the longest supply and longest return piping. The lengths of circuits to the various radiators may be equalized by using a *reversed return* main (see Fig. 6). In some cases *reversed return* mains require no more piping than *direct return* systems.

With *gravity* circulation and *direct* return piping it is necessary to design the longest circuit for the available circulating head, and to obtain the same resistance in all other circuits by proper selection of pipe sizes, by addition of fittings, or by use of orifices. When a *reversed return* system is used, it is usually found that very little adjustment is required to attain uniform distribution to all radiators.

Forced circulation in two-pipe systems, because of increased available circulating head, permits design for higher velocities with a consequent reduction in pipe sizes. The increased velocity also shortens the heating-up period and facilitates control of circulation. Reversed return mains are also advantageous in forced circulation systems, in equalizing piping resistance to all heating units.

TABLE 5. CLASSIFICATION OF HOT WATER HEATING SYSTEMS

PIPING ARRANGEMENT	TYPE OF CIRCULATION	EXPANSION TANK	
One-Pipe	Gravity	Open	Closed
	Forced	Open	Closed
Two-Pipe Direct Return	Gravity	Open	Closed
	Forced	Open	Closed
Two-Pipe Reversed Return	Gravity	Open	Closed
	Forced	Open	Closed

PIPING SYSTEM DESIGN

In designing hot water heating systems certain assumptions are usually made for the purpose of simplification as follows:

1. Water temperature drop is assumed to be 30 to 35 deg for gravity systems and 20 deg for forced circulation systems. These values usually result in economical design but, particularly in large forced circulation systems, it is necessary to take into account the cost of pumping the water required at various velocities in relation to the annual charges in the capital cost of the system.

2. Water velocities in forced systems in excess of 4 fps in piping of 1¼ in. I. D. or less are likely to cause disturbing noises in residences. In factories or in installations having larger pipe sizes, velocities as high as 8 or 8.5 fps are not uncommon.

3. Design outlet water temperatures in gravity systems are generally selected between 140 and 200 F (with the average approximately 180 F); while forced circulation design temperatures vary from 170 to 220 F, although higher temperatures can be used if the pressure in the system corresponds.

4. For forced circulation systems, the allowable friction loss, which is based upon the available circulating head, is determined partially by the characteristics of the pumps available.

5. Forced hot water system friction should usually be held between 600 and 250 milinches per foot. Above 600 milinches high velocities would be encountered, and below 250 milinches circulation would become too slow, so that much of the rapid response expected from forced circulation would be lost.

The water to be circulated is

$$W = H/(C \Delta t) \tag{2}$$

where

W = weight of water, pounds per hour [gallons per minute = $W/(8 \times 60)$].
H = heat required, Btu per hour.
C = specific heat of water (= 1).
Δt = drop in temperature between supply and return, Fahrenheit degrees.

The following graded series of examples of the design of hot water piping systems will illustrate the fundamental principles and methods. The differences between reversed return and direct return systems are shown, and the methods of balancing the several radiators or circuits are illustrated. A simple gravity system is shown in Fig. 7, and an elementary forced circulation system is diagrammed in Fig. 8.

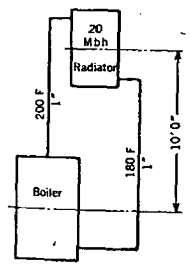

FIG. 7. GRAVITY SYSTEM

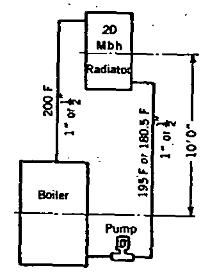

FIG. 8. FORCED CIRCULATION SYSTEM

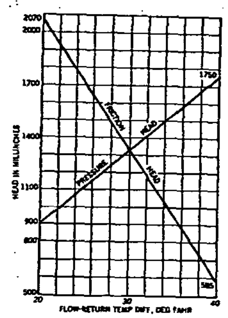

FIG. 9. DETERMINATION OF REQUIRED TEMPERATURE DIFFERENCE

Elementary Gravity System

Example 1: A simple gravity-circulation system is illustrated in Fig. 7 with one radiator that is giving off heat at the rate of 20,000 Btu per hr or 20 Mbh. The boiler imparts heat to the water at the same rate, and the water circulates at a uniform velocity. *This uniform velocity is such that the friction of the circuit is equal to the head developed by the difference in density between the supply and return water and the height of the system.* The circuit consists of 1 boiler, 1 radiator, 2 ells, 1 radiator valve and a total of 24 ft of pipe.

Solution: With the average water temperatures of 200 and 180 F in the supply and return risers, respectively, the head will be 90 milinches per foot of water column. This head may be found from Fig. 1. Since the center of the radiator is 10 ft above the center of the boiler, the total head of the circuit is 10 x 90, or 900 milinches, or 0.9 in. of 190 F water. The friction of the circuit must then also be 900 milinches. The friction of 1 ft of 1 in. pipe is found from Fig. 2 to be about 46 milinches at 20 Mbh, and the corresponding velocity 9 in. per second. Note that all values in Fig. 2 are based on a temperature difference of 20 deg.

Similarly, if a 1¼ in. pipe were to be used, the friction head would be about 12 milinches per foot, and the corresponding velocity about 5 in. per second, from Fig. 2.

To find the friction in the elbows, boiler, radiator, and valve, Table 1 is used, and the entire circuit is found to be equal to 10 elbow-equivalents plus 24 ft of pipe. Each elbow-equivalent is equal to a pipe length of 25 times the nominal diameter. Then the equivalent lengths of straight pipe are 45 ft of 1 in. pipe or 50 ft of 1¼ in. pipe. In many cases, it is sufficiently accurate to add 50 percent to the total pipe length to correct for resistance of fittings.

Hence, if 1 in. pipe is used, the friction of the circuit will be 45 × 46, or 2070 mil-