SECTION 9.12

REFRIGERATION, HEATING, AND AIR CONDITIONING

MELVIN A. RAMSEY

HEATING

Heat is usually generated at a central point and transferred to one or more points of use. The transfer may be by means of a liquid (usually water), which has its temperature increased at the source and gives up its heat at the point of use by reduction of its temperature. It may also be transferred by means of a vapor (usually steam), which changes from a liquid to a vapor at the source and gives up its heat at the point of use by condensation. Pumps may be required in both of these methods.

HOT WATER CIRCULATING

A centrifugal pump best meets the requirements of this service. Water is usually used in a closed circuit so that there is no static head. The only resistance to flow is that from friction in the piping and fittings, the heater, the heating coils or radiators, and the control valves. In selecting the pump, the total flow resistance at the required flow rate should be calculated as accurately as possible, with some thought as to how much variation there might be as a result of inaccuracy of calculations or changes in the circuit because of installation conditions. It is not good practice to select a pump for a head or capacity considerably higher than that required, as this is likely to result in a higher noise level as well as increased power.

When hot water is used for radiation in a single circuit, through several radiators, the water temperature variation is usually only about 20 F° (11 C°) at the time of maximum requirements, so there is not too great a difference in heat output between the first and last radiator in the circuit. With the flow rate based on water at 180° to 200°F (82 to 93°C) to heat air to about 75°F (24°C), a 10% reduction in the flow would have little effect, as the actual difference would increase to only 22 F° (12°C), and the reduction in the heat output of the radiator with 178°F (81°C) water would be only about 2%. Reference to Section 8.1, on the selection of pumps and the prediction of performance from the head-capacity pump curves and system head-flow rate curves, will show that a rather large undercalculation of circuit head loss would be necessary to produce a flow rate 10% less than desired.

Greater temperature differences are frequently used for other radiation circuits, and a reduced flow rate may have a greater temperature differential than in the single circuit. Whatever the condition, the pump should be selected only after full consideration of all the factors, and not by use of so-called safety factors, which are likely instead to be "trouble factors."

Air in the Circuit Initially, the entire circuit will be full of air that must be displaced by the water. Arrangements should be provided to vent most of the air before the pump is operated. Even if all the air is eliminated at the start, more will be separated from the water when it is heated. Any water added later to replace that lost to revaporation will result in additional trapped air when the water is heated. Means must be provided for continuous air separation, but this cannot be accomplished by vents at high points in the piping because the flow is usually turbulent and the air is not separated at the top of the pipe.

A separator installed before the pump intake will remove the air circulating in the system. In a heating system, an air separation device is often provided at the point where the water leaves the boiler or other heating source. If the pump intake is immediately after this point, this is the point of lowest pressure and highest temperature in the system, and therefore it is the point where separation of air from the water can be most effectively achieved.[1]

If there are places in the system where the flow is not turbulent, air may accumulate and remain at these points and interfere with heat transfer. Automatic air vents should seldom or never be used. If they are used, it is important that they be located only where the pressure of the water is always above that of the surrounding air, whether the pump is operating or idle. Otherwise, the air vent becomes an air intake.

Several important factors influence the choice of a pump for a hot water system with a number of separate heating coils, each having a separate control. Many systems in the past used three-way valves to change the flow from the coil to the bypass. When two-way valves are used, low-flow operation may occur for a large portion of the operating time. For this type of operation, therefore, the pump selected should have a flat performance curve so the head rise is limited at reduced flows. A very high head rise can cause problems when many of the valves are closed. Excessive flow rates through the coils and greater pressure differences across the control valves are some of the problems that can be avoided with a flat pump curve. A centrifugal pump should not operate very long with zero flow, for it would overheat. This condition is controlled by using one or two three-way valves, a relief bypass, or a continuous small bleed between the supply and the return line. Whichever means is used to control minimum flow, the circuit must be able to dispose of the heat corresponding to the pump power at that operating condition, without reaching a temperature detrimental to the pump.

Types of Pumps Many pumps for hot water circulation are for flow rates and heads in the range of in-line centrifugal pumps that are supported by the pipeline in which they are installed. Such pumps are available up to at least 5 hp (3.73 kW) and operate with good efficiency. More important than the type of pump are the performance and efficiency.

For greater flow rates and heads (and even for the smaller ones), the standard end-suction pump can be used. In the intermediate range, the use of an in-line or end-suction pump is a question not of one being better than the other but whether one or the other is better suited to the overall design and arrangement. Practically all the in-line or end-suction pumps for this service use seals instead of packing.

If the hot water system is of the medium- or high-temperature type, above 250°F (121°C), the pump must be carefully selected for the pressure and temperature at which it will operate.

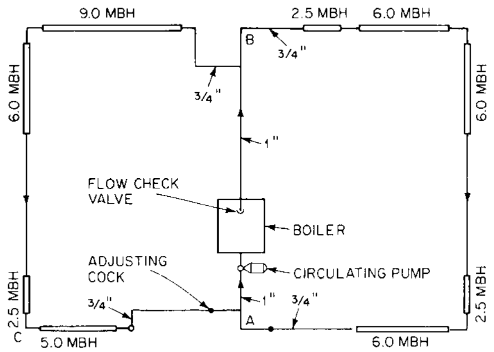

FIGURE 1 A series loop system

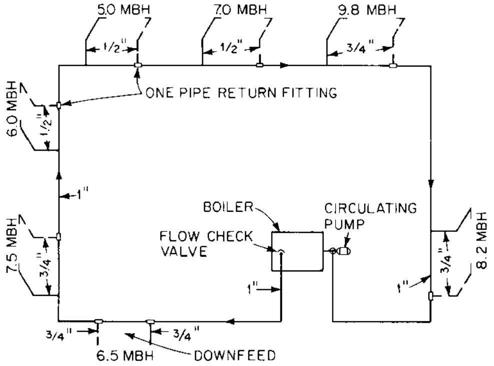

FIGURE 2 A one-pipe system

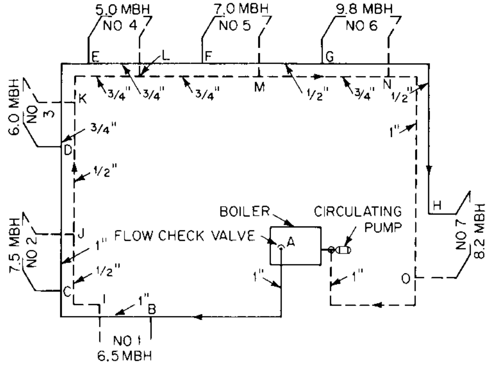

FIGURE 3 A two-pipe reverse-return system.A circuit with primary-secondary pumping provides variable temperature at constant flow rate for two or more coils.

Types of Water Circuit There are several types of water circuits. Those shown in Figures 1 and 2 are suitable for smaller systems and can be used for larger systems by having several of these circuits in parallel. The one shown in Figure 3 is suitable for small or

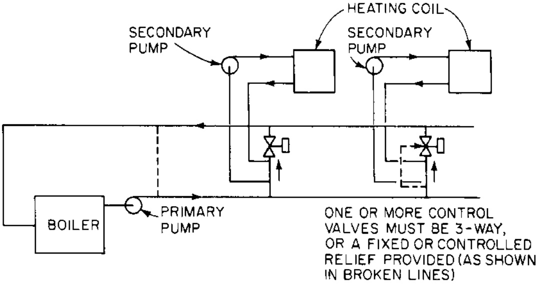

FIGURE 4 A circuit with primary-secondary pumping to provide variable temperature at constant flow rate for two or more coils

very large circuits, but the reverse return would add considerably to the cost if the circuit extended in one direction instead of in a practically closed loop as shown. For the extended circuit, a simple two-pipe circuit, with proper design for balancing, would be used.

There are a number of reasons for using other circuits, particularly primary-secondary pumping where the system is more extended or complicated, such as continuous circulation branches with controlled temperature. When a coil heats air, part or all of which may be below freezing, the velocity of the water in the tubes and its temperature at any point in the coil must be such that the temperature of the inside surface of the tube is not below freezing. The circuit shown in Figure 4 makes this possible.

Primary-secondary pumping permits flow rates and temperatures in branch circuits to be different from those in the main circuit without the flow and pressure differences in the mains or branches having a significant effect on each other. There are many possible primary-secondary circuits to meet different requirements.

Steam Heating Systems No pumping is required with the smallest and simplest steam systems if there is sufficient level difference between the boiler and condensers (radiators, heating coils, and so on) to provide the required flow. When insufficient head exists between the level of the condensate in the condenser and the boiler to produce the required flow to the boiler, a pump must be introduced to provide the required head. Because the condensate in the hot well will be at or near its saturation temperature and pressure, the only *NPSH* available to the pump will be the submergence less the losses in the piping between the hot well and the pump. A pump must be selected that will operate on these low values of *NPSH* without destructive cavitation.

In many cases, particularly for very large systems, vacuum pumps are used to remove both the condensate and air from the condensers. This permits smaller piping for the return of condensate and air, more positive removal of condensate from condensers, and, when high vacuums—above 20 in (0.5 m)—are possible, some control of the temperature at which the steam condenses. The use of vacuum return, particularly with higher vacuums, helps reduce the possibility of frozen heating coils exposed to outside air or to stratified outside and recirculated air. Vacuum return pumps are available for handling air and water. Vacuum, condensate, and boiler-feed pumps with condensate tanks are all available in package form.

Most condensate pumps are centrifugal. Vacuum pumps may be rotary, including a rotary type with a water seal and displacement arrangement.

Fuel Oil When oil burners are fairly far from the oil storage tank or when there are a number of burners at different locations in a building, a fuel oil circulating system is required. The flow rate is relatively low—1 gpm (3.8 liters/min) would provide more than 8,000,000 Btu/h (560,000 Gcal/s or 2,343,000 W)—and a small gear pump is usually used.

AIR CONDITIONING

Many air conditioning systems produce chilled water at a central location and distribute it to air cooling coils in various locations throughout the building or group of buildings. Centrifugal pumps are particularly well suited for this service.

The type of circuit and the number of pumps used require an evaluation of several factors:

1. The cooling requirements usually vary over a wide range.
2. Flow rate through a chiller must be kept above the low point where freezing would be possible and below the point where tube damage would result. Some methods of chiller capacity control require a constant flow rate through the chiller.
3. The temperature of the surface cooling the air must be low enough to control the relative humidity.[3] This limits the use of parallel circuits through chillers when one circuit may not be in operation and permits unchilled water to mix with water in the operating chiller. Under these conditions, it is difficult or impossible to attain a sufficiently low mixture temperature and the control of flow rate and water temperature in the air cooling coils is limited.[4]
4. Below-freezing air may sometimes pass over all or part of a coil. This condition would require a flow rate and water temperature adequate to keep the temperature of all water-side surfaces of tubes above freezing. Many water circuits are available to achieve the desired results. For control of the relative humidity, the air flow circuit must also be considered. Figure 5 shows a circuit for cooling coils with a variable air flow rate at constant air-leaving temperature and with two chillers in series. In addition, the two chillers are shown in parallel with a third chiller. This arrangement permits continuous flow through the coils to reduce the possibility of freezing when the average temperature of the air entering the coil is above freezing, but the usual stratification results in a below-freezing temperature for some of the air entering the coil. The word *reduce* is used because full prevention requires appropriate air flow patterns, water velocities, and temperatures to assure that the water side of the surface will not be below freezing at any point in the coil. One of the coils is also arranged to add heat whenever the temperature of the air leaving the coil must be above that of the average air-entering temperature. Some circuits attempt to obtain the desired results from the circuit in Figure 5 with fewer pumps. However, the use of fewer pumps, although it would reduce the cost slightly, would also require three-way instead of two-way valves, would make control somewhat more complicated, and would almost certainly result in greater power consumption. The circuit shown permits pump heads to match the requirements exactly. It also permits stopping an individual pump when flow is not required in one of the circuits; two-way valves 1, 2, and 3 will reduce pump circulation and the power of pump 3 at partial cooling load.

Air Separation and Removal The methods for handling air with chilled water are about the same as those for hot water except that there is not usually a rise in temperature above that of the make-up water to produce additional separation of air. An expansion tank is required, but the reduced temperature difference requires a much smaller tank than with hot water.

Condenser Water Circulation Condenser water may be recirculated and cooled by passing through a cooling tower, or it may be pumped from a source such as a lake, ocean, or well.

Cooling Tower Water Centrifugal pumps are used for circulating cooling tower water. The circuit, which is open at the tower where the water falls or is sprayed through the air, transfers heat to the air before the water falls to the pan at the base of the tower. A pump then circulates the water through the condenser, as shown in Figure 6. In this case, the pump must operate against a head equal to the resistance of the condenser and piping plus the static head required to the tower from the water level in the pan.

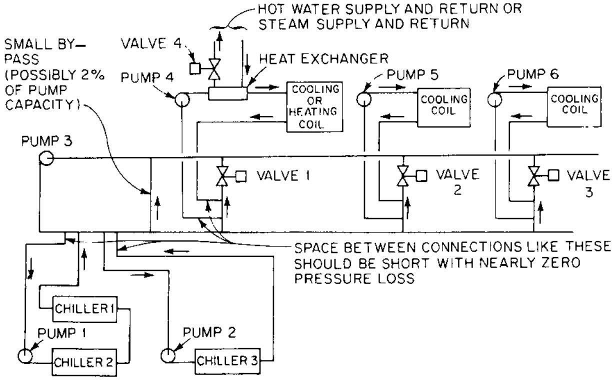

FIGURE 5 Pump 3 does not operate unless pump 1 or pump 2 operates. Pump 1 operates only if chiller 1 or chiller 2 is required and operating. Pump 2 operates only if chiller 3 is required and operating. Pump 4 operates when air circulates over the coil to which the pump is connected, if cooling or heating is required, or if any air enters this coil below about 35°F (12°C). Pumps 5 and 6 operate in the same manner for the coils to which they are connected. Operation of pumps 4, 5, and 6 helps to equalize the temperature of air streams that enter the coils at different temperatures, and thus it may be desirable to operate these pumps continuously when air circulates over the coils. Valves 1 and 4 are interlocked, and so one must be closed before the other can open. Also, valve 1 should be prevented from opening if the temperature of the water in the pump 4 circuit is above about 90°F (32°C).

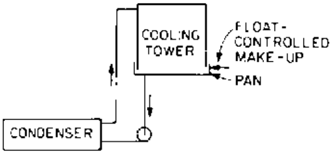

FIGURE 6 Cooling tower with condenser below pan water level

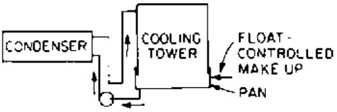

FIGURE 7 Cooling tower with condenser above pan water level

Figure 7 shows a somewhat similar circuit except that here the condenser level is above the pan water level. The size of the pan of a standard cooling tower is sufficient to hold the water in the tower distribution system so the pan will not overflow and waste water each time the pump is shut down. This capacity also assures that the pan will have enough water to provide the amount required above the pan level immediately after start-up, without waiting for the make-up that would be needed if there was any overflow when the pump stopped. When the condenser or much of the piping is above the pan overflow, the amount draining when the pump is stopped will exceed the pan capacity unless means are provided to keep the condenser and lines from draining. In Figure 7, it will be noted that the line from the condenser drops below the pan level before rising at the tower. This keeps the condenser from draining by making it impossible for air to enter the system. This is effective for levels of a few feet, but useless if the level difference approaches the barometric value. Such large level differences should be avoided if possible because they require special arrangements and controls.

When a cooling tower is to be used at low outside temperatures, it is necessary to avoid the circulation of any water outside unless the water temperature is well above freezing. The arrangement shown in Figure 8 provides this protection. The inside tank must now provide the volume previously supplied by the pan, in addition to the volume of the piping from the tower to the level of the inside tank. Condensers or piping above the new overflow level must be treated as already described and illustrated in Figure 7, or additional tank volume must be provided.

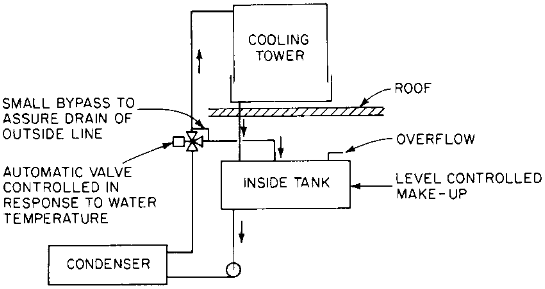

FIGURE 8 Cooling tower with inside tank to permit operation when outside wet-bulb temperatures are below freezing

The only portion of the inside tank that will be available for the water that drains down after the pump stops is that above the operating level. This level is fixed by the height of liquid required to avoid cavitation at the inlet to the pump. The suction piping to the pump must remove only water from the tank without air entrainment.[5] The size of this pipe at the tank outlet should be determined not by pressure loss but by the velocity that can be attained from the available head. Exact data on this are not available, but the required velocity at the *vena contracta* (about 0.6 of the pipe cross-sectional area) can be calculated from $V = (2gh)^{1/2}$ where h is the height of the operating level above the *vena contracta*. The outlet from the tank should be at least as large as that from the cooling tower.

Well, Lake, or Sea water Centrifugal pumps are used for all of these services. The level from which the water is pumped is a critical factor. The level of the water in a well will be considerably lower during pumping than when the pump does not operate. When pumping is from a lake or from the ocean, the drawdown is usually not significant. When pumping is from a pit where the water flows by gravity, there will be a drawdown that will depend on the rate of pumping. With a sea water supply, there will be tidal variations. A lake supply may have seasonal level differences.

All these factors must be taken into consideration in selecting the level for mounting the pump to assure that it will be filled with water during start-up. Check or foot valves may be used for this purpose. Also, the head of the water entering the pump at the time of highest flow rates must not be so low that the required *NPSH* is not available.

To assure proper pump operating conditions, the pump is frequently mounted below the lowest level expected during zero flow conditions, as well as below the lowest level expected at the greatest flow rate. These conditions may require a vertical turbine pump. The motor should be above the highest water level with a vertical shaft between the motor and the pump bowls, or the motor can be of the submerged type and connected directly to the pump bowls.

Refrigeration For refrigeration systems with temperatures near or below freezing, pumps are often required for brine or refrigerant circulation. The transfer of lubrication oil also frequently requires pumps.

Brine Circulation The word *brine,* as used in refrigeration, applies to any liquid that does not freeze at the temperatures at which it will be used and which transfers heat solely by a change in its temperature without a change in its physical state. As far as pumping is concerned, brine systems are very similar to systems for circulating chilled water or any liquid in a closed circuit. A centrifugal pump is the preferred choice for this service, but it must be constructed of materials suitable for the temperatures encountered. For some brines, the pump materials must be compatible with other metals in the system to avoid damage from galvanic corrosion.

Tightness is usually more important in a brine circulating system than in a chilled water system. This is true not only because of the higher cost of the brine but also because of problems caused by the entrance of minute amounts of moisture into the brine at very low temperatures.

Refrigerant Circulation For a number of reasons—including pressure and level considerations as well as improvement of heat transfer—the refrigerant liquid is often circulated with a pump. The centrifugal pump is usually preferred for this purpose.

The liquid being pumped as a refrigerant may be the same one that is pumped as a brine. Whereas the material is all in liquid form throughout the brine circuit, some portion of it is in vapor form during its circulation as a refrigerant. In a refrigerant circulating system, most of the heat transfer is by evaporation, condensation, or both.

As there are changes from liquid to vapor, the liquid to be pumped must be saturated in some portion or portions of the circuit. Sufficient *NPSH* for the pump must be provided by the level of saturated liquid maintained in the tank where the liquid is collected. The level difference required for the *NPSH* must provide adequate margin to compensate for any temperature rise between the tank and the pump. This is an important consideration because the liquid temperature will usually be considerably lower than that of the air surrounding the pump intake pipe.[5]

When the pump is not operating, it may be warm and may contain much refrigerant in vapor form. It is usually necessary to provide a valved bypass from the pump discharge back to the tank so gravity circulation can cool the pump and establish the prime.

Pumps for this service may require a double seal, with the space between the seals containing circulated refrigerant oil at an appropriate pressure. This will reduce the possibility of the loss of relatively expensive refrigerant and eliminate the entrance of any air or water vapor at pressures below atmospheric. A hermetic motor may also be used for this service and thus avoid the use of seals.

Lubricating Oil Transfer Because the flow rates for lubricating oil transfer are rather low, the gear pump is usually preferred. The *NPSH* requirement is also critical here because, although the oil itself is well below the saturation temperature at the existing pressure, it contains liquid refrigerant in equilibrium with the refrigerant gas. Any temperature rise or pressure reduction will result in the separation of refrigerant vapor. It is important, therefore, to design the path for oil flow from the level in the tank where it is saturated with the same safeguards necessary for refrigerant pumping.

To reduce the oil pumping problem, the oil can be heated to a temperature above that of the ambient air and vented to a low pressure in the refrigerant circuit. This eliminates temperature rise in the pump as well as in the suction, with the corresponding reduction of available *NPSH*.

Usually, the oil flow is intermittent, and the best results are obtained by continuous pump operation discharging to a three-way solenoid valve. This discharge would be bypassed back to the tank whenever transfer from the tank is not required. This assures even temperature conditions and a pump free of vapor.

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