

210 ft. The preliminary design friction loss is then found in Table 1, as in *Example 1*, to be 2 1/4 ft per 100 ft or 270 mi per ft. At this average design friction loss (see Table 1) a 1-in. main will be used for the required flow of 5 gpm.

From manufacturers' data at 5 gpm flow, the pressure drop from a 1-in. fitting is established at 3000 mi or 0.25 ft. If any heating units are located below the main gravity head due to temperature difference should be subtracted from available fitting pressure drop. In this example, the riser and convactor friction pressure drop should not exceed 3000 mi or 0.25 ft.

The friction loss through the 3/4-in. riser to the 9.8 MBh convactor was calculated to be 0.23 ft or 3450 mi in *Example 1*. This loss plus the 0.1-ft (1200-mi) loss in the convactor, equals 0.38 ft (4650 mi) which exceeds the capacity of the fitting. If 3/4-in. risers are used, however, the riser pressure drop is considerably reduced. For 9.8 MBh flow the pipe friction drop is 0.34 ft for 100 ft (40 mi per ft). The equivalent length changes from 22 to 26 ft. The riser pressure drop is then 26 x 0.34 or 0.09 ft (26 x 40 or 1040 mi). The head loss through the convactor circuit is then 0.09 + 0.1 or 0.19 ft (2240 mi). Since this is below the available fitting pressure drop, the riser size is satisfactory.

Other upfeed risers are sized in a similar manner.

The piping to the 6.5 MBh convactor below the main is sized as follows:

The water in this circuit will cool to room temperature during off periods. The center line of the convactor is 5 1/2 ft below the main. The thermal head opposing circulation in the convactor circuit when one riser is filled with 210 F water and the other has 70 F water is found to be 465 mi per ft or 465 x 5.5 = 2560 mi total. Subtracting 2560 from the 3000 mi pressure drop in the fittings leaves 440 mi available to start circulation. The combined convactor and riser pressure drop equals 1380 mi even when a 1-in. riser is used. Since the convactor and riser pressure drops are greater than the available fitting pressure loss, a change must be made. The total fitting pressure drop could be increased by adding a supply one-pipe fitting, or by increasing fitting pressure drop through use of a larger pump. In this case, the riser is sized on the basis of an added fitting. In accordance with the sizing procedure followed in this example, a 3/4-in. riser is adequate.

The pipe sizes selected should be recalculated at the design flow rates either in milinches as shown in the upper part of the following table or in feet per hundred feet as shown in the lower part of the table.

Section	Pipe Size In.	Load MBh	Loss per Foot of Pipe Mi	Length—ft			Total Friction Loss Mi*
				Linear Pipe	Elbow Equiv.	Total Equiv.	
Main	1	50	240	140	87 ^b	227	54,500
8 one-pipe fittings at 3000 mi*							24,000
Total							78,500
							6.55 ft

Section	Pipe Size In.	Load MBh	Loss per 100 Ft of Pipe Ft	Length—ft			Total Friction Loss Ft
				Linear Pipe	Elbow Equiv.	Total Equiv.	
Main	1	50	2.0	140	87 ^b	227	4.54
8 one-pipe fittings at 0.25 ft head*							2.0
Total							6.54

* Mi = milinches.

^b The elbow equivalent length is based on: 8 elbows, 1 tee, 2 gate valves, 1 flow check valve and 1 boiler.

* The actual value for resistance of the one-pipe fittings should be obtained from the fitting manufacturers. They are frequently lower than the value assumed in this example.

The pump capacity required is 5.0 gpm at 6.54 ft head. The 1 1/2 in. pump as shown in Fig. 9 would meet the re-

quirements of the system based on the assumptions stated for the problem.

Series-Loop System—Description and Design

This system, illustrated in Fig. 11, consists of one or more loops or circuits. In each circuit, as the same water is circulated through the heating units in succession, the size of pipe should not vary materially in any portion of a circuit. The system circuit length thus becomes very important because it influences directly the water flow rate, pressure drop, and temperature drop. Since the water temperature in each

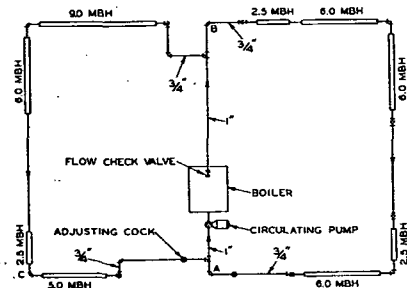


Fig. 11.... A Series-Loop System

successive heating unit decreases progressively, some designers consider it necessary to increase progressively the size of heating units sufficiently to compensate for the drop in temperature. If a small design temperature drop, such as 20 deg or less is used, it may not be necessary to increase the heating units in size toward the end of the circuit.

Various considerations affecting the design of a series-loop system are given in the following paragraphs:

1. It may be possible to eliminate all or large sections of the distribution main and thereby reduce cost. In large buildings it may be necessary to use a partial two-pipe main in combination with the series-loop system for certain sections or divisions of the building.

2. The practicability of the system will depend upon the quantity of water to be circulated through the heating units and the friction loss. Baseboard or finned-type pipe elements for series-loop systems are usually manufactured from standard steel pipe or copper tubing. The friction loss can be determined from Figs. 3 and 4.

3. If a series-loop system serves more than a single space, and if the design temperature drop for the system is in excess of 20 deg, the size of the heating unit should be determined on the basis of the temperature of the water entering the particular heating unit and the temperature drop across the unit. The temperature drop through a particular heating unit is equal to the capacity of that unit divided by the capacity of the total radiation circuit multiplied by the total temperature drop of the circuit.

4. Since the temperature of the water supplied to heating units in the series-loop system cannot be regulated, it is advisable to provide dampers in the cabinets containing finned pipe or baseboard radiation to permit adjustment of the heat delivery by each unit. Valves or adjusting fittings, if used in the water circuit, would affect the performance of the entire loop and would not be a satisfactory means of controlling the heat output of the units.

Hot Water Heating Systems

Certain disadvantages of the series-loop system are:

1. The difficulty of making suitable provision for adjustment and balancing of the system.
2. The total circulating head required may be excessive.
3. The design of the system may be more difficult than for one-pipe or two-pipe main systems.

Example 3: A series-loop system is to be designed for the residence used in *Examples 1* and *2* for two-pipe and one-pipe design. No heat will be supplied to the basement. The total heat loss equals 45,500 Btu. Baseboard-type radiation having a rating of 0.5 MBh per linear foot at an average temperature of 190 F, is selected as the radiation used. The heating units are of baseboard type having a rated output of 0.5 MBh per linear foot at an average temperature of 190 F. They are connected by 3/4-in. pipe. A 20-deg design temperature drop will be used.

Solution: For a 45.5 MBh load 4.55 gpm must be circulated for a 20-deg temperature drop. For a single looped main the measured length equals 140 ft. The approximate equivalent length equals 140 x 1.5 or 210 ft. If the 1 1/2-in. pump, Fig. 9, were initially selected, it would develop a 6-ft head at 4.55 gpm delivery. For an available head of 6 ft and an equivalent length of 210 ft (nearest to 210 ft) Table 1 shows that only 3 gpm will circulate through the 3/4-in. main. A larger, and more costly pump may be tried. The 3-in. pump, Fig. 9, has 12.7 ft available head at 4.55 gpm delivery. If 12-ft available head and 250-ft equivalent length are used as the nearest available values, Table 1 indicates that a flow of 4.3 gpm at a velocity of 2.6 fps will be established through the 3/4-in. main. However, because of cost, appearance, and temperature drop considerations, this may not be desirable.

If the system is divided into two loops, as shown in Fig. 11, a smaller pump may be used and the system temperature drop decreased.

The 1 1/2-in. pump at 6-ft head for 4.55 gpm is again selected for preliminary sizing of piping.

The measured supply main length plus the length of the longest loop circuit is 106 ft. The equivalent length equals 106 x 1.5 or 159 ft. For 6-ft available head and 160 ft equivalent length, Table 1 indicates that the friction loss would be 3 1/4 ft per 100 ft or 450 mi per ft. At this friction loss the supply main would be of 1-in. size for a flow of 7 gpm (which is more than the required 4.5) and the 3/4-in. looped main would deliver 3.7 gpm (more than the required 2.25 gpm). Because the flows are more than required, the system temperature drop would be less than 20 deg. A smaller pump could therefore be used if desired.

The pipe sizes should be recalculated at the design flow rates as follows:

Section	Heat Load MBh	Design Flow Gpm	Friction Loss Ft/100 Ft	Pipe Size In.	Equiv. Ft	Total Equiv. Ft	Press Drop Ft
AB	45.5	4.55	1 1/4	1	38.0*		
					2 elbows	5.0	
					2 gate valves	2.5	
					1 flow valve	50.0	
					1 boiler	7.5	101
							1.77
BCA	22.5	2.25	1 1/4	3/4	70*		
					8 elbows	13.6	
					1 cock	1.7	
					2 tees @ 50%	13.6	
						99	1.5
Total							3.27

* Actual pipe length.

Since the total system head loss equals 3.27 ft at a flow of 4.55 gpm and the 1 1/2-in. pump is a satisfactory selection.

If desired, the actual design temperature drop can be determined. Because the pump head at 4.55 gpm is greater than 3.27

ft, the flow in the system will increase until pump head and flow equal system pressure drop and flow. Construction of a system curve, as described under centrifugal pumps, shows that for the system with the pipe size selected and with the 1 1/2-in. pump, equilibrium will be reached at 6-ft head and 6.2 gpm flow. The actual temperature drop for design conditions would then be (45/6.2) x 20 or 14.5 deg, approximately.

Combination Systems

Three types of systems have been illustrated, namely: one-pipe, two-pipe reversed-return, and series-loop. Actually the design for a particular building may be a composite of two or even all three of these types of systems. For example, a two-pipe reversed-return system of distribution may be used with a number of one-pipe loops in a single building such as an apartment house, or a two-pipe reversed-return system may be used with a main riser at each end of a building with a series-loop system used to serve the space on each floor of the building. In any case, it is well to bear in mind the principles of design involved in each particular type of system for that portion of the installation where it is used.

Adjustment of Flow and Capacity

Where the heating elements and piping are properly sized and arranged, a hot water system is, to a large extent, self-adjusting. This is so because the mean temperature of the water flowing inside the heating unit is the most important factor in determining its output. If the flow of water is within 5 to 15 percent of the correct value for a given heating unit, the difference in mean temperature will not exceed 1 or 2 deg and, consequently, the effect on heat output will be negligible. However, the limitations of commercial pipe sizes and pipe arrangement sometimes result in flow rates considerably different than those required to develop the proper output of the heating units. A means of adjusting the heat output of heating elements and branch circuits must be provided in the system to correct these effects.

Adjusting means may be necessary due to the type of system, for example, the two-pipe system using direct-return mains. In this system the water flow circuits are hydraulically unbalanced, because the water for the first heating load taken off the main is the first to be returned. As a result, the first heating unit will receive a much greater flow than is required to develop its rated output. The flow through the last heating unit can be so low that practically no heat is delivered. The poor distribution of flow in the direct-return system can be corrected by the installation of orifices or of adjusting fittings or valves, by means of which the system is balanced after it is placed in operation. In some cases, proper flow distribution can also be established by careful pipe size selection. That is, the piping can be sized so that the pressure drop through each piping circuit is the same at the design flow rate.

These troubles are minimized by the reversed-return system, Fig. 8. In this system the water for the first heating load taken off the main is the last to be returned, and all circuits are of approximately equal length. Proper hydraulic balance is therefore easily obtained and the system is inherently self-adjusting. While the reversed-return piping circuit is much preferred, in some large installations a saving in pipe can be effected by use of a direct-return system.

When selecting the type of piping arrangement such as one-pipe, two-pipe, series-loop, upfeed, and downfeed, the