00	6.75	6.25
Return-tubular . . .	9.00	8.50	8.25	8.00
Firebox	9.00	8.50	8.25	8.00
Vertical tubular . .	8.00	7.75	7.50	7.00
Water-tube	10.50	10.00	9.00	8.00
Cast-iron sectional .	8.60			

The average evaporation per pound of coal for different kinds of boilers is given in Table II. This table gives the evaporation per pound of coal that may be expected under average conditions, but the actual evaporation obtained may be less or more than that given in the table, which is intended merely as an approximate guide when there is no available data showing the evaporation of the kind of boiler selected under conditions similar to those that will obtain when the proposed plant is operated.

Example.—A cylindrical boiler is to generate 600 pounds of steam per hour, burning 10 pounds of coal per square foot of grate surface per hour; what grate surface will be required?

Solution.—By Table II, an evaporation of 6.75 lb. of water per pound of coal may be expected. Then, applying the rule given,

$$G = \frac{600}{10 \times 6.75} = 8.8 \text{ sq. ft., nearly. Ans.}$$

35. Ratio of Grate Surface to Radiation.—The requisite area of grate necessary to supply a given amount of direct steam radiation may be found approximately by dividing the total amount of radiating surface by a factor varying between 100 and 160, selecting a factor in accordance with the character and probable management of the heating boiler. For ordinary work, where the boiler is given attention by unskilled labor, a factor of 100 may be used to advantage; when a skilled fireman attends the boiler, a factor of 160 may be selected. For example, a heating boiler rated to supply 1,600 square feet of direct radiation, including ordinary losses, should have a grate area of 1,600 ÷ 100 = 16 square feet if operated under ordinary conditions, or 1,600 ÷ 160 = 10 square feet if the boiler is to be carefully handled.

TABLE III

SIZE OF SQUARE CHIMNEYS FOR STEAM HEATING

Square Feet of Direct Steam Radiation	Approximate Equivalent in Horsepower	Height of Chimney, in Feet								
		25	30	40	50	60	80	100	120	150
		Length of Side, in Inches								
100	1	6.9	6.8	6.6	6.5	6.4	6.2	6.1	6.0	5.9
300	3	9.1	8.9	8.6	8.3	8.1	7.8	7.6	7.4	7.3
500	5	10.6	10.3	9.8	9.5	9.3	8.9	8.6	8.4	8.2
700	7	11.8	11.4	10.9	10.5	10.3	9.8	9.5	9.3	9.0
1,000	10	13.3	12.9	12.3	11.8	11.5	11.0	10.6	10.3	9.9
1,500	15	15.5	14.9	14.1	13.6	13.1	12.5	12.0	11.7	11.3
2,000	20	17.1	16.4	15.7	15.1	14.6	13.8	13.3	12.9	12.4
3,000	30	20.1	19.3	18.3	17.5	16.9	16.1	15.4	14.9	14.3
4,000	40	22.6	21.8	20.5	19.6	18.9	17.9	17.0	16.6	15.9
5,000	50	24.8	23.9	22.4	21.5	20.7	19.6	18.7	18.0	17.3
6,000	60	26.8	25.7	24.2	23.1	22.3	20.2	20.1	19.4	18.5
7,000	70	28.6	27.5	25.9	24.7	23.8	22.4	21.4	20.6	19.7
8,000	80	30.3	29.1	27.4	26.1	25.1	23.6	22.6	21.8	20.8
9,000	90	31.9	30.6	28.8	27.1	26.4	24.9	23.7	22.8	21.8
10,000	100	33.4	32.1	30.1	28.7	27.6	26.0	24.8	23.9	22.8
12,500	125	36.9	35.4	33.2	31.6	30.4	28.6	27.2	26.2	25.0
15,000	150	40.0	38.4	36.0	34.3	32.9	30.9	29.5	28.3	27.0

CHIMNEYS FOR STEAM-HEATING BOILERS

36. The values given in Table III have been calculated for different heights of chimney and for different amounts of direct radiation. The table gives the actual length of the side of square chimneys in inches. In order to find the diameter, in inches, of a corresponding round chimney, the length of the side of a square chimney given in the table should be multiplied by 1.13. In the table, the approximate horsepower of the boiler is given in the second column; the values there given are based on the assumption that a boiler of 1 horsepower will furnish sufficient steam for 100 square feet of direct radiating surface.

POWER BOILERS

37. Power boilers are those that generate steam for use in driving engines, and for operating other machinery. The pressure carried in power boilers is therefore much higher than that required only for heating purposes, and power boilers are consequently constructed of such materials and in such a manner that they will resist the greater internal pressure.

The extensive heating systems of large manufacturing establishments require the use of boilers primarily intended for the generation of steam for power purposes; the general design and construction of the boilers commonly employed only for heating are such as to limit their use to buildings of comparatively small size.

Power boilers occupy a prominent place in the heating of large office and other public buildings, state and federal institutions, such as asylums, jails, court houses, etc., and in theaters, hospitals, schools, etc., where, in many cases, they furnish steam for heating only. Whenever power is necessary, however, the boilers can be used to supply steam for the heating system as well, a steam pressure suitable for the power-generating apparatus being carried in the boilers, and reduced to a pressure suitable for the heating system by means of a reducing valve.

38. Power boilers may be divided into fire-tube, water-tube, and sectional boilers. Fire-tube boilers always have the tubes enclosed by a shell, made of wrought-iron or steel plate, and hence are often called **shell boilers.** The ordinary types are either horizontal or vertical.

STEAM-HEATING SYSTEMS

GRAVITY CIRCULATING APPARATUS

FUNDAMENTAL PRINCIPLES

39. Definitions.—Steam-heating pipe systems wherein the water of condensation is returned to the boiler by gravity are known to the steam-heating trade as **gravity circulating apparatus.** When properly installed, they heat with safety and economy, and are noiseless and easily managed. The element of economy is secured by returning to the boiler, for reevaporation into steam, the water of condensation from the radiators or other heating surfaces. No heat is wasted, the condensation returning to the boiler at a temperature of, say, 180°, after the steam and water of condensation have given off practically 1,000 British thermal units per pound in warming the air in the various rooms of the building.

Pipes that serve to convey steam from the boiler or other source of supply and to distribute it to several branches, are known as **steam mains.** They are usually run along the cellar ceiling, being hung from the first-floor beams by adjustable iron hangers. These steam mains pitch downwards from the highest point near the boiler to the lowest point at the farther end of the mains. The pitch should be at least $\frac{1}{2}$ inch in 10 feet, so that the water of condensation may freely flow to the lower end of the main.

An **overhead main** is a steam main that is run horizontally, or nearly so, at an elevation higher than the radiators that it supplies, and is supplied from the boiler by a vertical **rising main.**

Risers are vertical pipes that rise from floor to floor to convey steam from the steam main to the radiators or coils on the several floors. **Drop risers** are those in which the steam flows downwards to the radiators or coils from a steam main above, usually in the attic.

A **return main** is a nearly horizontal line of pipe that receives all water of condensation from the heating system and returns it to the boiler or otherwise disposes of it. It is usually run near or under the cellar floor.

A **dry return main** is one that is run above the water-line of the boiler and, consequently, is partly filled with steam.

A **wet return main** is one that is run below the water-line and is filled with water at all times. As a rule, this is more reliable than a dry return main except in places where the main is subject to frost.

Return risers are those vertical pipes that take the water of condensation from the radiators or coils on the several floors of a building and convey it to the return main.

A **drip pipe, relief,** or **bleeder** is a small pipe used to drain water of condensation away from the foot of risers or from a low point, pocket, or trap in the main steam pipes. In running steam mains, it is common practice to connect relief or drip pipes to the main at points where a reduction in the size occurs, and ordinary reducing fittings are used. This serves to prevent water hammer by relieving the main of condensation at points where it would otherwise accumulate. By using eccentric fittings, however, so as to bring the bottom of the main into line throughout its length, the use of many bleeders, or drip pipes, may be obviated. In any case, a relief pipe should be connected to the extreme end of the main to drain the water of condensation into the main return.

40. Principle of Steam Circulation.—Suppose that a vessel *a* partly filled with water, is placed over a fire *b*, as shown in Fig. 8, and connected to a pipe loop *c d e f*. If the water is boiled in *a* and part of it is converted into steam, the steam forming in the steam space of *a* will increase the pressure within it, and will compress the air in the pipes *c*, *d*, and *e* so that the air pressure in *e* will equal the steam pressure in *a*. Since these pressures are equal, the water-line in *e* will be level with the water-line in *a*. These water-lines will be level at all pressures so long as the pressures on them are equal. If a cock or valve is attached to the pipe *e* above the water-line, and the air is allowed to be forced out of the system by steam filling the pipes *c*, *d*, and *e*, the water-line in *e* will rise slightly because the pressure on it will be slightly less. This is due to the fact that a part of the steam in *d* and *e* becomes condensed and a certain pressure is required to cause a flow of steam to supply this loss. This difference of pressure, however slight, must be compensated for in *e* by an increased head of water, so that the water column in *e* and that in *a* may be in equilibrium. Suppose, now, that the surface of the pipe exposed to the air is increased, as shown by the coil *g*, to such an extent that the pressure in *e* is 1 pound per square inch less than that in *a*, due to the more rapid condensation of the steam; the water-line in *e* will rise about 30 inches above the level of that in *a*, as shown at *h*. If the flow of steam is retarded, such, for instance, as by a globe valve being placed on *c* or *d*, or by small pipes being used, the difference in pressure, and consequently, the difference in the water-lines, will be greater; but if larger pipes are used, the resistance to the flow of steam will be decreased, and the difference between the water levels will be correspondingly less. Since the water of condensation from the coil falls by gravity in *e*, it also tends to increase the height of the water-line, because a head of water is required to cause a flow from *e* to *a* through *f*, and thus convey the water of condensation back to *a*.

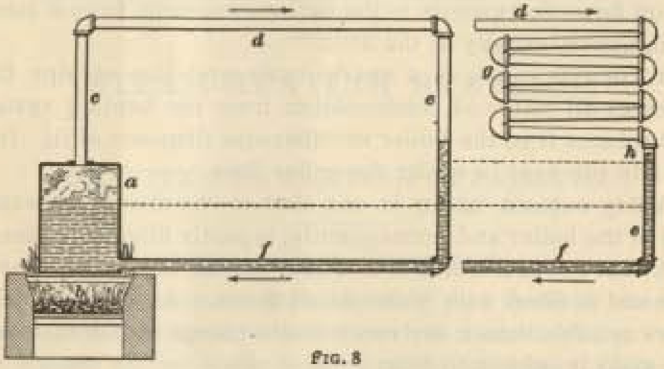

FIG. 8

DESIGN OF PIPING SYSTEMS

GENERAL PRINCIPLES OF DESIGN

41. In planning any system of steam pipes, there are two things to be kept always in mind and that must be fully provided for: these are drainage and the movement of the pipes by expansion or contraction. No heating can be done without condensation, and the water thus produced must be disposed of promptly and completely and in a manner that will prevent interference with the steam supply.

Expansion and contraction are inevitable, and the movement due thereto is repeated every time the system undergoes any considerable change in temperature. This movement must be provided for, otherwise it will break the joints and make serious trouble.

42. Saturated steam will part with its heat only by condensation. No matter how small the amount of heat emitted, a corresponding amount of condensation must take place. If the amount of condensation is small, the water may remain suspended in the steam, making the steam wet;

but if the amount is considerable, it will collect and flow or drain toward low points. All pipes that supply steam must be carefully graded, that is, inclined so that the water will flow by gravity in the proper direction. Care must be taken to avoid the formation of pockets, or depressions, in which water may collect. Return pipes should also be inclined so as to discharge the water by gravity into the drip pipes, and should also be free from depressions, or pockets.

The downward grade given to return pipes should be as nearly uniform as practicable. There should be no upward bends or loops, because air is likely to collect in them and impede the flow of the water.

When the returns are connected to a main that is located above the water level, and if there is any perceptible difference in the pressures at the various radiators thus connected, the steam will flow backwards through the return pipes toward the points of lowest pressure, and thus interfere with the drainage and cause water hammer.

43. The hammering noises frequently heard in steam pipes are caused by the violent collision of bodies of water, either with each other, or with the elbows and other fittings that change the direction of the flow, or with the end of the pipe or chamber.

When water is carried through a pipe by a current of steam, the water has a tendency to form into slugs, which fill the bore of the pipe and move along like pistons. When there is a lower pressure in front of one of these slugs, the pressure behind the slug drives it forwards at high velocity, so that when it strikes an obstruction the impact produces a loud noise.

It is sometimes quite difficult to locate the point where water hammer occurs, owing to the fact that metal pipes are good conductors of sound and transmit shock and vibration over long distances. Sound is very deceptive, because vibrations may travel a great distance along a pipe muffled at the point where water hammer occurs, and will come out loud and clear at some point where the pipe is exposed.

44. Points at which an unusual quantity of water can collect in a piping system are called **water pockets,** and are very dangerous in pipes through which steam flows at high velocity. Ordinarily, the water will accumulate quietly until the pocket is full, when the current will suddenly pick up a part of the water, sometimes all of it, and carry it forwards in a compact mass. The body of water moves with the same velocity as the steam, and when it arrives at an elbow or T, where the direction of the flow is changed abruptly, it strikes the fitting like a projectile, and the blow is often sufficient to crack the fitting, or even break it.

A water pocket in a steam pipe that supplies an engine is particularly dangerous, because the water is liable to go over into the cylinder in a flood. This usually results in a smash up, because the engine is not provided with a drainage apparatus of sufficient size to handle so much water.

CLASSIFICATION OF SYSTEMS

45. Considered with reference to the element of pressure alone, steam-heating systems are divided into two classes: (1) those that are operated under a pressure greater than 10 pounds by the gauge are known as **high-pressure systems;** (2) those that are operated between atmospheric pressure and 10 pounds gauge pressure are known as **low-pressure systems.** The latter class of systems is the one in most common use.

With the high-pressure system of heating, less radiating surface is required, and the piping may, in some cases, be made one size smaller than for pressures of from 2 to 5 pounds; the fall of pressure that may be permitted at the radiators is, however, no greater than in a low-pressure system; hence, the size of the piping can be reduced but little. The high-pressure heating system, which is sometimes employed in factories and workshops, requires a better and hence more costly, class of steam generators than are commonly employed in low-pressure heating, and the radiators also require to be made extra strong. High-pressure heating is not recommended for domestic work.

46. Viewed solely from the standpoint of the circulation of the heating medium, steam-heating systems may be classified under two general divisions: (1) those in which the water of condensation from radiators and coils flows back to the boiler by gravity are known as **gravity return systems;** (2) those in which the water of condensation is forced back to the boiler from the return mains of the heating system by a pump, steam loop, steam return trap, or other such appliance are known as **forced return systems.** Both systems may have wet or dry returns.

The gravity return system is used where the full boiler pressure is carried on the heating system. It cannot be used elsewhere. The forced return system is used when the boiler pressure is higher than the pressure in the heating system, as, for example, when a pressure-reducing valve is used on the live steam-supply pipe to the heating system.

METHODS OF INSTALLATION

47. The low-pressure gravity circulating apparatus commonly used for warming buildings by steam is essentially composed of: (1) a boiler, or steam heater, as it is often called, in which steam is generated by the heat of combustion of some fuel; (2) a number of radiators or coils, so constructed that steam from the boiler may flow into them and be condensed by transmitting heat through the coils or radiators to the air and objects surrounding them; (3) a system of pipes that convey steam from the boiler to the radiators, and return the water of condensation to the boiler when the steam has parted with its latent heat; that is, when it has been condensed.

48. Broadly speaking, there are two general systems of piping buildings, the *one-pipe system* and the *two-pipe system*, both of which are frequently modified to suit peculiar local or other conditions. The chief difference between the several systems consists, in a large measure, in the method of arranging the piping for returning the water of condensation to the boiler. Various methods of arranging the piping are employed, and many modifications of the different systems are used in practice. Those most frequently used are described and illustrated further on.

The comparative economy of the two general systems depends largely on the conditions under which they are installed. When properly designed, it has been found in practice that both systems give equally satisfactory results However, considerable expense, both in material and labor, is often saved by the fitter in using the one-pipe system, or a combination of it with some of the features of the two-pipe system. The intelligence with which modifications of either system are planned has much to do with the efficient operation of the apparatus. The expense of installation has been found to be greatly affected by local practice; that system with which the workmen in a given section of the country are most familiar is generally the cheaper to install. Throughout the western portion of the United States, the one-pipe system is regarded with particular favor, and it is there successfully used in some of the largest office buildings and other large structures. Somewhat greater care is necessary in laying out one-pipe systems, in order to make satisfactory provision for the flow of steam and the water of condensation in the same piping. The fact that the currents of steam and water move in opposite directions necessitates larger piping, which must be properly proportioned and carefully graded.

ONE-PIPE SYSTEMS

49. General Description.—A very common method of distributing steam to the several radiators in a building is by means of the **one-pipe system,** shown in Fig. 9. The boiler *a*, which is set on the cellar or basement floor, furnishes steam at a very low pressure, usually from 2 to 5 pounds by the gauge. The steam main *b*, the duty of which is to convey steam to the several risers *c*, *c* through which it flows to the radiators *d*, *d* placed within the rooms to be warmed, is connected to the steam space of the boiler and is so suspended from the floor joists by hangers that it will have a uniform fall of about ½ inch in 10 feet from its highest point, which is immediately above the boiler, to its lowest point *f*. When steam is generated in the boiler, it is forced into the steam main; from there into the risers; and thence into the radiators. The air that the pipes contain is forced out of the system to the atmosphere through air vents or small valves placed at suitable points in the system, usually on each radiator at the end opposite the steam inlet. The air is forced ahead of the steam, and if it finds no outlet it remains in the pipe and excludes the steam. As steam flows through the main and the risers, part of it will be condensed by transmission of heat through the pipes to the air and objects surrounding them. The water of condensation will fall by gravity to the bottom of the steam main, flow to its lower end *f*, and enter the bottom of the boiler through the return pipe *g*. The water of condensation from the radiators flows out therefrom and down the risers through the riser connections, and into the steam main, against the flow of the steam. If the riser connections to the steam main or radiator connections to the riser have too little pitch, or if the pipes are too small, the flow of the water of condensation through them will be resisted to such an extent by the flow of steam that the water of condensation will not flow off as quickly as it is formed, the result of which will simply be that the water will accumulate in the pipe until it is entirely closed, and snapping and hammering noises known as water hammer will take place. The steam main should be made sufficiently large, to prevent such a difference between the pressure in the boiler and that at the point *f* as will cause the water to back up in the main and retard the flow of steam to any riser connection.

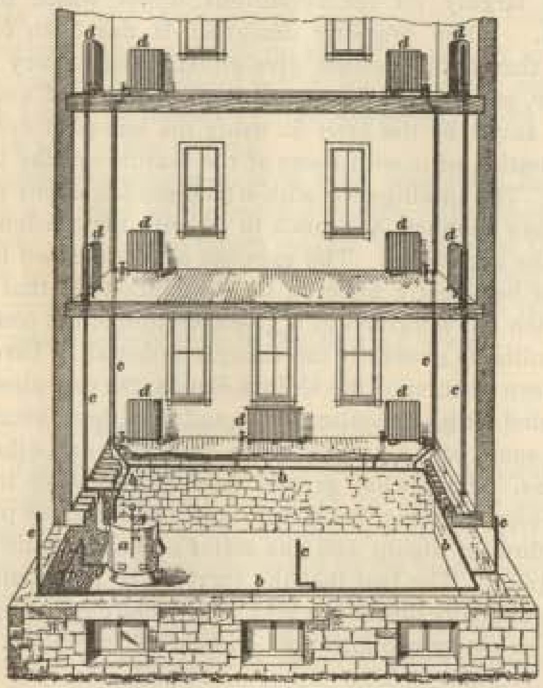

FIG. 9

50. Down-Feed or Drop-Riser System.—The one-pipe down-feed, or Mills, system of steam distribution is one in which the steam generated by the boiler passes directly upwards through a rising main to a system of distributing mains in the attic or space above the top story, from which drop-riser connections are taken to supply steam to the radiators on the floors below.

Fig. 10 shows a separate vertical main *a* running to the attic, where the horizontal main supply pipe *b* is located. Branches therefrom are taken to the drop risers *c*, *d*, *e*, and *f*, which are run down below the boiler water-line. The main return pipe *g* may be carried on the side wall or beneath the floor. This method is adopted where the cellar or basement can be used as rental space, or in stores where the space is required for exhibiting or selling goods, the pipes being so arranged as to leave the ceiling free for decoration. Furthermore, the drop system requires less headroom than is necessary for the steam pipe and branches of up-feed systems.

The main supply pipe extends from the boiler to the wall, thence upwards to the attic or top story through a chase, that is, a recess in the wall, in which it is concealed. In the

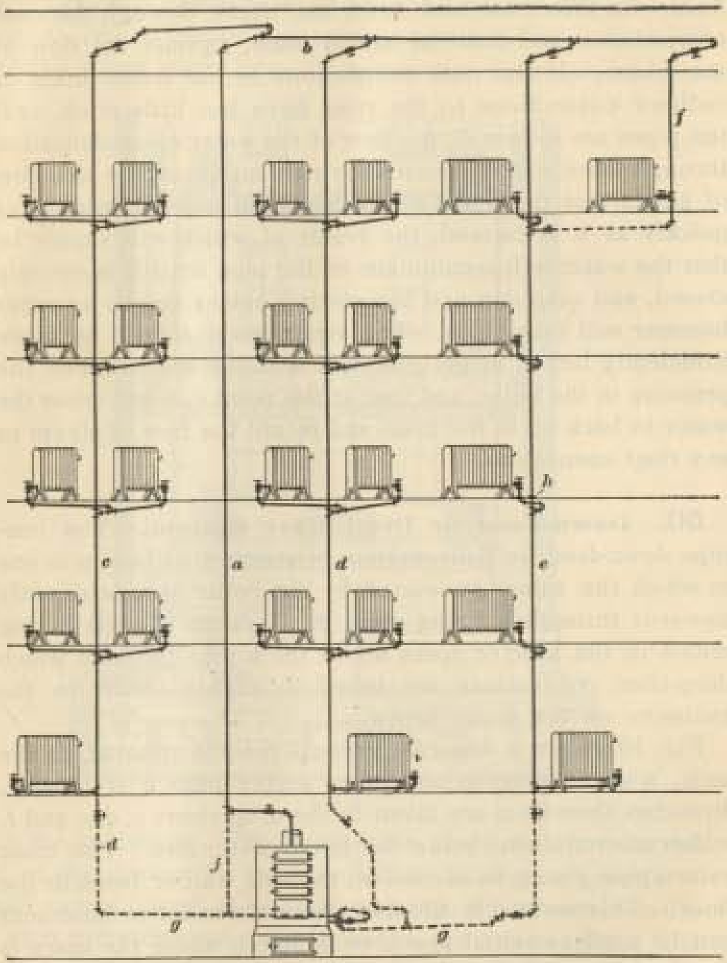

FIG. 10

attic, the main horizontal pipe may branch in any direction to connect with the drop risers. The drop riser *f* is connected to only one radiator on the floor beneath, and hence

the pipe may be run in the manner shown, the drip from the lower end of the pipe being connected to the drop riser *f*. If a valve is placed in this drop pipe at the top, a similar valve should be placed at the bottom. The valve on the drip pipe should be self-closing, as it is likely to be placed in such a position that it cannot be operated by hand, and hence a check-valve is ordinarily used. The riser *e* is shown as connecting to a single radiator on each floor. This riser is anchored at the center at *h*, so that the pipe above *h* expands upwards and the pipe below *h* expands downwards. The branch connections to the radiators connected to *e* are below the floor and are made with a swivel, so that the movement of the drop riser does not bring any stress on the connections, the elbows of the connecting pipes allowing the movement to be taken up by the tightening or loosening of the threads. The movement is so small where the swivel pipes are of proper length that the joint remains tight for years. If the branch connections were made to crosses in the drop risers, there would be no provision for expansion, which, if upwards, would raise the radiator connection. If this connection were stiff, so that it would not bend, the radiator would be lifted from the floor, and the water of condensation in the radiator would not drain back into the riser. Hence, the use of crosses should as a rule be avoided, though they may be employed when, as at *i*, the connection to the radiator is run above the floor and beneath the radiator, and connected, by means of an offset angle valve, at the end of the radiator farthest from the riser. If the pipe is long enough to spring, the radiator will not be lifted up or forced down by the expansion and contraction of the riser. To allow the pipe to drain properly, this method of making the radiator connection requires that the radiators shall have high legs.

51. The rising supply main *a* may be anchored at the center, or it may be supported at the bottom. If supported at the center, expansion is provided for by long horizontal branches or elbow swings at the top and the bottom. If no connections are taken from this riser, it may be secured at the bottom on masonwork, or by a stand at the foot of the pipe. In the latter case, the expansion movement will be upwards, where proper provision for it should be made in the pipe connection to the horizontal main *b*. If the connection between the boiler and the riser is short, the pipe may be graded so that the water of condensation from the rising main will drain to the boiler; but, if the pipe is long, a drip pipe *j* therefrom should be connected into the return main. The extensions of the drop risers below the first floor are called **drip pipes.** Each should have a check-valve where connection is made to the return, especially if there is a valve on the line at the top, as otherwise a considerable amount of water will be drawn up the drop riser by the creation of a partial vacuum due to condensation of the steam by the radiators after closing the valve at the top of the line. The steam valves should be so placed that water will not lodge in them, and horizontal pipes in the attic should drain to the drop risers.

TWO-PIPE SYSTEMS

52. General Principles.—The **two-pipe system** of distributing steam to the several radiators in a building, and of returning it to the boiler in the form of water, so that it may be reheated and redistributed as steam, is essentially composed of a series of pipes that connect the steam space of the boiler to one end of each radiator, and another series that connect the opposite end of each radiator to the water space of the boiler.

It is evident, therefore, that in a two-pipe system of steam heating, each radiator must be connected to two pipes—one of which is the steam inlet and the other the outlet for the water of condensation.

53. Common Feed and Return System.—There are many modifications of the two-pipe system. One is that in which riser lines are taken from the steam-distributing main, each riser supplying steam to one vertical line of radiators,

a corresponding return riser being run to accompany each distributing riser, and into which all the radiators of that line are emptied, as shown at *B*, Fig. 11. In this figure, the boiler *a* is set in the cellar of the building as usual, and the

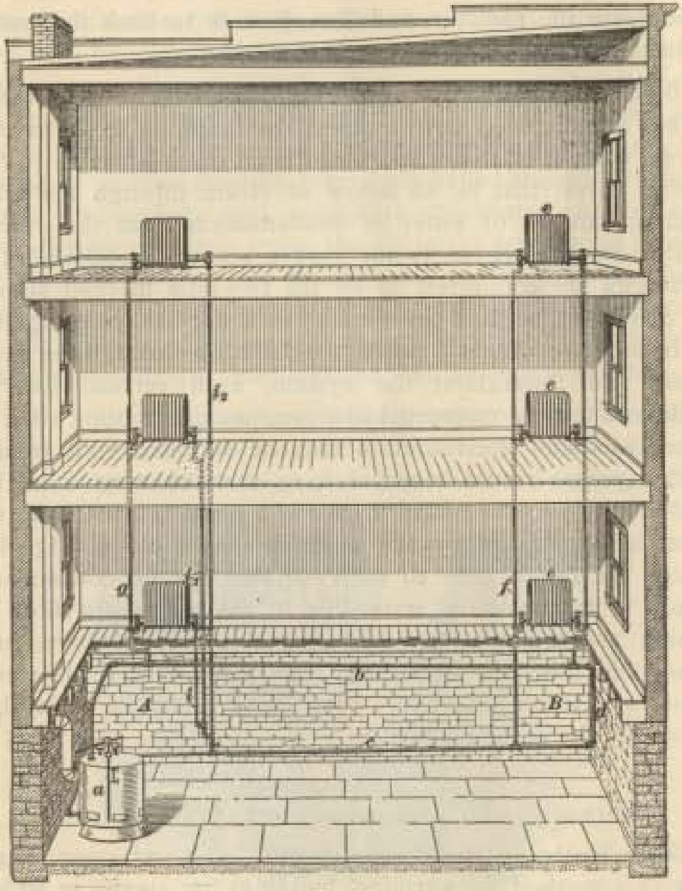

FIG. 11

steam-distributing main *b* pitches from the boiler, its extreme lowest end being connected into the return main *c* by the relief pipe *d*. It will be observed in the method of piping the radiators *e*, *e*, *e* that the return radiator connections deliver into the same return riser f above the water-line. Consequently, there is a liability of steam flowing from one radiator into another through the return riser. This is objectionable, because such an inflow of steam to any of the radiators is against the outflow of the water of condensation from the radiator, and the effect is to back the water into the radiator, and thus tend to flood it.

54. Common-Feed and Separate-Return System. When a radiator is double-piped, the intention is to have a direct current of steam and water from the inlet valve to the outlet valve; that is, an inflow of steam through the inlet and an outflow of water of condensation from the outlet. This object, however, is not always accomplished when the radiators are connected up by the two-pipe method shown at B, Fig. 11, because the circulation is not always complete.

In order to obtain a positive circulation through the radiators and throughout the system, each vertical line of radiators may be connected to a common distributing riser g, from which all the radiators may be supplied with steam, and separate return risers i, i_1, i_2, each running from its radiator to join the return main c at a point below the water-line, as illustrated by the method shown at A, Fig. 11. Since the return pipe to each radiator has no connections made to it above the water-line in the boiler, the flow of steam and water of condensation must be positive, and always in the same direction. This is the most reliable and most effective method of piping large radiators; it is also probably the most expensive.

INDIRECT AND SEMIDIRECT HEATING SYSTEMS

55. Indirect Heating System.—Indirect steam heating is a method of warming buildings by steam, in which the heating surfaces, or indirect radiators, are located outside of the rooms to be warmed, communication being had between the rooms and their respective radiators by means of large air conduits, commonly called *hot-air ducts*. By using this system of warming buildings, the radiators are

not open to view, as are direct radiators, but are entirely concealed; they are usually located in the cellars or basements of the buildings, and are completely encased by boxing of some material that is a non-conductor of heat. It is customary to encase each indirect radiator separately, using the radiator for a partition, as it were, to divide the box into two compartments, or chambers—an upper and a lower one. The upper chamber communicates with the room to be warmed by means of the hot-air duct, and the lower chamber communicates with the outer atmosphere by means of another conduit, commonly called the *cold-air duct*. Since the sections that constitute the entire radiator are spaced some distance apart, the air in the box, being heated by the radiator, will rise through the hot-air duct and flow into the room, cold air from the outer atmosphere replacing it. It will thus be seen that, by the indirect method of warming buildings, ventilation as well as heat is secured.

56. Fig. 12 shows how indirect radiators are commonly arranged to warm rooms on the ground floor. The radiator a is set in the middle of its casing, or box, and is suspended by iron hangers from the joists of the floor above. Steam enters the top of one of the end sections by the pipe shown, and leaves the radiator by a return pipe, not shown. Fresh air enters through the register face, or grille-work, which is

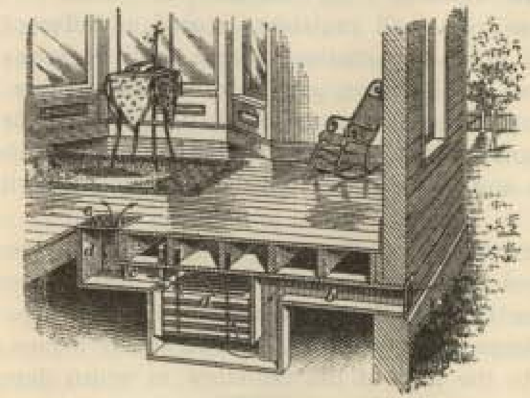

Fig. 12

secured over the mouth of the cold-air inlet duct *b*, made flush with the face of the wall, and passes through the radiator into the hot-air duct *c*, and then into the room above through a floor register *e*, as shown by the arrows. This arrangement of the heating surface is such that the room cannot be warmed without ventilation. If the radiator box were furnished with another inlet duct that would take a supply of air from the floor of the room, the room could be warmed without ventilation. This, however, in many respects is objectionable, because the same air is heated and reheated, breathed and rebreathed, and soon becomes vitiated, if the room is occupied. The hot-air duct is taken from the side of the casing and is furnished with a flat bottom. This is particularly advantageous for floor-register connections, because any sweepings from the floor that may fall through the register will accumulate in the bottom of *d*, and can easily be removed by simply lifting out the register; it prevents the dirt from falling on the radiator and clinging to the castings, from which it will be carried up into the room in the form of fine dust.

Indirect radiators are often made to deliver hot air into the rooms from wall registers located at different heights from the floors. Sometimes these wall registers deliver quite close to the floor, and at other times quite close to the ceiling. The proper point of delivery will depend on circumstances, such, for instance, as the outlet orifices from the room and the velocity at which the air enters the room.

57. Semidirect Heating System.—The semidirect, also called the *direct-indirect*, system of heating consists in placing radiators in front of windows, or at other points, and making connection with the outside air by means of ducts leading to the base of the radiators, in which dampers are placed for shutting off the outside air, as shown in Fig. 3. This provides for ventilation of the apartment wherein the radiator is placed. The radiators are similar to direct radiators in general outward appearance, but are provided with a base casting to confine the air and cause it to ascend through the spaces or flues between the sections. The radiator stands exposed in the room and therefore also serves as a direct radiator by emitting the heat from its exposed surface by radiation, while the air passing through the flues is warmed by convection. When the air from outside is shut off, serious impairment of the efficiency of the radiator is prevented by providing an additional damper in the base, and connecting it to the other damper, so that in closing one the other is opened, thereby allowing air from the room to circulate through the radiator flues. The duct from the base of the radiator through the wall is usually made of galvanized iron, fitted with a screen to exclude insects and prevent birds from building nests in the duct, and set at an incline, or provided with louvers, to prevent the rain from beating in. The duct usually measures 5¼ inches by 17 inches. Two or more can be used, if necessary, to supply the required amount of air. Inlets of this type should not be used where it is required to change the air of the room more than four times per hour. One disadvantage presented by semidirect heating systems is the fact that no satisfactory method has yet been devised for automatically regulating the flow of air over the heating surface under differing outside wind pressures. The wind pressure on the side of a building may range from a light summer breeze to a gale, and therefore the opening designed for a gentle breeze would be too large for the gale, and with the latter the cooling might take place so rapidly as to freeze the condensation in the bottom of the radiator. With satisfactory automatic regulating dampers, the semidirect method of heating would be more generally used. The emission of heat per square foot is greater in these radiators, and hence the boiler capacity must be greater, than for an equal amount of direct radiation.

SIZES OF PIPING

58. General Considerations.—The size of steam piping for a given purpose depends on several factors, among which are the steam pressure, the length of the pipe, and the frictional resistance offered by the line of pipe and the fittings. All these factors, including also the diameter of the pipe, influence the velocity with which the steam flows through the piping and hence the amount of steam that might be delivered in a given time; in fact, the flow of steam in pipes is affected by so many varying conditions that the formulation of accurate rules, general in application, for determining the requisite size of piping for heating systems is impracticable. Besides, rules taking into consideration all the surrounding conditions will, in any case, give only approximations to the correct results, since some of the factors must be assumed. Wide practical experience is required in order to give the correct value to some of the coefficients that affect the proper solution of the problem, and hence it is deemed advisable to present in tabular form the pipe sizes that have given good results in practice, in addition to a simple empirical rule.

Steam-heating mains should be proportioned according to the pressure to be carried, the distance to which the steam is to be transmitted, the drop in pressure desired, and the amount of radiating surface to be supplied. They are commonly reduced in size toward the end of the main as branches therefrom are taken off. Some pipe fitters decrease the size of mains in proportion to the decrease in the combined area of the branches to be supplied, but this is not regarded as being the best practice, as the reduction should be more gradual. It is sometimes specified that the main near the boiler shall have an area equal to the aggregate area of all its branches.

The frictional resistance to the flow of steam increases with the length of the pipe, the quantity of steam delivered being correspondingly diminished. Approximately, it varies inversely as the square of the velocity; that is, taking a velocity of 100 feet per second, for example, and assuming the reduction in pressure in 100 feet of main to be about 1½ pounds, with one-half of that velocity, or 50 feet per second, the reduction in pressure will be only one-fourth of 1½ pounds, while with one-fourth the velocity, or 25 feet per second, there will be one-sixteenth of 1½ pounds reduction in pressure.

In the design of extensive heating systems, such as are commonly found in public and semipublic buildings in large cities, as well as in a great many state institutions, such as asylums and jails, it is essential that the lengths of the various pipes be carefully considered in determining their diameter previous to installation. Within the limits of reason, the larger the pipes the more satisfactory will be the results in heating, but considerations of economy and acceptable engineering practice should operate to prevent the use of pipes larger than are actually required.

59. Sizes of Mains for Two-Pipe Systems and Direct Radiation.—The amount of radiation that can be supplied by steam mains of different sizes, 100 feet long, in a two-pipe system, and with different steam pressures, is given in Table IV, which is due to A. R. Wolff. In this table, it is assumed that 1 square foot of radiating surface will transmit 250 British thermal units per hour; hence, the values in the columns headed Total Heat Transmitted, British Thermal Units, are obtained by multiplying the values in the columns headed Direct Radiating Surface, Square Feet, by 250. The number of square feet of radiation that a pipe longer or shorter than 100 feet will supply can be found by multiplying the number of square feet of radiation corresponding to the size of the pipe, and taken from the table, by a factor that is the square root of the quotient obtained by dividing 100 by the length of the main, in feet. In order to obviate the necessity of calculating the factor mentioned, its value for the lengths of main most often found in practice is given in Table V. The length of main to be used in this calculation of radiation is not its actual length, but the actual length corrected for obstructions by fittings, etc., and called the *equivalent length*. In low-pressure heating apparatus, the obstruction offered to the flow of steam by bends and fittings should be reckoned as being equivalent to increasing the length of the main by the

TABLE IV

SIZES OF MAINS, DIRECT RADIATION, TWO-PIPE SYSTEM

Diameter of Supply Inches 100 Feet Long	Diameter of Return Inches 100 Feet Long	2 Pounds Pressure		5 Pounds Pressure	
		Total Heat Transmitted British Thermal Units	Direct Radiating Surface Square Feet	Total Heat Transmitted British Thermal Units	Direct Radiating Surface Square Feet
1	1	9,000	36	15,000	60
1¼	1	18,000	72	30,000	120
1½	1¼	30,000	120	50,000	200
2	1½	70,000	280	120,000	480
2½	2	132,000	528	220,000	880
3	2½	225,000	900	375,000	1,500
3½	2½	330,000	1,320	550,000	2,200
4	3	480,000	1,920	800,000	3,200
4½	3	690,000	2,760	1,150,000	4,600
5	3½	930,000	3,720	1,550,000	6,200
6	3½	1,500,000	6,000	2,500,000	10,000
7	4	2,250,000	9,000	3,750,000	15,000
8	4	3,200,000	12,800	5,400,000	21,600
9	4½	4,450,000	17,800	7,500,000	30,000
10	5	5,800,000	23,200	9,750,000	39,000
12	6	9,250,000	37,000	15,500,000	62,000
14	7	13,500,000	54,000	23,000,000	92,000
16	8	19,000,000	76,000	32,500,000	130,000

TABLE V

FACTORS FOR MAINS

Length of Pipe, Feet	200	300	400	500	600	700	800	900	1,000
Factor	.71	.58	.5	.45	.41	.38	.35	.33	.32

following amounts: right-angle elbow, 40 diameters; globe valve, 125 diameters; entrance to **T**, 60 diameters. Thus, if a main 3 inches in diameter has an actual length of 124 feet, and three elbows, two globe valves and one **T**, its equivalent length will be

$$124 + 3 \times 40 \times \tfrac{3}{12} + 2 \times 125 \times \tfrac{3}{12} + 1 \times 60 \times \tfrac{3}{12}$$
$$= 231.5 \text{ feet.}$$

The following examples show how Tables IV and V may be used:

EXAMPLE 1.—What size of supply main is required to supply 850 square feet of direct radiation with steam at 5 pounds pressure, the equivalent length of the main, that is, including the resistance offered by fittings, being 100 feet?

SOLUTION.—In the right-hand column of Table IV, the nearest numbers to 850 are 480 and 880. The number 880 is a little more than 850, but is much nearer to it than 480. Therefore, follow horizontally across the table from 880 to the corresponding size of pipe given in the left-hand column, which is 2½ in. Ans.

EXAMPLE 2.—What size of supply main is required to supply 9,086 square feet of direct radiation with steam at 5 pounds pressure, the equivalent length of the main being 800 feet?

SOLUTION.—By referring to Table IV, it is seen that 9,086 sq. ft. of direct radiation may be supplied by a 6-in. pipe 100 ft. long. But, as the length of the main is 800 ft., it follows that a larger pipe must be used. The next size larger is 7-in. pipe, which, if 100 ft. long, will supply 15,000 sq. ft. of direct radiation.

To determine what amount of radiation a 7-in. pipe 800 ft. long will supply, it is necessary to multiply 15,000 by .35, which is the factor, taken from Table V, for a main 800 ft. long. A 7-in. pipe 800 ft. long will supply 15,000 × .35 = 5,250 sq. ft. of direct radiation. This shows that a 7-in. main is too small; therefore, it will be necessary to try the next larger size of pipe in a similar manner, thus: 21,600 × .35 = 7,560 sq. ft. An 8-in. pipe is therefore too small. Now try the 9-in. pipe. 30,000 × .35 = 10,500 sq. ft. This is somewhat larger than is actually required, but, being very near to the given amount of radiation, 9,086 sq. ft., the size of pipe capable of supplying 10,500 sq. ft., that is 9-in. pipe, should be used. Ans.

To compute the area required for a given amount of radiation supplied by a main of greater length than 100 feet, multiply the area of the pipe corresponding to the amount of radiation, as given in Table IV, by the square root of the quotient obtained by dividing the length of the main in feet by 100.

Example 3.—At 5 pounds pressure, with the two-pipe system, how large a main is necessary to supply 5,000 feet of radiation, the main being 400 feet long?

Solution.—In the last column of Table IV, it will be found that the amount of radiation nearest to 5,000 ft., viz., 4,600 ft., requires a main 4½ in. in diameter. Dividing 400, the length of the main, by 100 and extracting the square root of the quotient gives a factor of 2, by which the area of the 4½-in. pipe is to be multiplied to obtain the requisite area of a main 400 ft. long to supply 5,000 ft. of radiation; thus, 2 × 15.96 = 31.92 sq. in., to which the area of a 6-in. pipe most nearly corresponds. The correctness of the result thus obtained may be checked by multiplying the amount of radiation given in the last column of Table IV, opposite the 6-in. pipe, viz., 10,000, by the factor given in Table V, for a main 400 ft. long; thus, 10,000 × .5 = 5,000 sq. ft., showing that the required main should be 6 in. in diameter. Ans.

Example 4.—With steam at 2 pounds pressure, how large a main will be required to supply steam to 5,000 feet of radiation, the main being 700 feet long?

Solution.—Dividing the length of main by 100 and extracting the square root of the quotient, a factor of 2.65 is obtained, by which the area of a pipe corresponding to a diameter of about 5½ in. must be multiplied to obtain the size of pipe required to meet the stated conditions. It will be noticed that Table IV does not give the size of main for 5,000 ft. of radiation operated at 2 lb. pressure, but it is evident from the table that it will be about 5½-in. Steam pipe of this diameter is not manufactured, and hence, taking the enclosed area of a circle 5½ in. in diameter, viz., 21.76 sq. in., and multiplying by 2.65, 21.76 × 2.65 = 57.66 sq. in. is obtained. An 8-in. pipe has an internal area of 50.04 sq. in., while a 9-in. pipe has an area of 62.73 sq. in. It is therefore evident that an 8½-in. pipe will be required, but since piping of that size is not manufactured and it is better to err on the side of safety, a 9-in. pipe should be used. Ans.

60. Sizes of Mains for Indirect Radiation.—In estimating the sizes of pipes to supply indirect radiation under natural draft, it is customary to consider that 1 square foot of indirect radiation will condense as much steam as 2 square feet of direct radiation. Therefore, Table IV can be used, but the amount of indirect radiation must be doubled to find its equivalent in direct radiation.

Example.—What size of supply pipe is required to supply steam at a pressure of 2 pounds to 530 square feet of indirect radiation, the equivalent length of pipe being 75 feet?

Solution.—Equivalent in direct radiation is 530 × 2 = 1,060 sq. ft. Referring to Table IV, it will be noted that a 3½-in. pipe 100 ft. long will supply 1,320 sq. ft. of direct radiation at a 2-lb. pressure, and that a 3-in. pipe 100 ft. long will supply 900 sq. ft. of direct radiation. If the supply main were longer than 100 ft., it would be necessary to use a 3½-in. pipe. But, as the length of the main is only 75 ft. it is safe to use a 3-in. pipe. Ans.

61. Sizes of Mains for Direct-Indirect Radiation. The sizes of mains for supplying direct-indirect, or semi-direct, radiators with steam can be found in the manner described for indirect mains, except that the equivalent in direct radiation is found by adding 50 per cent. to the amount of direct-indirect radiation.

62. Sizes of Mains for One-Pipe Systems.—The pipe sizes given in Table VI, which is based on good practice, are such as will insure satisfactory results with single-pipe systems in which the water level in the return above the boiler water-line (representing the drop in pressure) is from 6 to 12 inches, the steam pressure varying from ½ to 2½ pounds per square inch.

Example.—What size of main is required for a one-pipe system to supply 12,000 square feet of direct radiation, the main being 400 feet long?

Solution.—Find 12,000 in the left-hand column of Table VI, follow along horizontally toward the right to the 400-foot column, which is the third one from the right, where the proper size required is given, namely, 9-in. pipe. Ans.

Since in single-pipe work the steam and water of condensation flow through the same pipe and frequently in opposite directions, it is necessary to use larger pipes than with two-pipe systems, so as to insure as free a flow of the opposing currents as practicable. Before using Table VI, the equivalent length of the main should be found in the manner described in Art. **59.** Bearing in mind that a steam main for steam-heating work should never be less than 1 inch in diameter, and then only for short lengths of mains and

TABLE VI

SIZES OF MAINS, DIRECT RADIATION, ONE-PIPE SYSTEM

Radiating Surface Square Feet	Length of Main, in Feet								
	20	40	80	100	200	300	400	600	1,000
	Nominal Diameter of Pipe, in Inches								
20	1	1	1¼	1¼	1¼	1¼	1½	1½	1½
40	1¼	1¼	1¼	1¼	1½	1½	2	2	2
60	1¼	1¼	1½	1½	1½	1½	2	2	2½
80	1½	1½	1½	1½	2	2	2	2½	2½
100	1½	1½	1½	1½	2	2	2½	2½	3
200	2	2	2	2	2½	2½	3	3	3½
300	2	2	2	2	2½	2½	3	3	4
400	2	2	2½	2½	2½	3	3	3½	4
500	2½	2½	2½	3	3	3	3½	4	4½
600	2½	2½	2½	3	3	3½	3½	4	4½
800	2½	2½	3	3½	3½	3½	4	4½	5
1,000	3	3	3½	3½	4	4	4	4½	6
1,400	3	3	3½	4	4	4½	4½	5	6
1,800	3½	3½	4	4	4½	4½	5	5	7
2,000	3½	3½	4	4½	4½	5	5	6	7
3,000	4	4	4½	5	5	6	6	7	8
4,000	4½	4½	5	5	6	7	7	8	9
6,000	5	5	5	6	7	7	7	8	10
8,000	5	5	6	6	7	8	8	9	11
10,000	6	6	6	7	7	8	8	9	12
12,000	6	6	6	7	8	8	9	10	12
14,000	7	7	7	8	8	9	10	11	14
16,000	7	7	8	8	9	10	11	12	14
18,000	8	8	8	9	10	10	11	12	14
20,000	9	9	9	10	11	11	12	14	16

for small amounts of radiation, the pipe sizes given in Table VI may be multiplied by .8 to obtain the requisite diameter of supply mains for a two-pipe system. The corresponding diameter of return main may then be taken from Table IV. In applying Tables IV and VI to the same case of a two-pipe system, a slight difference in the result may occur; this is due to the fact that the tables represent the successful practice of different engineers rather than absolute values based on purely theoretical considerations.

63. Sizes of Returns.—The sizes of the return pipes not only depend on the capacity of the system as a whole, but are materially affected by the character of the returns, that is, whether wet or dry. The smallest return piping may be used when the returns are sealed by being carried below the boiler water-line or by being trapped to establish an artificial water-line in them. With wet or sealed returns, it is considered good practice to make the area of the return piping equal to about one-fourth that of the steam piping in plants where the steam pipe is larger than 3 inches in diameter, although some engineers make the diameter of the return in such plants about one-half that of the steam main. Where the steam pipe is less than 3 inches in diameter, it is customary to make the return one or two sizes smaller than the corresponding steam pipe. With dry returns, it is considered good practice to make the area of the piping equal to about one-half that of the corresponding steam pipe. It is good practice never to use a return smaller than 1 inch in diameter, although a ¾-inch pipe may be employed in some cases where the amount of radiation to be drained is small. Table IV indicates sizes of return pipes, with corresponding steam mains, that have been found to work satisfactorily in practice. The diameter of return pipes from indirect heating surfaces should be about 50 per cent. greater than for a similar amount of direct radiation.

64. Sizes of Drip Pipes for Steam Mains.—Since the amount of water of condensation to be handled by drip or relief pipes is practically an unknown quantity, no general rule can be given for proportioning them. It has been found in practice, however, that ordinarily the sizes given in Table VII are ample for draining covered mains of various lengths. Larger drip pipes than are actually necessary to relieve the steam main of condensation should not be used. Drip pipes should be connected to the return in such a manner as not to impede the circulation but rather enhance the velocity with which the water of condensation returns to the boiler.

TABLE VII

SIZES OF DRIP PIPES FOR COVERED STEAM MAINS

Diameter of Steam Main Inches	Length of Steam Main, in Feet					
	100	200	400	600	800	1,000
	Diameter of Drip Pipe, in Inches					
Up to 2	½	½	¾	¾	1	1¼
3	½	¾	¾	1	1¼	1¼
4	¾	¾	1	1¼	1¼	1½
5	¾	¾	1	1¼	1½	1½
6	¾	1	1¼	1½	1½	2
7	1	1	1¼	1½	2	2
8	1	1	1¼	1½	2	2½
9	1	1¼	1½	2	2½	2½
10	1¼	1¼	1½	2	2½	3
11	1¼	1¼	1½	2	2½	3
12	1¼	1¼	1½	2½	3	3½
14	1½	1½	2	2½	3	4
16	1½	2	2½	3	3½	4

65. Sizes of Drip Pipes for Risers.—The sizes of drip pipes at the foot of risers of one-pipe systems depend on the amount of radiation supplied from the risers. Ordinarily, the sizes given for return pipes in the second column from the left in Table IV are suitable and will give satisfactory results by using them in conjunction with the figures given in the radiation column under the 5-pound pressure.

EXAMPLE.—A one-pipe riser supplies 700 square feet of direct radiation; what should be the size of the drip pipe that connects its base to the return main?

SOLUTION.—In the right-hand column of Table IV, the number nearest 700 sq. ft., and higher than it, is 880 sq. ft. Following along horizontally to the second column from the left hand, it is noted that the size of drip pipe required is 2 in. Ans.

EXHAUST AND VACUUM HEATING SYSTEMS

EXHAUST STEAM-HEATING SYSTEMS

66. Economy.—The **exhaust system** of steam heating is, in every respect, a low-pressure system, except that it is provided with special apparatus that adapts it to receive the exhaust steam from engines and pumps. It is used only for the purpose of saving and utilizing the heat in exhaust steam that would otherwise go to waste. The magnitude of this waste may easily be seen when it is considered that exhaust steam at atmospheric pressure contains 966 British thermal units per pound that are available for heating. The practice of allowing exhaust steam to escape into the atmosphere when it can be used in heating apparatus, either for house warming or heating liquids, etc., is therefore inexcusably wasteful.

To secure an adequate supply of exhaust steam for heating by placing a back pressure of 2 pounds per square inch on an engine operating with a mean effective pressure of, say, 50 pounds, will increase the coal consumption less than 1 per cent.; whereas for an equal amount of heating by means of live steam, the exhaust steam being discharged into the atmosphere, the coal consumption will probably be increased fully 60 per cent.

The amount of radiating surface that may effectively be supplied with exhaust steam by an engine of given size is estimated by allowing about 4 square feet of radiation to each pound of steam exhausted per hour. In other words, assuming that an engine developing 150 horsepower will have available for exhaust heating 20 pounds of steam at atmospheric pressure, per horsepower per hour, the amount of radiating surface that may be supplied with exhaust steam from such an engine will be 150 × 20 × 4 = 12,000 square feet.

The available amount of exhaust steam necessarily varies with the work done by the engine, whose governor is adjusted so that a sufficient weight of steam will be admitted to preserve uniformity of speed under a variable load, only a small weight of steam being admitted if the work is light, and vice versa.

67. General Arrangement.—The general arrangement of apparatus for controlling the steam supply and drainage is an exhaust steam-heating system as shown in Fig. 13. The steam-heating main *a* is connected to the exhaust pipe *b* and also to a pipe *c* that supplies live steam from the boilers. When live steam is used, it passes through a pressure-reducing valve *e* and is lowered in pressure to the desired amount before entering the heating main. By this arrangement, the heating system will be supplied with exhaust steam as long as the engines are in operation, but if for any reason the supply becomes insufficient to maintain the proper pressure, live steam will enter through the reducing valve and make up the deficiency. If the supply of exhaust steam becomes excessive, so that the pressure rises unduly, the excess of steam will escape by opening the back-pressure valve *f* and blowing into the atmosphere. When the engines are stopped, the steam in the heating apparatus is prevented from passing backwards and filling them with water by means of the check-valve *g*. This valve is similar to the valve *f* in construction and is so nearly balanced by its counterweight that it will open very easily. The relief valve *f* is usually adjusted to blow off at a pressure about 1 pound higher than that maintained by the reducing valve *e*. The exhaust steam is passed through a separator *d* before entering the heating system, for the purpose of removing the entrained water, and especially for removing the oil that accompanies it from the engine.

The drainage from the heating apparatus is collected in the pipe *h* and is returned to the boiler by means of a pump *p*, as shown. The returns have no direct connection with the boiler, consequently the water level in them may be maintained at any convenient height, as at *i*, *i*. This is accomplished by means of the pump and its governor *m*. The pump governor is merely a closed vessel containing a float *u* that rises and falls with the water level. The steam that drives the pump is taken from the high-pressure pipe *c*

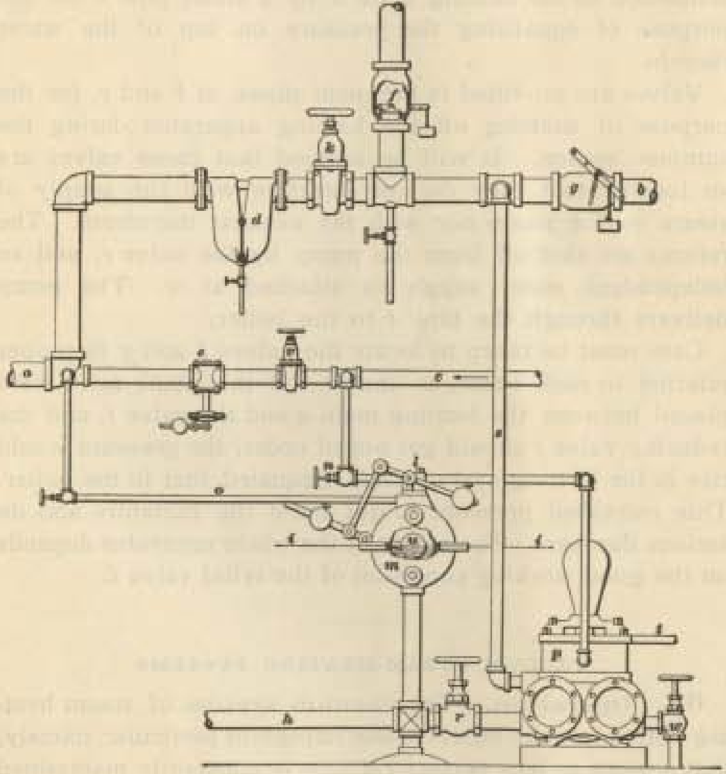

FIG. 13

through the stop-valve *n* and passes through a throttle valve *l* that is controlled by the float. When the water rises above the desired level, the float opens the throttle and starts the pump; when it subsides, the float is lowered and shuts off the steam. The exhaust from the pump is turned into the exhaust main through the pipe *s*. The pump governor is connected to the heating main *a* by a small pipe *o* for the purpose of equalizing the pressure on top of the water therein.

Valves are provided in the main pipes, at *k* and *v*, for the purpose of shutting off the heating apparatus during the summer season. It will be noticed that these valves are so located that they do not interfere with the supply of steam to the pump nor with the exhaust therefrom. The returns are shut off from the pump by the valve *r*, and an independent water supply is attached at *w*. The pump delivers through the pipe *t* to the boiler.

Care must be taken to locate the valves *f* and *g* in proper relation to each other, as shown. If the check-valve were placed between the heating main *a* and the valve *f*, and the reducing valve *e* should get out of order, the pressure would rise in the heating system until it equaled that in the boiler. This increased pressure might burst the radiators and do serious damage. The safety of the whole apparatus depends on the good working condition of the relief valve *f*.

VACUUM STEAM-HEATING SYSTEMS

68. Operation.—The **vacuum system** of steam heating differs from all others in one important particular, namely, that a more or less perfect vacuum is constantly maintained in the returns by pumps or other devices. This permits the system to be operated with steam of any convenient pressure, high or low, and from any source, either exhaust or otherwise. The pressure and temperature throughout the whole system may be adjusted and maintained at any degree between full-boiler pressure and a low vacuum, thus making the system adjustable to suit all conditions of weather and

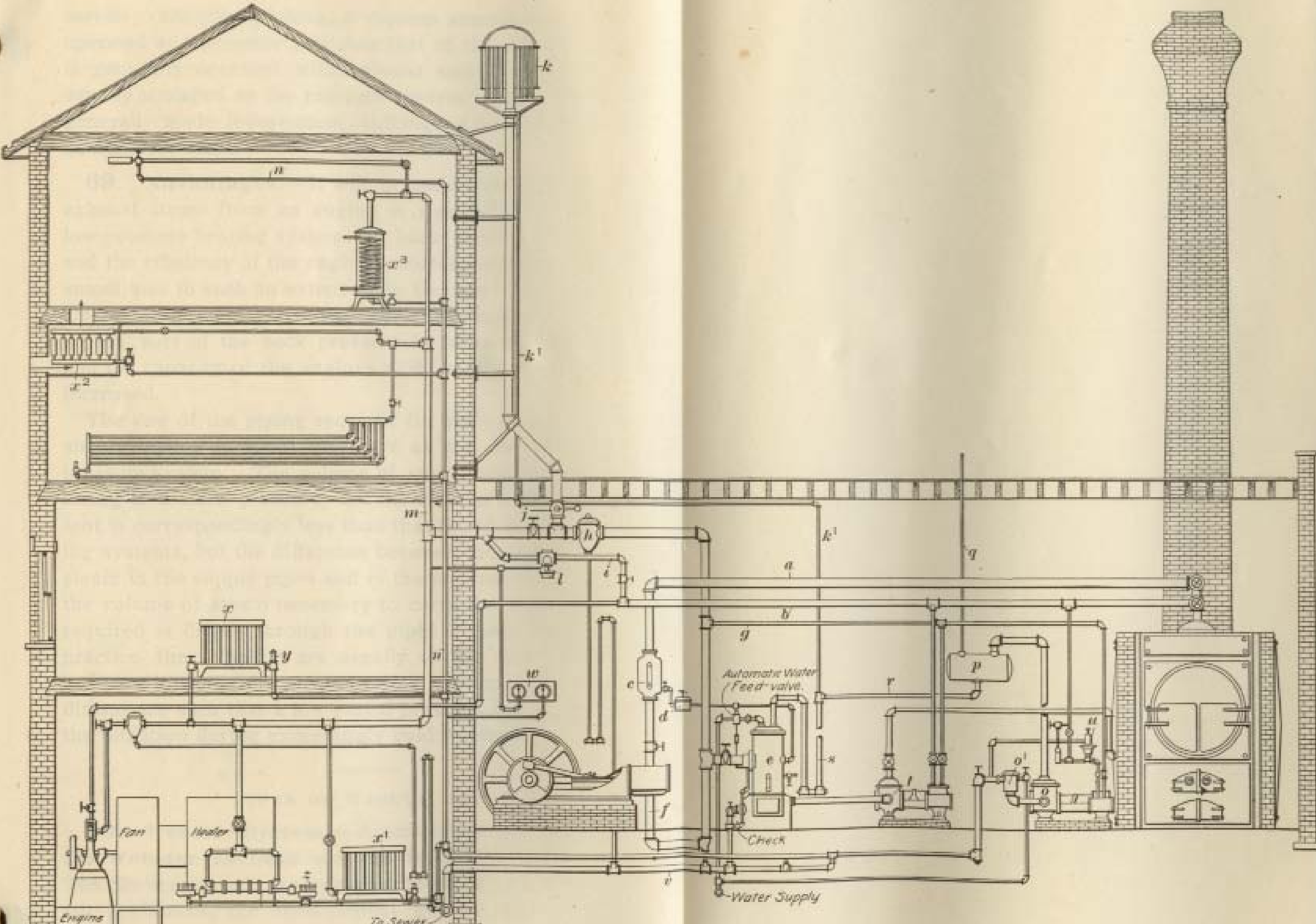

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FIG. 14

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service. Strictly speaking, a vacuum system is one that is operated at a pressure less than that of the atmosphere, and is generally operated with exhaust steam. The piping is usually arranged on the two-pipe system, and the returns are generally made independent, although it is not necessary to do so in all cases.

69. Advantages.—It will be understood that when the exhaust steam from an engine is turned into the ordinary low-pressure heating system, the back pressure is increased and the efficiency of the engine is correspondingly decreased, sometimes to such an extent as to become very detrimental. One of the principal advantages of the vacuum system is that a great part of the back pressure is taken off the engines, and the capacity of the engines to do useful work is thereby increased.

The size of the piping required for the vacuum system of steam heating is about the same as for the ordinary low-pressure system. The volume of steam required is greater, owing to the low pressure, and the amount of heat per cubic foot is correspondingly less than that found in ordinary heating systems, but the difference between the pressures of the steam in the supply pipes and in the returns is so great that the volume of steam necessary to carry the amount of heat required is driven through the pipes without difficulty. In practice, the radiators are usually of the same size as for ordinary low-pressure steam-heating systems when the conditions are such that a low steam pressure can be applied to the radiation during exceedingly cold weather.

TYPES OF VACUUM SYSTEMS

70. Webster System.—A conventional arrangement of the **Webster vacuum system** is illustrated in Fig. 14. The illustration serves to show methods of connecting different appliances, the arrangement given being modified in practice to suit the conditions imposed. The pipe *a* supplies steam to the main engine only, while the pipe *b* supplies steam for the pumps and fan engine. A separator *c* is placed in the pipe *a* near the engine. The drip from this separator passes through a steam trap *d* to the feedwater heater *e*. Exhaust steam from engines and pumps passes through the pipes *f* and *g* into a closed feedwater heater connected to the main vacuum return pipe through which the air is extracted, and the pressure in the heater reduced to less than that of the atmosphere. The partial vacuum in the feedwater heater causes the steam to flow freely into the heater, where it is condensed and heats the make-up water required to supplement the water of condensation returned from the heating system. The exhaust pipe *f* from the engine rises to the ceiling, where the exhaust pipe *g* from the pumps connects into it, as shown. A grease extractor *h* is inserted in the exhaust pipe before connection is made to the heating apparatus, to which a live-steam by-pass connection *i* is provided. The escape pipe is provided with a back-pressure valve *j* and is carried upwards from a point near the grease extractor to and above the roof of the building, where it terminates in an exhaust head *k*, from which the condensation is dripped back to the feedwater heater through k^1, the oil and grease having been extracted. Live steam may be employed for heating, when necessary, the steam passing from the main *b* through the reducing valve *l* to the heating main, or riser, *m*. The return pipe *n* is carried downwards to a point below the level of the feedwater heater, and is thus made a sealed return, although the pipe could be carried above the heater if required. This return pipe does not connect with the feedwater heater directly, but with a vacuum pump *o*, in the connection to which a strainer o^1 is placed, and a jet of cold water is introduced to cool the return water and thereby assist the pump in maintaining the vacuum. The water and the air drawn from the return pipe are forced by the pump into a receiver *p*, placed at an elevation above the feedwater heater, so that the water in the receiver will flow by gravity into the feedwater heater. The receiving tank *p* has a vent pipe *q* to the atmosphere through which the air in the system is discharged. In the pipe *r* from the receiver *p* a water trap or loop seal *s* is provided, so that in case of a pressure in the system, the water or the steam in the feedwater heater will not escape should the vacuum pump be stopped. The seal also prevents the atmosphere from rushing into the heater when the pressure in the heater is below that of the atmosphere. The water in the feedwater heater is pumped into the boiler by a feed-pump *t*. The vacuum pump *o* is fitted with an automatic controlling device *u*, connected to the steam and vacuum pipes, so that the pump will slow down when the vacuum has reached a certain point and speed up again as the vacuum is lost. The make-up water supply to the feedwater heater is automatically controlled. The waste drips from the grease extractor *h* and the overflow from the feedwater heater *e* are connected into a pipe *v* that discharges into the sewer. Each drip pipe is connected to this waste pipe by loop seals, so that in case a pressure exists in the system, the seals will not allow steam to escape. If these seals are not capable of preventing the steam from passing through the pipe, it becomes necessary to use a steam trap. When the engine is not running, steam for heating may be supplied through the pipe *b*. Only one valve is shown as being provided to shut off the supply of live steam, but there should be a valve at each side of the reducing valve *l*, around which a by-pass should be arranged, so that the reducing valve could be repaired, if necessary, without shutting down the apparatus. The gauges shown at *w* indicate, respectively, the pressure on the heating main *m* and the vacuum on the return main *n*.

71. The connections to the radiators and other fixtures are somewhat different from those commonly employed with gravity systems. Taking the radiator *x*, for example, the steam-supply radiator connection is provided with an angle valve, but the return pipe has a trap *y* or thermostatic valve, shown in section in Fig. 15, in the connection at the radiator. In operation, when the radiator is cold the expansion stalk *a*, Fig. 15, in the valve will be contracted, so that when steam is admitted to the radiator the partial vacuum in the return pipe will cause the steam to fill the radiator quickly, the water of condensation falling to the bottom of the radiator and being drained into the return pipe through the passages *b*, *c* and *d*, *d* in the valve-seat bushing *e* that is surrounded by a protecting strainer *f*. The steam, when it comes in contact with the stalk, expands it, and the orifice *c* of the valve is contracted or closed. As the stalk cools again, the orifice is enlarged and the water passes out of the radiator. Adjustment of the stalk is obtained, as indicated, by means of the screw *g* at the top of the valve, Fig. 15.

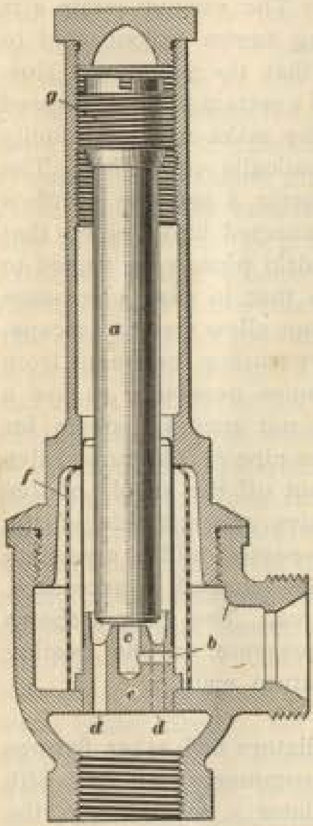

Fig. 15

Before inserting the valve-seat bushing *e*, the radiator should be cleaned of any grease, dirt, or grit that might clog the orifice and thus impair the efficiency of the valve. For this purpose dirt pockets are placed in the connections at *z*, Fig. 14, where a hot-blast heater coil is shown connected to the return below the level of the return pipe at the pump. The heating surface in the coil is greater than one thermostatic valve can control, and hence a multiple thermostatic-valve device is used. This valve device represents a combination of several expanding stalks that are inserted in one body, the action being the same as with one stalk, or the first stalk may be heated and closed while others are open, according to the amount of water and temperature.

The radiator x', Fig. 14, is below the pump level, and the condensation from it is raised above the top of the radiator to keep it free from condensation. In an ordinary gravity-heating job this would be difficult, but with the vacuum system the pressure on the return pipe is considerably less than that in the radiator, and hence the water will be forced up to the level required to discharge it into the pump. This arrangement, however, is not advisable where it can be avoided. In a conventional way, the method of connecting to indirect radiators is shown at x^2, while at x^3 is shown the method of connecting water heaters where steam is used to heat water for domestic use. Old heating systems may be altered to vacuum systems wherein the operating pressure will not exceed that of the atmosphere.

72. Except for use in connection with small radiators, the thermostatic valve shown in Fig. 15 may be superseded by the motor valve shown in Fig. 16. The latter comprises a float *a* through which extends loosely a hollow stem *b* attached to the piston *c* and carrying a valve disk *d* that is held to its seat by the spring *e*. The operation of the piston *c* depends on the difference between the pressure in the radiator and that in the return line. When the radiator is not condensing steam, the valve disk *d* is held to its seat by the spring *e*, and only a slight escape of air through the stem *b* is possible. When the water of condensation flows into the valve, the float *a* rises until the port *f* is closed by the plug *g*, when the pressure above the piston *c* will become the same as that in the return pipe, with which the upper chamber is in communication through the hollow stem *b*. The higher pressure of the supply side raises the piston *c* and attached valve disk *d* so as to

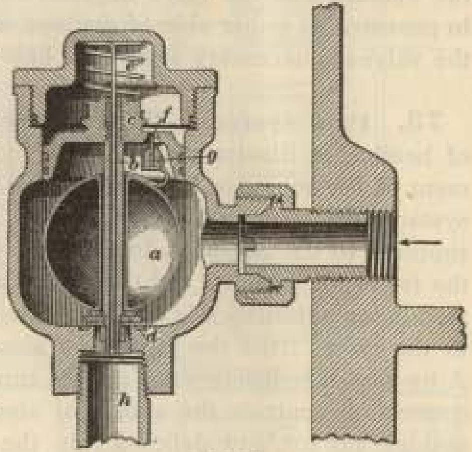

Fig. 16

permit the escape of water of condensation into the return pipe *h*. With the escape of condensation the float *a* descends, opening the port *l* and thereby causing an equalization of the pressure on both sides of the piston *c*; the spring *e* then again seats the valve disk *d* ready for another operation, previous to which any accumulation of air is drawn out of the radiator into the return pipe through the hollow stem *b* by the suction of the vacuum pump to which the return piping is attached.

Before inserting the interior mechanism of the valve, it is necessary to see that all burrs, chips, sand, pipe cement, and other dirt are washed out of the radiators and piping system, steam being permitted to blow freely through the apparatus for several days if possible. After the washing-out process is finished, the inner parts of the valve may be placed in position, care being taken that the valve guide at the end of the hollow stem enters its seat properly. Since the operation of the valve depends solely on the difference in pressure on either side of the piston *c*, no readjustment of the valves is necessary after once being properly set.

73. Paul System.—What is known as the **Paul system** of heating is illustrated in Fig. 17. The general arrangement of the mains in the basement is similar to that of the systems previously described. From the boiler *a*, steam is supplied to the engine *b*, from which the exhaust passes to the feedwater heater *c* and thence to the heating system, the feed-pump automatically returning the water of condensation to the boiler from the receiver *d* alongside the feed-pump. A by-passed reducing valve *e* in the supplementary live-steam connection controls the supply of steam from the boiler in making up for any deficiency in the available amount of exhaust steam. The escape pipe to the roof is provided with a lightly weighted back-pressure valve *f*. The return pipe is connected to an automatic pump governor. The steam pipe *g* connects to the exhausting apparatus *h*, the discharge pipe from which is connected to the exhaust escape pipe to the atmosphere. The air pipes are connected to the suction opening in the exhausting apparatus *h* and have a

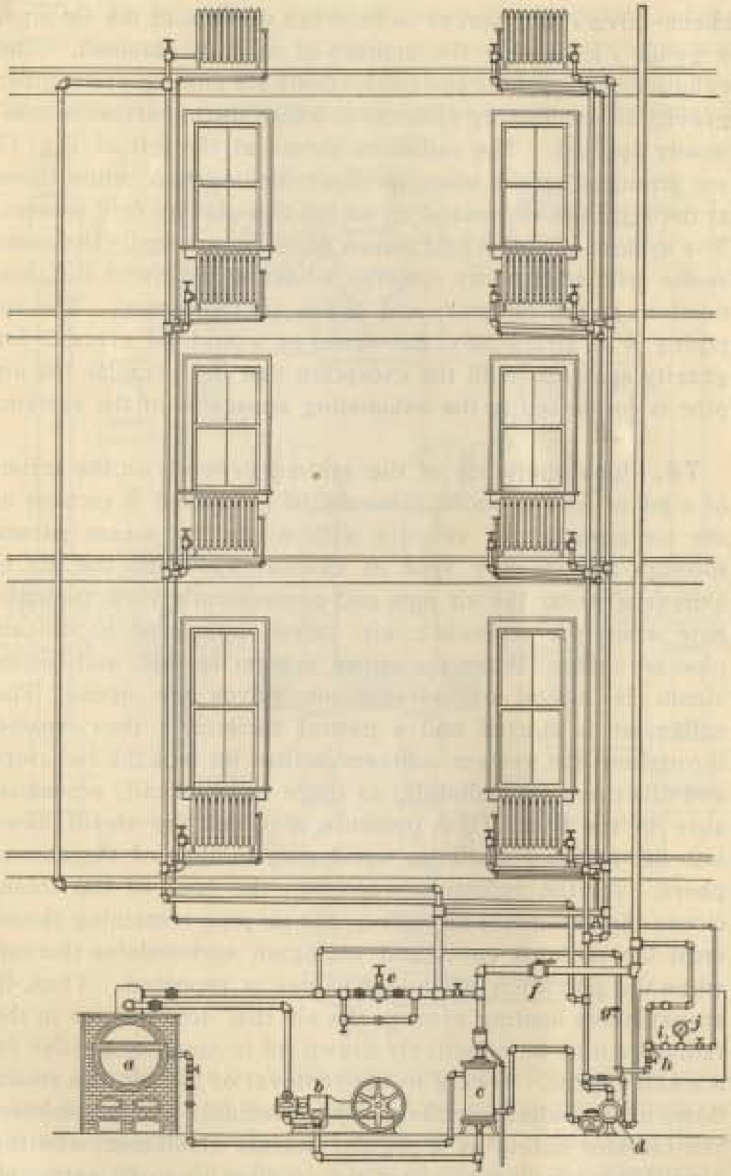

Fig. 17

check-valve *i* that serves to hold the vacuum in the air pipe, a gauge *j* indicating the amount of vacuum obtained. The exhausting apparatus and connections are auxiliary to regular gravity steam-heating systems to which the apparatus is commonly applied. The radiators shown at the left of Fig. 17 are arranged on the one-pipe down-feed system, while those at the right are connected up on the two-pipe up-feed system. The system of steam and return pipes is practically the same as for ordinary gravity systems, so far as the risers and connections to the radiators and mains are concerned. The air piping *k* is practically the same as would be erected for gravity systems, with the exception that in the cellar the air pipe is connected to the exhausting apparatus of the system.

74. The operation of the system depends on the action of a jet of steam under pressure in producing a vacuum in the air pipe by the velocity with which the steam passes through an ordinary type of ejector, by which the air is exhausted from the air pipe and consequently from the radiator when the automatic air valves connected to the air pipe are open. When the entire system is cold, and before steam is turned on, all the air valves are open. The exhauster is started and a partial vacuum is thus created throughout the system. Steam is then let into the radiators and fills them immediately, as there is practically no resistance to the flow. The pressure at which the steam flows into the radiator need be equal only to that of the atmosphere. As the radiators warm up, the heat of the steam closes the automatic air valves, the air pipe remaining closed until the radiator cools and air again accumulates therein, when the operation of the air valves is repeated. Thus, in an extensive heating system, the air that accumulates in the radiators may be effectively drawn off in small quantities by a small ejector. Owing to the removal of the air, the steam flows to the radiator without any appreciable gauge pressure, the radiator acting as a regular surface condenser, and the air valve operating to allow the cooling air to be extracted as it accumulates.

75. In Fig. 18 is shown the exhausting apparatus for a plant having a large number of radiators, the apparatus being arranged in duplicate so that one of the ejectors may be operated in case the other should become disarranged.

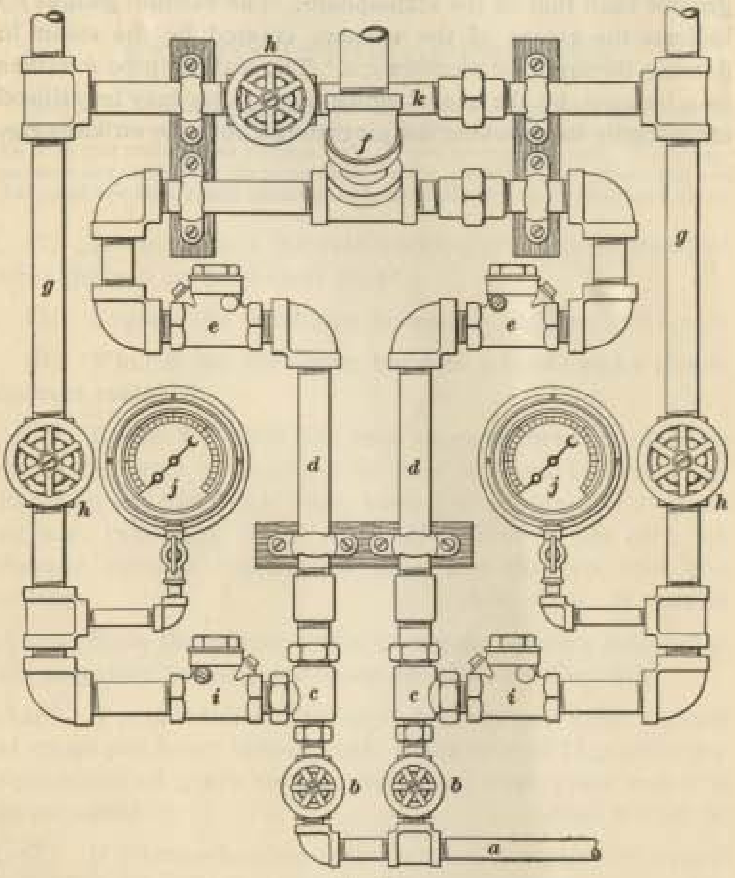

FIG. 18

Live steam enters the exhausting apparatus through the pipe *a* and one or both of the valves *b*, *b*, passing to the ejectors *c*, *c*, pipes *d*, *d*, check-valves *e*, *e*, and through *f* to the exhaust escape pipe. The flow of steam through the ejectors *c*, *c* creates a partial vacuum in the air-line piping *g*, *g*, through which the air is drawn from the radiators. The valves *h*, *h*, *h* provide for the independent operation of either half of the apparatus, while the check-valves *i*, *i* serve to prevent the establishment of a pressure in the air piping equal to or greater than that of the atmosphere. The vacuum gauges *j*, *j* indicate the extent of the vacuum created by the steam in flowing through the ejectors *c*, *c*. The valved pipe *k* serves as a by-pass, by the use of which one ejector may be utilized temporarily in removing the air through both the air lines *g*, *g*.

STEAM HEATING

Serial 1081 Edition 1

EXAMINATION QUESTIONS

Notice to Students.—*Study the Instruction Paper thoroughly before you attempt to answer these questions.* **Read each question carefully and be sure you understand it;** *then write the best answer you can. When your answers are completed, examine them closely, correct all the errors you can find, and* **see that every question is answered;** *then mail your work to us.*

P3 P3 (1) About what is the safe working pressure of standard wrought-iron or mild-steel pipe?

P3 P4 (2) Explain the difference between a radiator and a coil.

P8 P10 (3) What is the difference between a direct and a direct-indirect radiator?

P16 P23 (4) By the 2-20-200 rule, how many square feet of direct steam radiation is required to heat a room 14 feet long, 12 feet wide, and 9 feet high, having 40 square feet of glass surface, two sides being exposed? Allow 20 per cent. for leakage through cracks and heat loss through floor and ceiling. Ans. 45 sq. ft., nearly

P18 P28 (5) State the requirements of a good heating boiler that are necessary to generate steam rapidly and efficiently.

P22 P34 (6) A return-tubular boiler is to generate 1,000 pounds of steam per hour; burning coal at the rate of 12 pounds per square foot of grate surface per hour, what grate area will be required? Ans. 9.8 sq. ft.

P29 P36 (7) If a house-heating boiler is rated to supply 800 square feet of direct radiation under ordinary conditions, how many square feet of grate surface will be required? Ans. 8 sq. ft.

P27 P37 (8) In house-heating work, how should the steam main be graded in order to drain properly?

P37 P39 (9) Describe the difference between a dry return main and a wet return main.

P29 P42 (10) In designing a piping system, what must be considered and provided for in regard to condensation of the steam and heating and cooling of the pipes?

P30 P43 (11) Describe how water hammer is caused in steam pipes.

P30 P49 (12) Briefly describe the general direction of the flow of steam and water of condensation throughout a one-pipe system having a main run around the cellar in the form of a loop.

P35 P5 (13) Describe the one-pipe down-feed, or Mills, system of steam distribution, and state what advantages it possesses over the ordinary up-feed system.

P38 P5 (14) What is the principal distinguishing feature of a two-pipe heating system?

P40 P54 (15) Describe briefly the common-feed and separate-return system of piping.

P40 P55 (16) Describe the method of warming buildings by indirect radiation.

P42 P53 (17) Briefly describe the semidirect system of heating.

P45 P54 (18) What size main is required in a two-pipe system to supply steam at a pressure of 5 pounds to 450 square feet of indirect radiation, the length of the pipe being 100 feet?

Ans. $2\frac{1}{2}$ in.

P49 P62 (19) What size of main 100 feet long is required to supply 20,000 square feet of direct radiation in a one-pipe system?

Ans. 10 in.

P45 P57 (20) If a 3-inch main, 100 feet long, will supply 900 square feet of direct radiation in a two-pipe system, how many square feet will it supply if the main is 400 feet long?

Ans. 450 sq. ft.

P53 P66 (21) Which is more economical, to carry back pressure on the engine, in order to utilize the exhaust steam for heating purposes, or to heat with live steam direct from the boiler, allowing the engine to exhaust into the atmosphere?

P57 (22) Name one of the chief advantages of the vacuum system of heating using exhaust steam.

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