inches, and if $1\frac{1}{4}$ in. pipe is used, the friction will be 50×12, or 600 milinches. A 1 in. pipe would, therefore, be too small and a $1\frac{1}{4}$ in. pipe too large to permit the desired circulation with a flow-return temperature difference of 20 deg.

If the circuit is of 1 in. pipe, the circulation will take place with a temperature difference greater than 20 deg, and if the circuit is of $1\frac{1}{4}$ in. pipe, the circulation will take place with a temperature difference smaller than 20 deg. To find, for example, the temperature difference at which a circuit of 1 in. pipe would transmit the required 20 Mbh, assume the difference to be 40 deg.

From Fig. 1, the head available for producing circulation would be 175 milinches per foot, or 1750 for the system, for a temperature drop from 200 to 160 F. The friction of the system may be found from Fig. 2; the chart of this figure is based on a temperature difference of 20 deg; if the temperature difference were 40 deg, the heat conveyed would be twice that shown in the chart. Hence, find 10 Mbh on the lower scale, proceed vertically upward to the intersection with the 1 in. line, and from there to the left scale read 13 milinches per foot. Note that the velocity would then be only about 5 in. per second. The total friction would then be 45×13 or 585 milinches. Since the head would be 1750, circulation would take place with a temperature difference less than 40 deg. The required temperature difference may be determined by constructing the diagram of Fig. 9, from which it appears that the temperature difference with which the 1 in. pipe circuit would function is about 30 deg. Hence, if the flow riser temperature is 200, the return riser temperature will be 170, and the average water temperature in the radiator about 185 F.

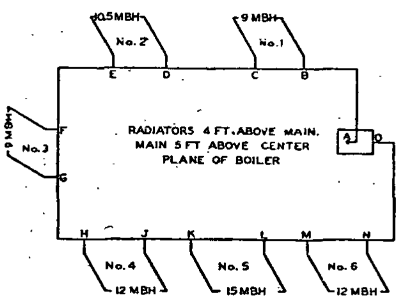

FIG. 10. ONE-PIPE GRAVITY CIRCULATION SYSTEM (EXAMPLE 3)

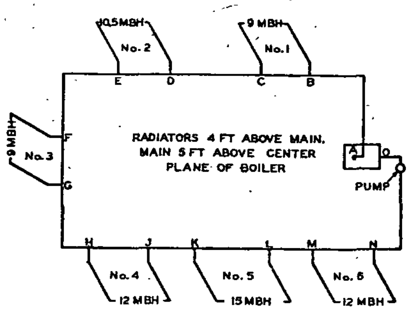

FIG. 11. ONE-PIPE FORCED CIRCULATION SYSTEM (EXAMPLE 4)

Elementary Forced Circulation System

Example 2: Design a system for the piping arrangement shown in Fig. 8, according to one of the outlined procedures. The procedure may be as follows: Assume the head developed by the circulating pump and the pipe size and, find the flow-return temperature difference; or, assume the head developed by the pump and the flow-return temperature difference, and find the pipe size; or, assume the pipe size and the flow-return temperature difference, and find the head which the circulating pump must develop.

Solution: Assume that the circulating pump will develop a head of 2 ft or 24,000 milinches and that a 1 in. pipe is to be used. The equivalent length of the circuit will then be 45 ft, as in Fig. 7, and the available head will be 24,000/45, or 533 milinches per foot. In Fig. 2, find 533 on the left scale, move horizontally to the intersection with the 1 in. pipe line, and read about 77 Mbh delivered by the pipe (with a velocity of about 35 in. per second) for a temperature difference of 20 deg. Since the circuit is to deliver only 20 Mbh, the temperature difference will be 20 divided by 77 and multiplied by 20, or 5.2 deg. Hence, if the flow riser temperature is 200, the return riser temperature will be about 195, and the average water temperature in the radiator about 197.5 F.

If a $\frac{3}{4}$ in. pipe were used instead of a 1 in., the equivalent length of circuit would be 35 ft instead of 45; the unit head, 686 milinches instead of 533; the velocity, 27 in. per second instead of 35; the temperature difference, 19.5 instead of 5.2; and the average water temperature in the radiator, about 190.5 instead of 197.5 F.

If the 1 in. pipe is used for the circuit, the gravity head will be 22 milinches per foot, or 220 for the circuit (Fig. 1, 200 to 195). Since this is only 1 percent of the pump head (24,000 milinches), it may be neglected in the calculation, as was done previously. However, there are cases in which the gravity head is so large compared with the pump head that it should be included in the calculation.

The methods just described for the design of the two elementary systems are fundamental, and apply to the design of all hot water heating systems. In every system, however large and complicated, the pipe system must be such that the head forcing the water from the boiler to any one radiator is equal to the friction in that radiator's circuit when the radiator is receiving its proper quantity of hot water, and the system is functioning at a steady rate.

Other examples illustrating design of various systems follow.

One-Pipe Gravity Circulation System

Example 3: Select pipe sizes for the one-pipe gravity system having a total load of 67,500 Btu, shown in Fig. 10. Assume: flow temperature 190 F, return temperature 160 F, mains 5 ft above datum plane of boiler, center plane of radiators 4 ft above the mains, length of main 100 ft.

Solution: From Fig. 1 the available circulating head for 190 F flow and 160 F return temperature is 126 milinches per foot of height. The available circulating head for design of the main is therefore $5 \times 126 = 630$ milinches. The measured length of main, plus 50 percent added for resistance of fittings, equals 150 ft equivalent length.

The main can then be designed for a friction loss of $630 \div 150 = 4$ milinches per foot. From Table 2 at 4 milinch friction loss, a 2 in. pipe will supply 33 Mbh and a $2\frac{1}{2}$ in. pipe will supply 53.1 Mbh at 20 deg drop. This is equivalent at 30 deg drop to 49.5 Mbh for 2 in., and 79.6 Mbh for $2\frac{1}{2}$ in. pipe. A $2\frac{1}{2}$ in. main will therefore be selected, and the pressure drop will be somewhat less than 4 milinches per foot.

The piping from main to radiators is sized in a similar manner. Assume that water reaches point B, Fig. 10, at 190 F and has a 30 deg drop in the radiator circuit. From Fig. 1 the available head is 126 milinches per foot of height or a total of $4 \times 126 = 504$ milinches for the circuit (with the radiator 4 ft above the main).

The measured length of piping is 11 ft and the fittings add 14 elbow equivalents (which would be equivalent to 22 ft if the pipe size is assumed to be $\frac{3}{4}$ in.); the equivalent length is therefore 33 ft. The circuit can therefore be designed for a friction loss of $504 \div 33 = 15$ milinches per foot.

From Table 2 by interpolation a $\frac{3}{4}$ in. pipe would supply 5.85 Mbh at 20 deg drop or 8.78 Mbh at 30 deg drop. Since the load is 9 Mbh, the $\frac{3}{4}$ in. size will be satisfactory.

The remaining radiator circuits may be sized in a similar manner. Allowance should be made in one-pipe gravity systems for the drop in temperature which occurs in the supply main as the cooler water returns from the radiators. The drop will be in the same proportion to the total drop of 30 deg as the load supplied to any point in the main bears to the total system load, *e.g.*, the temperature at D will be $190 - \left(\frac{9000}{67{,}500} \times 30\right) = 186$ F. At point F the temperature will be $190 - \left(\frac{9000 + 10{,}500}{67{,}400} \times 30\right) = 181$ F.

One-Pipe Forced Circulation System

Example 4: Select pipe sizes for the one-pipe forced circulation system having a load of 67,500 Btu shown in Fig. 11. Assume a water temperature drop of 20 deg. The water temperature does not affect the size of piping, but does affect the radiator sizes required.

Solution: The water to be circulated at 20 deg drop will be $67{,}500 \div 20 = 3375$ lb per hour or $\frac{3375}{8 \times 60} = 7$ gpm.

By reference to manufacturers' pump capacity charts (typical example, Fig. 12),