In actual practice, the circulation of water in a hot-water heating system is much more complicated than that shown in a simple circuit like Fig. 34. Every radiator then has a separate circuit of its own which must have approximately the same resistance as every other circuit. Each of these circuits has an individual length, height and amount of heat to be delivered. If any one circuit has a great advantage over the others, it will increase this advantage by heating the main return, which subtracts from the effective height of all the other radiators involved.

If the risers to radiator *B*, Fig. 37, were changed to 1½ in. and all other connections remained as shown, the hot water would pass through this radiator with a very small temperature drop and back into the return main. This would subtract 3 ft. of effective height from radiators *C* and *D* and might even cause reverse circulation.

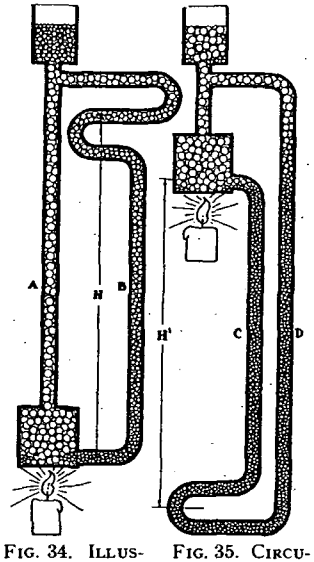


FIG. 34. ILLUSTRATES PRINCIPLE OF GRAVITY CIRCULATION

FIG. 35. CIRCULATION IMPOSSIBLE WITH THIS ARRANGEMENT

With gravity hot-water heating the force tending to cause circulation is very small. For 40 deg. drop, it only amounts to $\frac{3}{16}$ in. of water pressure for each foot of effective height. There is very little data available on the flow of hot water in pipes under conditions such as are found in gravity work. The pioneers in this field adapted their formulae from tests made on large cast iron pipes such, as are used in city water works. These formulae were not adapted to conditions such as are found in gravity hot-water heating, but they were the only ones available at the time. All modern formulae are based on the experiments of German engineers with pipes and fittings, such as are found in that country. How these compare with ours is a matter of conjecture.

DESIGNING A GRAVITY SYSTEM

To make all the radiators in a gravity circulating system correspond with one another, it is necessary to assume a temperature drop for the circuit, and then equalize all the individual circuits to this temperature drop. To be correct it should be based on a weight difference between the flow and return risers as weight difference and temperature drop do not correspond at different water temperatures. It is usual to assume an average water temperature of 180 deg. fahr.

A low-temperature drop requires larger piping, and is not so responsive to the fire because there is more water in circulation, but due to the low-water velocity it is much easier to balance. A low-temperature drop is better where several radiators are taken from a single main as in the one-pipe system.

SELECTING THE RIGHT PIPE SIZE

The charts, Fig. 36, show the pipe sizes required for temperature drops of 20, 30 and 40 deg. The vertical lines represent the total length of the circuit, divided by the effective height. The length of the circuit should be figured as if a separate pipe were carried from the heater to each individual radiator and back to the heater again, as is indicated in the diagram, Fig. 37. The effective height in simple circuits should be the distance between the center of the heater and the center of the radiator. In compound circuits such as is shown at *AA*, Fig. 37, the mean effective height would be the B.t.u. delivered by each separate heat emitting unit, multiplied by its effective height, the sum being divided by the total B.t.u. of the circuit. The horizontal lines in the charts represent the capacity of the circuit in B.t.u. per hour and in square feet of radiation. It is better to work from the B.t.u. side of the chart, as a square foot of radiation is a meaningless term. The chart for a 30 deg. drop has been made opposite hand from the 20 deg. and 40 deg. charts to save space.

Knowing the number of B.t.u., or the square feet of radiation, follow the line horizontally to the vertical line representing the ratio of the effective height to the length of the circuit. The next lower diagonal line, representing the size of pipe, gives the answer required.

For example, 10,000 B.t.u. would be supplied to a circuit 100 ft. long with 10 ft. of effective height by an 1¼-in. pipe with a 20 deg. drop, by a 1 in. pipe with a 30 deg. drop and a 1 in. pipe with a 40 deg. drop, but the total capacity in the case of the 40 deg. drop would be about 17,000 heat units.

The pipe sizes, as given above would be correct if a separate pipe were taken from the heater to each radiator, with a separate return from each radiator back to the heater. From 10 to 30 per cent would have to be added to the actual length of the circuit to allow for the additional resistance of fittings. It is customary to run all these different circuits as far as possible in a single main. This decreases the frictional resistance because of the additional capacity of the larger pipes.

RESISTANCE IN PIPES AND FITTINGS

The chart in Fig. 38 gives the proportional resistance of pipes in terms of a smaller size. For example, the 2-in. line crosses 2½-in. at 0.3, the 3-in. at 0.13, the 3½-in. at 0.05 and the 4-in. at 0.025. A circuit made up of 10 ft. of each of the above sizes, while having a total length of 40 ft. would only have a resistance equal to 15 ft. of 2-in. pipe. In many cases the proportional resistance of the larger pipes will balance the additional resistance of the fittings. A chart showing the resistance of fittings is given under the section on Forced Hot-Water Heating.

The size of the mains must be proportioned to the greatest ratio between length of circuit and effective height.

These charts may be used for any type or form of gravity hot-water heating having from 6 to 60,000 sq. ft. of radiation. The principle involved is the same for residences, greenhouses, or industrial buildings. Hot-water circulation is positive and certain, provided that none of its basic principles are violated.