Schneider Electric

Three-Way Valves Application Information

For many years, three-way mixing[1] valves and three-way diverting* valves have been commonly used for controlling temperature and flow, or both, in water circuits of heating and air conditioning systems. Despite this, there is still wide-spread confusion and conflicting opinion regarding their proper application. This is principally due to a lack of information on how and why three-way mixing and diverting valves differ from each other and how each type may be used to its best advantage.

WHY THREE-WAY VALVES ARE USED: (the order of presentation below is random and in no way implies priority of importance or frequency of use.)

1. To maintain constant flow (an therefore constant pumping head) in a supply system with a heat exchanger (such as a water chiller or boiler), while controlling the output of zone heat exchangers. As water flow is throttled to the zone heat exchanger by a three-way valve, more supply water is by-passed to the return, thereby maintaining a nearly constant flow (and pumping head) in the supply system. See Fig. 1.
2. To maintain constant water flow in a zone heat exchanger while controlling its heat output. In this case, a secondary pump is required for each zone heat exchanger. The three-way valve varies the amount of return water recirculated from the zone heat exchanger in relation to the amount of supply water delivered to the ex- changer from the primary circuit. Thus, heat output is individually controlled by varying the temperature of the exchanger supply water, rather than the water flow rate. See Fig. 2.

[1] Defined shortly.

3. To maintain constant supply water flow and temperature to refrigeration condensing-unit heat exchanger. Cool water, from a cooling tower or other source, is mixed with return water from the condenser, as needed, to maintain desired inlet water temperature. Flow remains relatively constant. See Fig. 3.
4. To vary the temperature of primary or zone supply water where the main heat exchanger, such as a boiler, delivers water at a constant temperature. Return water from the system or zone is mixed with water from the main exchanger to obtain the desired supply water temperature. This supply water temperature is often reset from outdoor temperature. See Fig. 4.
5. To provide for changeover of year-around air conditioning systems from hot water supply to chilled water supply.
   a. When two-pipe distribution systems are used, the entire system or pumping zone is changed over from heating to cooling (or from cooling to heating) at the same time. A two-position three-way changeover valve with a very slow-acting actuator (15 to 30 minutes) is often used to slow automatic changeover without overloading the chiller, or “shocking” the boiler with too cold return water. Use of a changeover valve with a long timing allows gradual cool-down or warm-up of the distribution system. See Fig. 5.
   b. On four-pipe distribution systems, two three-way valves may be used to obtain year-round control of a zone heat exchanger with two position control on both heating and cooling cycles (refer to Fig 6), or one two-position three-way changeover valve may be used to connect the zone exchanger with the proper return while the supply control valves furnish hot or chilled water as required (refer to Fig. 7.

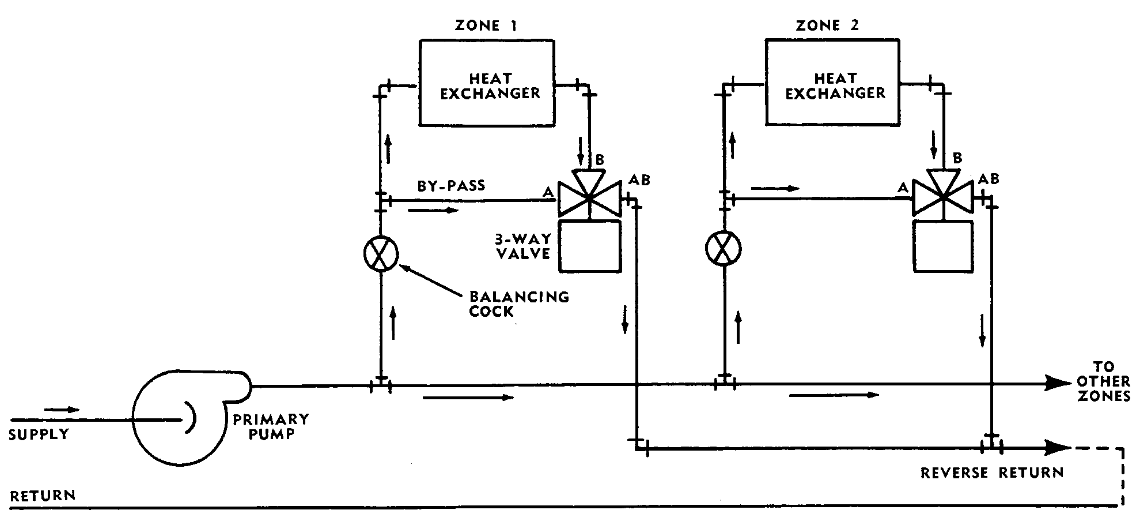


Figure-1 Throttling (or By-Pass) Control of Zone Heat Exchangers.

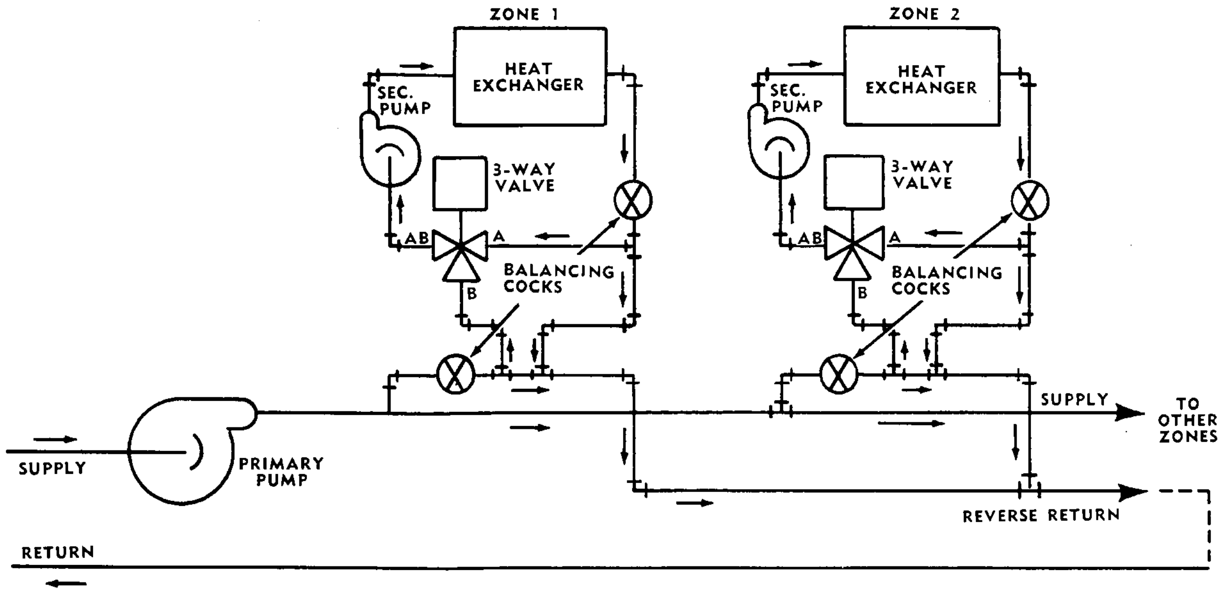


Figure-2 Constant Flow — Variable Temperature Control of Zone Heat Exchangers with Secondary Pumps.

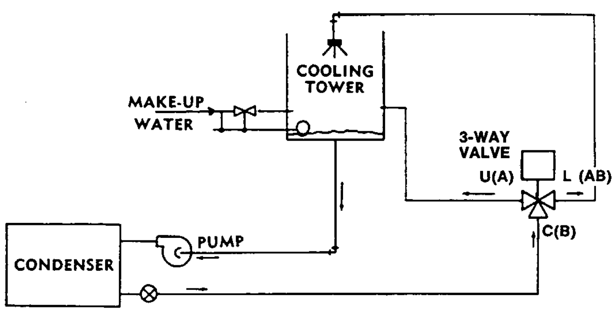


Figure-3 Constant Flow — Constant Temperature Control of Condenser Cooling Water.

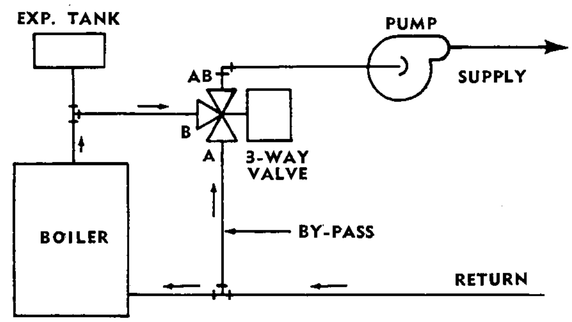


Figure-4 Constant Flow — Variable Temperature Control of Hot Water Supply.

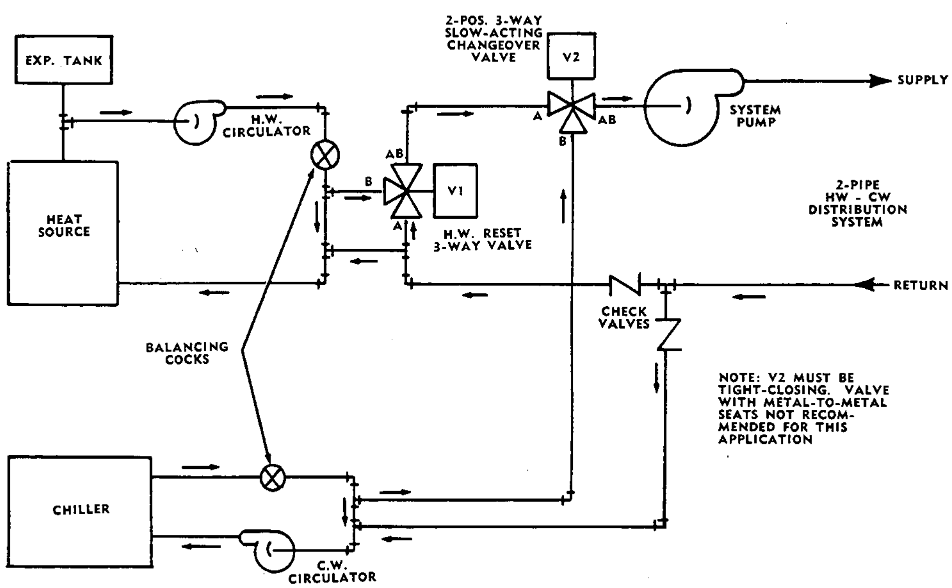


Figure-5 Changeover Applications — 2-Pipe Distribution Systems.

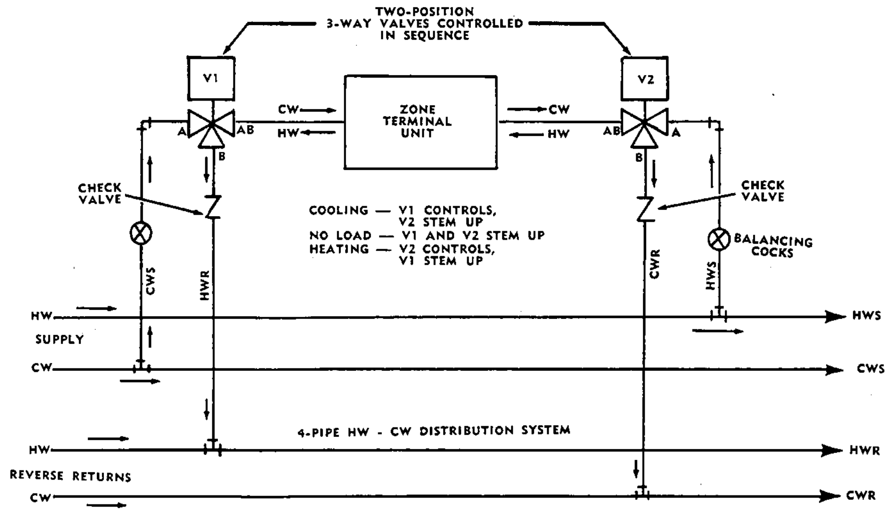


Figure-6 Two-Position Zone Control With Changeover — 4-Pipe Distribution Systems.

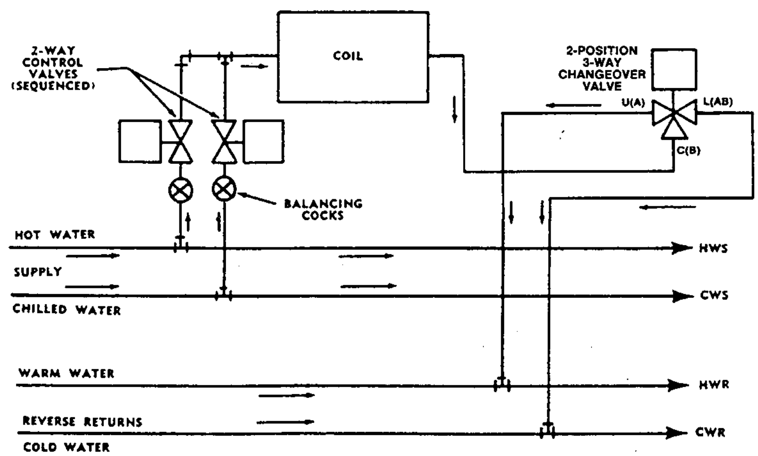


Figure-7 Proportional Zone Control With Changeover — 4-Pipe Distribution Systems.

TERMINOLOGY

Although a three-way valve is generally thought of as any valve having three pipe or tubing connections, there are actually two distinctly different types as stated previously. The ASHRAE GUIDE AND DATA BOOK, FUNDAMENTALS ANDEQUIPMENT, defines these as MIXING VALVES and DIVERTING VALVES. The difference is in the internal construction of the valve bodies themselves, and it is this internal construction which determines how the valve must be piped, regardless of the application.

MIXING VALVE DEFINED

Of the two types, three-way mixing valves are more commonly used in the heating and air conditioning field. This valve can be considered as an adaptation of a two-way, single seated valve body. See Fig. 8. A second seat is added in the body and the throttling plug is modified to provide the upper seating surface. Some three-way valves are actually made from two-way body castings by this method.

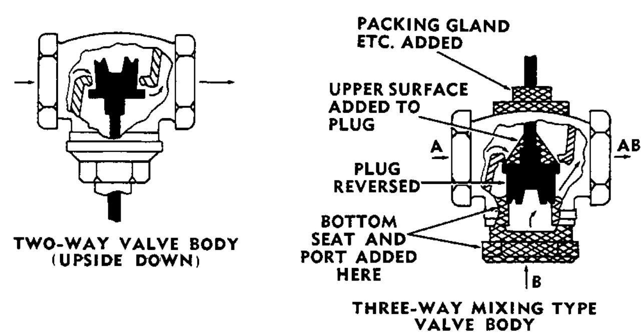


Figure-8

This type of three-way valve must be used only for mixing service. That is, the two individual ports A and B are inlets and flow must enter either or both ports, leaving through the common port AB. Direction of flow must be such that the valve plug closes against the force created by fluid flow through the valve. It is also good practice to pipe two-way valves such that the actuator works against the force developed by fluid flowing through the valve. This assists in obtaining good flow control, even at low flow rates when the valve plug is positioned near the seat.

If a three-way mixing type valve were piped for diverting service, that is, with flow entering the common port AB and leaving individual ports A and B, valve plug chatter or instability would usually result. When the plug is positioned toward either seat, force created by the velocity pressure of the fluid flowing through the port will tend to slam the plug down against the seat. See Fig. 9. When the plug closes the port completely, the velocity pressure will drop to zero (since there is no flow) and the plug will tend to back off the seat. This results in instability and chatter. This situation is further found in all linkages connecting the valve plug to the control actuator that positions it.

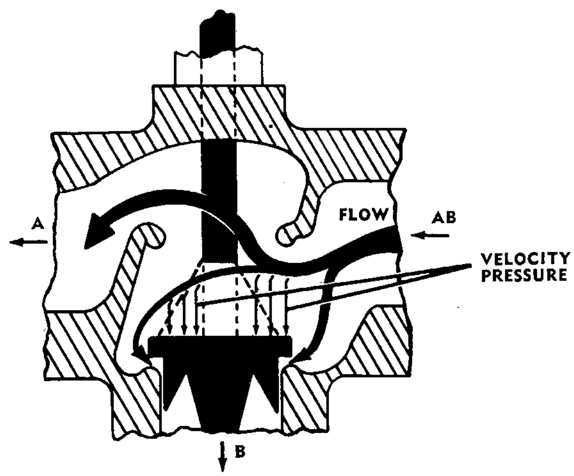
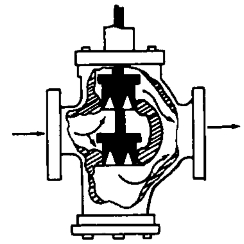
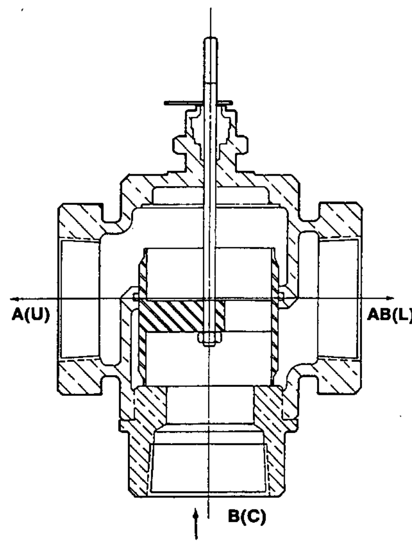


Figure-9 Mixing Type Three-Way Valve (Piped Incorrectly for Diverting Service).



TWO-WAY DOUBLE SEAT
VALVE BODY



THREE-WAY DIVERTING TYPE
VALVE BODY

Figure-10

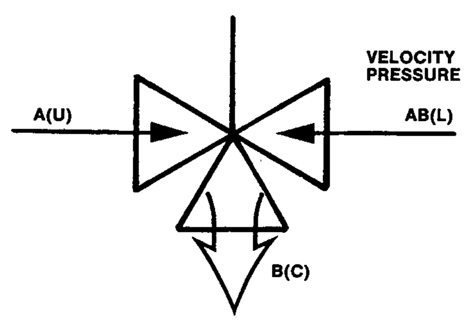


Figure-11 Three-Way Diverting Type Valve (Pipe Incorrectly for Mixing Service).

TERMINOLOGY

The terms “mixing service” and “diverting service” as used here refer only to the direction of fluid flow through the valve body, and do not refer to the application of the valve in the system. For instance, the application described in Fig. 1 is often referred to as a “diverting” application of a three-way valve because, as the valve modulates, a portion of the supply water is diverted around the coil. Actually, the use of the word diverting in this instance is misleading, because the valve itself can be piped either for mixing service (Fig. 12) or diverting service (Fig. 13). A better word to describe this situation would be a “by-pass” application of a three-way valve. Naturally, the piping method chosen will depend on what type of valve body is specified. Normally, a mixing type body piped as shown in Fig. 12 would be preferred for this application.

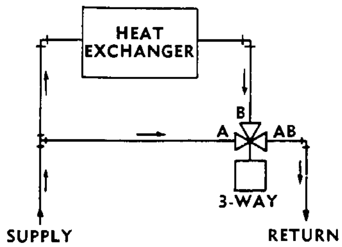


Figure-12 Three-Way Mixing Valve on “By-Pass” Application.

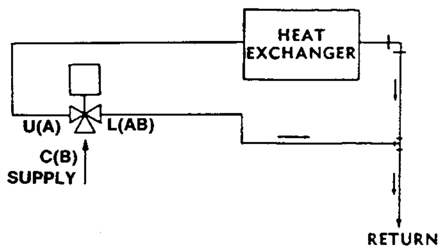


Figure-13 Three-Way Diverting Valve on “By-Pass” Application.

TWO- POSITION VALVES

The previous discussion on the internal construction of three-way valves for mixing and diverting service applies to modulating and two position valves. If a mixing type valve were used piped for one inlet and two outlets (diverting), the plug would tend to slam against the seat at each end of the actuator stoke and chatter at intermediate positions. Mixing type three-way bodies must not be used on two-position diverting applications.

PRESSURE RATINGS DESCRIBED

Another area of some confusion has been the static and close-off of differential pressure ratings required when using three-way valves.

First, the type of piping system- closed or open loop-will influence the requirements.

Closed loop systems for this discussion are defined as those in which the piping system is not open to atmosphere at any point (except for venting), and a static fill pressure above atmospheric pressure is maintained in the piping circuit.

Open loop systems are defined as those where the piping system is open to atmosphere at some point, such as normally found in cooling tower applications.

Other considerations, such as the location of the valves with respect to the pump, will also influence the ratings required. Typical applications can be broken down into four general categories with their basic requirements as follows:

I. CONSTANT FLOW IN PRIMARY CIRCUIT-CLOSED LOOP

Typical applications where the three-way valves are piped for constant flow in the primary pumping circuit include A and D (Fig. 1and 4) described previously. Operating requirements are as follows:

Static Pressure Rating: Must be equivalent to, or greater than, the static or “fill” pressure in the system. If the valve is located downstream from the primary pump (as in Applications A and B) the static pressure rating must be greater than the sum of static pressure plus pumping head pressure at that point in the system. Pump head pressure at the valve location is considered equal to total pump head minus piping friction loss in piping between the valve and the pump. From the above, a formula may be developed for determining the necessary valve body static pressure rating as follows:

$$\text{Static Pressure Rating (in PSI)} = \frac{(h_{fp}-h_t) + (h_p-h_f)}{2.31}$$

h_{fp} = Fill Pressure at low point of system in ft. of water

h_t = Distance of valve above low point of system in ft.

h_p = Total pump head in ft. of water

h_f = Friction loss in piping between valve and pump in ft. of water

See Fig. 14 for an example.

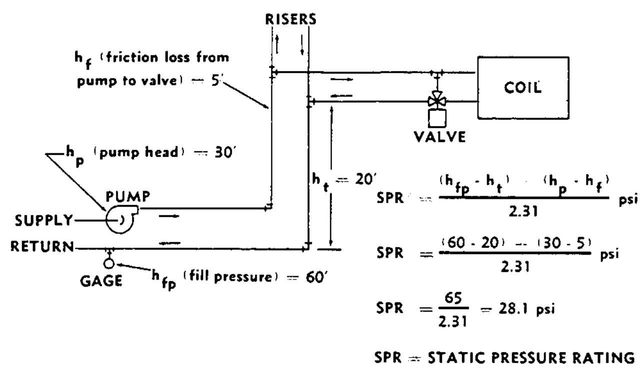


Figure-14 Valve Static Pressure Rating — Example.

Close-off Pressure Rating: Must be equivalent to the total pressure difference which can occur across either port when that port is closed. Normally, in closed loop system applications such as described previously in A,B or E, the water flow rate in the system remains nearly constant. (In A and B, that is why the three-way valve was used in the first place). Therefore, the pressure which the valve must close off against is only the pressure drop in the leg where water is flowing, that is, between the common port of the valve and the point where the by-pass joins the main system. See Figs. 15 and 16.

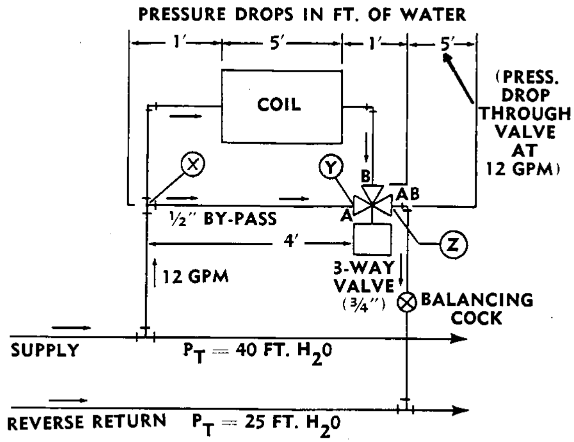


Figure-15 Close-Off Pressure Rating — Zone Control.

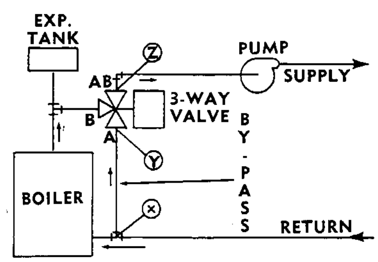


Figure-16 Close-Off Pressure Rating — H W Supply Control.

In Fig. 15, the maximum pressure the valve would have to close against would be equal to the sum of pressure drops in the coil, the coil piping, and the valve with full flow through the coil leg. This is due to the fact that when there is no flow through the by-pass, the pressures at points X and Y are the same. The pressure drop from point X to point Z is 12 ft. The pressure difference between Y (A port) and Z (common port) is therefore 12 ft. (or about 5.2 psi), and this is the highest pressure difference the valve must be able to close against. The pressure difference between supply and return mains, and the drops in the piping between point X and the supply main, and between point Z and the return main are not involved. The maximum pressure difference the valve must close against is equal only to the pressure drop from X to the valve through whichever port circuit (A or B) has the highest resistance at maximum flow (in this case the coil circuit), plus the pressure drop though the valve itself.

In Fig. 16 the situation is much the same. the valve must be able to close off against the highest pressure drop from point X to Z (through the boiler circuit and valve, or through the by-pass circuit and valve-whichever path has the greater resistance at full flow).

II. CONSTANT FLOW IN SECONDARY CIRCUIT- CLOSED LOOP

A typical application where the three-way valve is piped for constant flow in the secondary pumping circuit is application B described previously. Operating requirements are:

Static Pressure Rating: The static pressure requirements are the same here as in Case I, and may be determined in the same manner.

Close-off Pressure Rating: Again, the valve close-off pressure rating must be at least equivalent to the greatest pressure difference which can occur from either the A or B port (when closed) to the common (AB) port.

In a primary and secondary pumping system of this type, it becomes necessary to analyze some basic concepts before the requirements for the control valve can be determined. Normal practice is to pipe the take-offs for the secondary system as close together as possible on a bypass leg across the primary system supply and return. See Fig. 17. This serves two purposes: First, the bypass leg on the primary system allows for practically constant circulation in the primary pumping circuit, whether the secondary systems are using primary water or not.

Secondly, by keeping the pressure drop (ΔP) to an absolute minimum in the common pipe between the supply and return take-offs for the secondary circuit, the pumping head developed by the primary pump will be practically the same on both the supply and return of the secondary circuit. Therefore, the primary pump does not tend to cause flow in the secondary circuit; its only function becomes circulation of water in the primary circuit. The water flow rate in the secondary circuit is then determined only by the secondary pump, and the sizing and close-off pressure requirements of the three-way control valve are functions of the secondary circuit pump only.

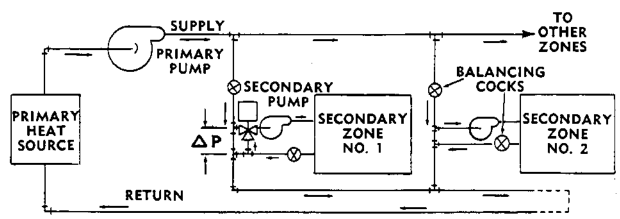


Figure-17 Primary-Secondary Pumping Circuits.

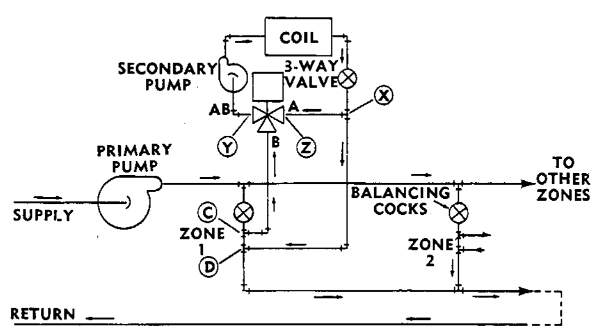


Figure-18 Valve Close-Off Requirement for Primary-Secondary Pumping Circuits.

Assuming the pressure drop from C to D at the supply take-off to the zone (refer to Fig. 18) is negligible as outlined above, the close-off pressure requirement for the three-way valve is independent of the pressures existing in the primary supply and return circuit. The close-off requirement will be equal to the greatest friction drop at full flow in either of the two legs from point X to the A or B ports, plus the pressure drop through the valve itself. Normally the friction drop will be greater in the circuit from X to the supply-return connection and back to port B (because it is longer than the X to A leg). Therefore, the close-off rating must normally be at least equal to the sum of the pressure drops from point X to port B Plus the valve pressure drop. When the A port is closed there is no flow from X to A, and the system pressures are equal at point X and port A. The pressure at point Y is less by the amount of friction drop from X to B plus the valve drop-hence the valve must close against this pressure difference when closing to port A.

III. THREE-WAY VALVE CHANGEOVER APPLICATIONS--- CLOSED LOOP

These applications include those where the valve is used for seasonal or zone changeover as described previously in E (Fig 5 and 6), or other applications where the valve must close against a pump in the system. Operating requirements are:

Static Pressure Rating: The static pressure rating requirement will normally be the sum of the static fill pressure plus the pump head pressure (developed by the highest head pump in the system) minus the height of the valve (in ft.) above the fill pressure measuring point. Obviously, all pressures must be in ft. of water before summation; the final sum may then be divided by 2.31 to obtain static pressure rating in psi.

Close-off Pressure Rating: The close-off pressure requirement will usually be equal to the pump pressure developed by the highest head pump in the system. This is true because when the valve is positioned to supply hot water, the chilled water pump may be off, and vice versa. The static fill pressure will be present on both the hot and chilled side of the valve ports (cancelling out), and the valve will have to close off against the pump which is running to prevent leakage into the part of the system which is shut down.

As 100% tight shut-off against pump head is a normal requirement in this application, two-position two-way valves with soft seats are often used in place of a globe type three-way valve with metal-to metal seats. The two-way valves may be either globe type or rubber lined butterfly and are arranged so that one opens as the other closes. When the valve size is 4” or larger, the butterfly type often has a cost advantage. Two valves applied to a tee can be linked together for operation from one actuator. Also, higher close-off pressure ratings and lower pressure drops are often characteristic of butterfly valves as compared to the same size globe type valve.

IV. OPEN LOOP TEMERATURE CONTROL-COOLING TOWERS

Open loop applications, where the control valve maintains a desired condition by varying the flow rate through that portion of the system open to atmosphere, present special problems. A typical example is the cooling tower application described previously under C, where a three- way valve can be used to maintain a constant inlet water temperature to the condenser. The valve selects the proportion of return water delivered to the sprays, and bypasses the rest to the sump, to maintain the desired inlet water temperature (at a constant flow rate) to the condenser. (See Fig. 19 and 20.)

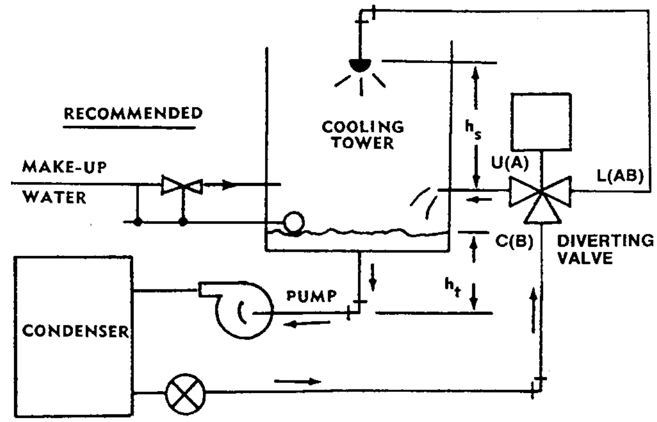


Figure-19 Cooling Tower Control — Open Loop.

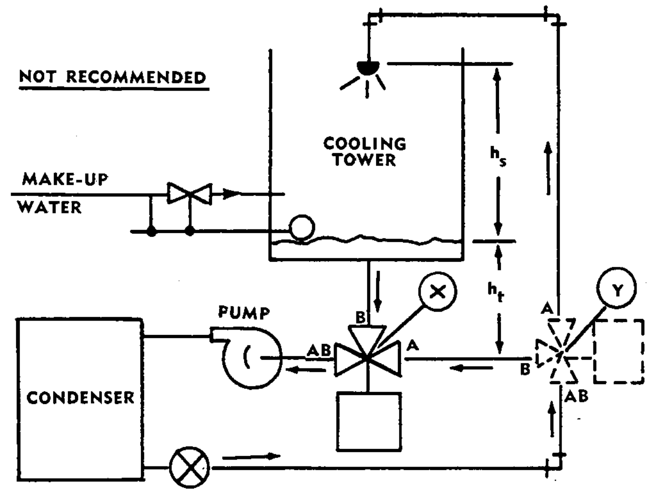


Figure-20 Cooling Tower Control — Open Loop.

This application is perhaps one of the most difficult as far as valve requirements and location are concerned. Large water flow rates are encountered on larger tonnage machines, particularly where absorption refrigeration units are used. High head pumps are also common due to condenser and piping friction losses at large flow rates, and also because the cooling tower is often located some distance away from the condenser.

VALVE TYPE AND LOCATION

A. Not recommended (Fig. 20, Location X): It has been general practice to specify a three-way valve for tower control located at point X in a piping arrangement as shown in Fig 20, allowing the use of a less expensive mixing type three-way valve body. This location often turns out to be unsatisfactory, however, as pressure drop through the valve plus piping friction losses may easily result in a negative operating pressure (below atmospheric pressure) at the pump inlet, causing pump cavitation. This is particularly true when the cooling tower is located some distance away, but at or near the same level as the pump, as the positive static head (h_t) will be very small in relation to piping and valve pressure losses. This location also has another problem as noted below, and is, therefore, not recommended.

B. Not recommended (Fig 20, Location Y): The problem of the control valve pressure drop appearing as a negative drop on the suction side of the pump can be eliminated by relocating the three-way valve to point Y in the same piping arrangement. However, this arrangement requires a diverting type three-way valve, and still has the disadvantage that the system pressure drop through the by-pass will be somewhat less than the pressure drop through the tower leg (which has much more pipe, spray heads, etc.). This is particularly true if the valve is located near the pump rather than at the tower, and results in an increased water flow rate through the pump and condenser as the valve modulates to by-pass more water around the tower under reduced loads. On water chillers. this will often lead to chilled water control instability (particularly on absorption machines) as well as to increased condenser pump horsepower.

This problem will be aggravated by locating the control valve near the pump rather than near the tower when the two are some distance apart. A manual balancing cock in the by-pass line will enable one to balance the flow with the control valve in the full by-pass position, but as the flow in the by-pass is reduced, the pressure drop across the balancing cock reduces as to the square of the flow. This creates a high pressure unbalance on the "B" port when the valve is open to the "A" port (tower leg), resulting in non-linear flow control by the three-way valve, with control instability likely whenever low flow rates through the by-pass are required to meet desired conditions.

The only real solution to obtaining good flow control, with a control valve located at point X or Y, is to use reduced trim on the by-pass port, or to use two different size two-way valves (such as butterfly valves) linked together so that as one closes the other opens. In either case, the size of the by-pass port or valve is reduced to compensate for the reduced piping friction on the by-pass leg. In this manner, balanced flow through both the tower leg and the by-pass leg is possible, but valve sizing is somewhat critical -- accurate calculations of piping friction losses for the piping as installed will be required to properly size the by-pass port or valve.

C. Recommended (Fig. 19): The above problems can be overcome by locating a diverting type three-way valve at the cooling tower piped to by-pass to the tower sump. This location has several advantages:

1. System operating pressure at the pump inlet is determined only by the height of the tower above the pump minus the pipe friction losses from tower to pump (h_t-h_f); the control valve pressure drop is not involved.
2. The total length of pipe (and, therefore, pressure drop) in the pumping circuit remains nearly the same as the valve modulates from the tower leg to the by-pass position. This results in a nearly constant water flow rate through the pump and condenser regardless of valve position and without the use of balancing cocks, reduced port trim, or a smaller valve on the by-pass leg, (Assuming that the pressure drop through the spray heads is a minor portion of total pump head requirements).
3. Tower winterizing requirements are greatly reduced or eliminated. Whenever the refrigeration machine is operated at outdoor temperatures below 32°F, the rejected condenser heat in the water by-passed to the tower sump, plus the fact that full water flow always circulates through the sump, will normally prevent any freezing of the sump and drain lines. Additional heat to prevent freezing will normally be needed only when the refrigeration machine is shut down. This would not be true if only spray water reached the sump during below freezing conditions, as would be the case with arrangements shown in Fig. 20.

VALVE SIZE AND PRESSURE RATINGS

A. Recommended Valve Size And Style: The control valve should be sized so that the valve pressure drop is at least equal to the pressure drop through the spray heads, plus the height (in ft.) of the spray heads above the valve.

For the diverting application shown in Fig. 20, when the valve size is 5" or above, it will often pay to consider the use of two butterfly valves mounted on a common tee and linked together for positioning from one control actuator, rather than specifying a more expensive globe type three-way diverting valve. The characterized flow characteristics of the butterfly valves will normally provide stable control when sized for sufficient pressure drop as outlined above. Although usually not a requirement for this application, tight-closing butterfly valves may be obtained by calling for the rubber-lined type, but these require more powerful actuators for the same size valve.

B: Static Pressure Requirement: In the case of Fig. 20, static pressure rating required for the valve body is practically nil, as the maximum total system pressure at this point will be equal to the friction pressure drop from port AB (L) through the valve piping and spray head, plus the height of the spray head above the valve when the valve is full open to port AB (L). The following formula may be used:

$$\text{Static Pressure Rating (in PSI)} = \frac{h_f + h_{sf}}{2.31} + Pv$$

h_s = height of spray head above valve in ft.

h_{sf} = friction pressure drop of spray head and piping to port AB (L) in ft. of water

P_v = valve pressure drop in psi

C: Close-off Pressure Requirement: The three-way valve must close off only against the greatest pressure drop in the two loops connected to ports A(U) and AB(L). In this case, both loops exhaust to atmosphere, with the spray head loop obviously having the higher pressure drop. The maximum close-off pressure requirement in psi [for port AB(L)] happens to be exactly the same as the static pressure requirement given above, and can be calculated using the same formula.

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