caused by pump operation.[15] It should have an internal overflow drain. Provision must be made to prevent water from freezing in the tank, the tank vent, and the pipe leading to the tank. These provisions are also required by the *ASME* code. The minimum tank volume should be equal to 6/100 of the total system water volume.

The *closed system* utilizes an air-tight tank which provides a means of pressurizing the system for operation over a wide range of conditions. As the excess water due to thermal expansion moves into the expansion tank, it compresses the air trapped therein and increases the pressure on the system. If the tank, or the amount of air in it, is too small, the pressure on the system will exceed the maximum allowable, causing the relief valve to waste water from the system. When the system cools, the pressure will drop to a value less than minimum, making the venting of air impossible or drawing air into the system if automatic air vent valves are located at a high point of the piping. If the tank is too large, it will cost more and require more space.

The size of a closed expansion tank is determined by: volume of the water in the system; range of water temperatures normal to operation of the system; pressure of the air in the expansion tank when the fill water first enters the tank; relationship of the height of the boiler which usually, but not always, is the item in the system with the lowest working pressure; the expansion tank, and the high point of the system; head of the circulating pump; location of the circulating pump with respect to the expansion tank connection, and the boiler.* The expansion tank size for a closed system may be determined from the following *ASME* formula. This formula should be used only for operating temperatures between 160 F and 280 F.

$$V_t = \frac{(0.00041\ t - 0.0466)V_s}{\dfrac{P_a}{P_f} - \dfrac{P_a}{P_o}} \tag{4}$$

where

V_t = minimum volume of the expansion tank, gallons.
V_s = system volume, gallons.
t = maximum average operating temperature, Fahrenheit.

A widely used formula recommended for temperatures below 160 F is:

$$V_t = \frac{E}{\dfrac{P_a}{P_f} - \dfrac{P_a}{P_o}} \tag{5}$$

where

E = net[16] expansion of the water in the system when heated from minimum temperatures to maximum temperature, gallons (See Fig. 16).
P_a = pressure in the expansion tank when the water first enters, usually atmospheric pressure, feet of water, absolute.
P_f = initial fill or minimum pressure, feet of water, absolute, at tank.
P_o = maximum operating pressure at tank, feet of water, absolute.

The volume of the water in a system should be determined from water capacities of heating units as given by manufacturers and the volume of pipe or tube from tables such as Table 4.

The required minimum pressure, P_f, and the maximum pressure in the expansion tank, P_o, may change for specific systems, depending on the

effect of relative pump and tank location on system pressure changes caused by pump operation. Refer to diagrams A, B, C, and D of Fig. 17 and following discussion.

The degree of system pressure change caused by pump operation is established by the pump head. Whether the pump head will be added to, or subtracted from the system static pressure at the time of pump operation is determined by the relative pump and tank location. This is so because *the junction of the tank with the system* is a point of *no pressure change* regardless of whether or not the pump operates. Consequently, when the tank is located close to the pump suction, the pump suction pressure is unchanged when the pump starts and the pump head appears as an increase of pressure on the system. Conversely, when the tank is located close to the pump discharge, the pump discharge pressure is unchanged

Table 4. Volume of Water in Standard Pipe and Tube

Nominal Pipe Size Inches	Standard Steel Pipe			Type L Copper Tube	
	Schedule No	Inside Diameter Inches	Gallons per Lin Ft	Inside Diameter Inches	Gallons per Lin Ft
3/8	—	—	—	0.430	0.0075
1/2	40	0.622	0.0157	0.545	0.0121
5/8	—	—	—	0.666	0.0181
3/4	40	0.824	0.0277	0.785	0.0251
1	40	1.049	0.0449	1.025	0.0429
1 1/4	40	1.380	0.0779	1.265	0.0653
1 1/2	40	1.610	0.106	1.505	0.0924
2	40	2.067	0.174	1.985	0.161
2 1/2	40	2.469	0.249	2.465	0.248
3	40	3.068	0.384	2.945	0.354
3 1/2	40	3.548	0.514	3.425	0.479
4	40	4.026	0.661	3.905	0.622
5	40	5.047	1.04	4.875	0.970
6	40	6.065	1.50	5.845	1.39
8	30	8.071	2.66	7.725	2.43
10	30	10.136	4.19	9.625	3.78
12	30	12.090	5.96	11.565	5.46

when the pump starts and the pump head appears as a decrease in pressure at the pump suction and on the system.

When the pump discharges away from the boiler and expansion tank (A, Fig. 17) all pressure changes created by pump operation are additive. A gage located at any point in the system will show an increase in the pressure on starting the pump equal to the friction pressure drop between the gage and the boiler inlet (tank). Since the tank is located on the boiler, boiler pressures are unaffected by pump operation. The minimum pressure, P_f, required, is equal to height of the system above the expansion tank, plus any pressure required to assure positive air venting and prevent boiling; if the maximum water temperature exceeds 212 F. The maximum pressure, P_o, depends upon the pressure rating of that item of equipment having the lowest rated working pressure, usually the boiler or boiler relief valve, and the vertical distance between it and the expansion tank. This arrangement is recommended where high head pumps are used.

When the pump discharges into the boiler and expansion tank, (B, Fig. 17) all pressure changes induced by pump operation are subtractive. A gage, located at any point in the system, will show a decrease in pressure on starting the pump equal to the pipe friction pressure drop between the gage