personal preferences of the purchaser, the designer should make certain that the heat output at the water temperature available is equivalent to the calculated heat loss from the space.

The heating units within each separately controlled circuit should be of similar types, for example; either all cast-iron or all fin-tube convector type units. Fan units should not be included in a controlled direct radiation zone. The radiation should be located at points of maximum heat loss or along outside walls, unless this is impracticable.

Determination of Water Flow Rate

The rate of water flow in a system is determined by the heat carrying capacity of the water. This capacity is the product of the rate of flow, the specific heat, and the temperature drop of the water as it passes through the heating units. The equation generally used to describe this relationship is:

$$H = Wc(t_1 - t_2) \quad (1)$$

where

H = heat carrying capacity, Btu per hour.
W = mass flow or weight of water, pounds per hour.
c = specific heat of water.
t_1 = temperature of water entering heating unit.
t_2 = temperature of water leaving heating unit.

The equation may be rewritten as follows for the purpose of convenience in use with Fig. 2.

$$H = Gwc(t_1 - t_2) \quad (2)$$

where

G = rate of water flow, gallons per minute.
w = rate of water flow per gallon per minute, pounds per hour.

The value of w should be obtained from Fig. 2 for the temperature at which the rate of flow is determined, and the value of c should be determined at the average temperature. For example: If water enters a heating unit at 210 F and leaves at 190 F, and a water flow of 1 gpm is measured at 190 F, the heat carrying capacity, found by substituting values from Fig. 2 in Equation 2, is

$$H = (1)(484)(1.005)(210\text{-}190) = 9728.4 \text{ Btu per hr or } 9.73 \text{ Mbh}$$

At 60 F the mass flow rate is 500 lb per hr at 1 gpm and the specific heat is very close to 1 Btu per lb, F deg. Accordingly, at a 20 deg temperature drop, 1 gpm will release 10 Mbh.

This value, 10 Mbh per gpm of water at a 20 deg temperature drop, is extensively used throughout the hot water heating industry in the calculation of data for low temperature systems. It is considered well within the limits of accuracy of heating system design. If 1 gpm will release 10 Mbh at a 20 deg drop, it will release 15 Mbh at a 30 deg drop, and 20 Mbh at a 40 deg drop.

Most low temperature systems installed today are designed on the basis of a 20 deg temperature drop. The temperature drop selected in the design of a system is used to determine the water flow necessary to supply the heat required under conditions of maximum heat loss with supply water temperature at a maximum value. If the supply water temperature is in-

creased at any time, the capacity of a heating unit and the temperature drop of water through the unit is increased accordingly. When the supply water temperature is modulated according to outside temperature, the temperature drop of the water in the system is considerably less than the design value during the greater part of the heating season.

The use of a design temperature drop greater than 20 deg should be considered where large quantities of required ventilation air are heated with extended surface coils, where the required pumping capacity is high, where pumping costs are a critical item, and where extended systems make a saving by the reduction in pipe size possible.

Factors considered in selection of a proper temperature drop for a system are: (1) the effect of the design average water temperature and water velocity on the capacity and cost of the heating units, (2) the size and cost of the piping, and (3) the initial and operating cost of the pump.

Design Water Temperature

The *design supply water temperature* is the maximum temperature of the water supplied to the system for the purpose of developing the selected rated capacity of the heating units.

The *design average water temperature* of a hot water heating system is the design supply water temperature less ½ the design temperature drop. Capacities of heating units are generally determined on the basis of the design *average* water temperature for cast-iron radiation and for baseboard or finned pipe radiation. Where a greater degree of precision is required to establish the capacity of heating units, for example, for contract and competitive bidding work, it may be desirable to determine heating unit capacities on the basis of design supply water temperature and temperature drop through the unit. This is particularly true where the secondary heating surface in the heating element of the unit is a large percentage of the total heating surface, as in convectors. Design supply water temperatures for radiation systems vary from 180 to 250 F, a common temperature being 210 F.

Factors considered in the selection of a design supply water temperature are the effect on the capacity of the heating unit, the effect on occupants who may be near the unit, and the greater possibility of boiling as the pressure varies.

Pipe Sizing Methods

The theoretical basis of calculations of head loss due to friction of fluids in pipe is the Darcy or Fanning equation, discussed in some detail in Chapter 4, Fuid Flow.

Pipe sizes for hot water heating systems are determined most conveniently from charts such as Figs. 3 to 6 and Table 1 showing pressure loss in relation to rate of flow and size of pipe. Allowance for fittings is generally expressed in elbow equivalents which is the number of 90-deg elbows that would have equivalent friction loss at the same rate of flow. Fig. 7 and Table 2 are useful in determining the number of elbow equivalents which then may be converted to equivalent length of pipe by means of Table 3. Figs. 3 to 7 and Tables 1 to 3 are based chiefly on empirical equations developed by F. E. Giesecke in cooperative research with the Society at the *University of Texas* and the *Engineering Experiment Station* of the *Agricultural and Mechanical College of Texas*.[2-12]

The friction loss used in sizing pipe for a system depends upon the type