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Volume 17 Issue May 2002

Selecting Condensate Transfer and Boiler Feed Equipment

When considering low pressure boiler systems, the question has been raised, why save the condensate? Why not dump the used condensate to drain and simply replenish the boiler with fresh make-up water? Because returning condensate has value. Why? Because, the returning condensate has a higher temperature than cold fresh water make-up. This means less energy that the boiler must add to heat the water. In most systems, the condensate is treated with additives to reduce corrosion. If condensate is dumped to drain and fresh make-up water is added, additional chemicals would be required to condition the water. Dumping hot condensate is thermal pollution, and the temperature of water that may be dumped to drain is regulated. Also, fresh water is not free. Every gallon of condensate dumped to drain must be replaced with one gallon of fresh water. For these reasons, condensate should be captured and reused.

Basics

In a simple one-pipe steam system, energy is added to water in the boiler, to create steam. The steam flows through the interconnecting piping to the radiation where it gives up its latent heat and condenses back into water (condensate). The condensate flows back to the boiler through condensate return piping where it repeats the cycle. The steam piping is designed for very low pressure losses, in the range of ounces. This enables the boiler to operate at low pressure. The condensate piping is pitched back to the boiler so the condensate is returned by gravity. The condensate flows back into the boiler when the weight of a vertical column of condensate exceeds the pressure loss of the steam piping. The static height of condensate is the "A" dimension shown in fig. 1. The height of the vertical column of condensate is 28 inches for each 1 psig boiler

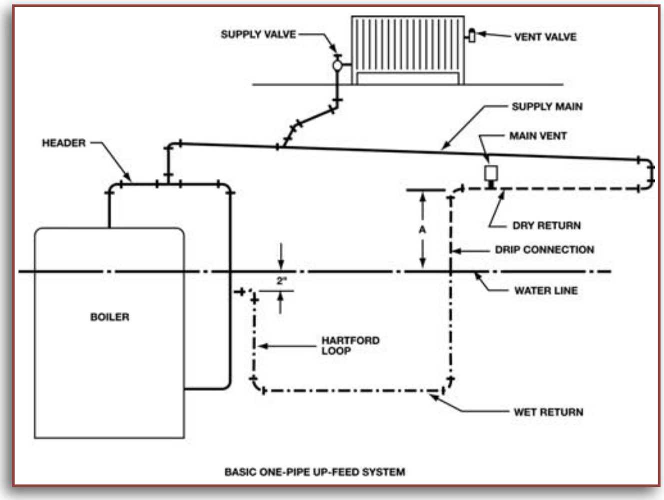

Figure 1. A basic one-pipe upfeed system.

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  - U Tube

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pressure. This simple system required no boiler feed pump to replenish the boiler with condensate.

The simple steam system did not remain simple. In time, the steam and condensate were separated into different lines. The one-pipe steam systems became two- pipe systems. Buildings and systems became bigger. Horizontal runs of return piping became longer. As a result, the installations lacked the vertical column height of water needed to push the condensate back into the boiler.

Installations lacking sufficient elevation to return the condensate by gravity needed a condensate return unit. Returning condensate to the boiler with an electrically driven pump resolved many installation problems.

A condensate return unit is a device that collects condensate, then sends it back to the boiler room with the use of a pump. The pumps are typically driven by electric motors. This article discusses the selection of electrically driven centrifugal pumps.

Condensate return equipment varies in size, materials and complexity. However, these packages all contain three common components: a holding tank to collect the condensate, a centrifugal pump, and an activating device to start and stop the pump. The tanks or receivers may be as small as 6 gallons or they may hold as much as thousands of gallons. They may be floor mounted, underground, or elevated on a stand to increase the static pressure to the pump. The most common receiver materials are cast iron or steel. Cast iron receivers are very durable; some manufacturers offer an extended warranty (20 years) against corrosion, and condensate pumps are specifically designed for this duty. The pump suction has a low-pressure drop to reduce NPSHR (discussed later). The pump is designed for intermittent duty with long periods of inactivity; and a switch that senses liquid level activates the pumps. The most common is a simple float switch or mechanical alternator.

Selecting Condensate Equipment

The selection of condensate handling equipment should be given careful consideration to maintain a properly balanced efficient steam system. The factors to consider when selecting condensate return equipment are:

- The system size
- The required discharge pressure
- The NPSHA of the system
- The amount of make-up required due to leakage
- Flash steam and steam consumed in industrial processes
- The change in load rate during various time periods

The condensate return rate can be calculated from the square feet E.D.R.(equivalent direct radiation by definition) served, the lbs/hr of steam used, the BTU heat load, or the boiler horsepower required. This information will enable you to select the size of the holding tank or receiver and the required volume of condensate the pump must move.

Determine Pumping Capacity

E.D.R. is the amount of heating surface that will give off 240 BTU/hr when filled with a heating medium at 215°F and surrounded by air at 70°F. Steam is the medium in the radiation. When steam condenses in the radiation, it gives up its latent heat then flows back as condensate. The latent heat of vaporization of 5 psig saturated steam is 960 BTU/lb. Using the conversion factor

1 E.D.R. = .25 lbs/hr. (condensate)

and knowing the square feet of heating surface (E.D.R.) the condensate unit will be serving, we can calculate the rate that steam will condense. Factoring in the density of water at the condensing temperature, we can convert the lbs/hr of water to a more common volumetric flow rate - gallons per minute.

At 32ºF,

$$\frac{62.4\ \text{lb}}{1\ \text{ft}^3} \times \frac{1\ \text{ft}^3}{7.48\ \text{gal}} = 8.34\ \frac{\text{lb}}{\text{gal}}$$

and

$$X\ \frac{\text{lb}}{\text{hr}} \times \frac{1\ \text{gal}}{8.34\ \text{lb}} \times \frac{1\ \text{hr}}{60\ \text{min}} = Y\ \frac{\text{gal}}{\text{min}}$$

or

$$X\ \frac{\text{lb}}{\text{hr}} \times \frac{1}{500} = Y\ \frac{\text{gal}}{\text{min}}$$

But:
at 200ºF, density is 60.1 and the factor is 482
at 300ºF, density is 57.3 and the factor is 460

We have standardized on the conservative factor of 500.

Using the formula lbs/hr ÷ 500 = gpm.

Therefore 1E.D.R. requires .0005 gallons/minute of steam condensing or

1000 E.D.R. = .5 gpm.

Converting the flow to gallons per minute simplifies pump and tank selection. The tank or receiver is sized for 1-5 minutes net storage capacity based on the return rate. Condensate pumps are typically sized for 2 x the condensate return rate. (See Conversion Factors)

Determine the Required Discharge Pressure

The pump must be sized to meet the total dynamic head required by the application. This is accomplished by solving the equation:

$$\frac{P_a}{W} + Z_a + \frac{V_a^2}{2g} + E_p = \frac{P_b}{W} + Z_b + \frac{V_b^2}{2g} + h_f$$

$$E_p = \left(\frac{P_b}{W} - \frac{P_a}{W}\right) + \left(Z_b - Z_a\right) + \left(\frac{V_b^2}{2g} - \frac{V_a^2}{2g}\right) + h_f$$

P_a = static pressure, lbf/ft^2
W = mass density, lbm/ft^3
Z_a = elevation ft.
V^2_a = average velocity
g = constant 32.2 (lbm-ft)/(lbf-s^2)
h_i = friction losses ft.
E_p = work performed by the pump (ft/lbf)/lbm
P_b = static pressure, lbf/ft^2
Z_b = elevation ft.
V^2_b = average velocity

The terms in this equation are the pumping energy required equals the change in pressure plus the elevation change plus the velocity change plus losses due to friction. The velocity change is often

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negligible so the equation is simplified to the following:

- Overcome any pressure differences
- Add static head to lift the condensate
- Overcome losses in the return piping, fittings, and valves

Once you've summed these terms add an additional 5 psig if the total pressure is below 50 psig. If the calculated sum is above 50 psig add 10 psig. This is a safety factor that allows for wear in the system.

Determine the NPSHA

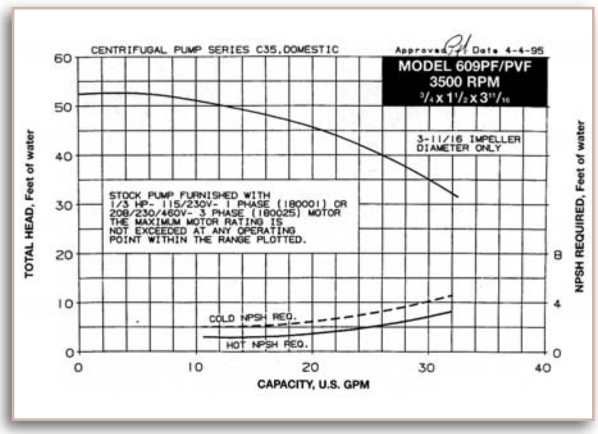

Figure 2. The NPSH curve for a sample pump.

As with all pump applications, NPSH must be considered. When selecting pumps for condensate this is especially critical. The amount of required head is a function of the pump design and is called Net Positive Suction Head Required (NPSHR). NPSHR is the amount of suction head required to prevent pump cavitation and is indicated on the pump curve. The NPSHR for a Model 609PF pump is illustrated in the curve above (figure 2) labeled NPSH REQ.

If the pressure in the pump drops below the vapor pressure of the condensate, cavitation or flashing will occur. Each application has an available net positive suction head (NPSHA). NPSHA is a function of the static head at the pump suction, velocity head, and vapor pressure of the liquid at the temperature being pumped. The NPSHA must always be greater than the NPSHR or noise and cavitation will occur. The formula for NPSHA is:

$$NPSHA = \frac{2.31(P_a - P_v)}{spgr} + (H_e - H_f)$$

Where:
- P_a, pressure in the receiver, psia
- P_v, vapor pressure of the liquid at its maximum temperature, psia
- H_e, elevation head, feet
- H_f, friction losses in the suction piping at the required flow rate, feet

In a vented receiver, P_a is atmospheric. H_e is the height of condensate above the pump suction, determined by the condensate unit design. H_f is the friction losses from the receiver to the pump suction. This is fixed by the condensate unit design. P_v is the vapor pressure of the liquid at the pumping temperature. For a particular, previously designed condensate return unit, the only variable is P_v. Since P_v is a function of temperature, once the condensate temperature is known we can determine NPSHA. The Hydraulic Institute recommends a margin ratio between the available and required NPSH (NPSHA/NPSHR) for various centrifugal pump applications. Using building services as the application category for boiler feed pumps or condensate return pumps, the ratio margin suggested by the Hydraulic Institute is 1.1 or 2'minimum. The Hydraulic Institute developed this margin ratio using field experience from many pump manufacturers as the basis.

Condensate units are typically pre-engineered to ensure that NPSHA is greater than NPSHR for a given temperature limit. Most manufacturers catalog their condensate return equipment by maximum temperature. (There is a correction factor for increased elevation. Boiling point decreases 1°F for every 500' increase in elevation.)

Condensate return units are primarily used to transport condensate from the far reaches of a steam system back to the boiler room when gravity flow is no longer feasible. In any system, there is a time lag between when steam leaves the boiler until it returns in the form of condensate. The greatest time lag exists during a cold start-up. In a cold system, the steam mains, radiators, and return piping are completely drained. When the system is put into operation, the steam mains and radiators require a volume of steam to fill the system. The volume of steam must come from the boiler during this period and causes a drop of water level in the boiler. Additional time is required for the condensate to flow through the return lines back to the boiler room either by gravity or to be pumped back from condensate transfer units.

The opposite condition occurs when the system is shut down; all the steam in the mains and radiators is returned in the form of condensate and must be stored for the next system start-up. During normal operation fluctuating load rates will cause surges of steam output and condensate return to occur in the system. The steam boiler system should be designed with an ample storage volume to compensate for the variations in flow rate.

In some systems, a condensate return unit can be used to maintain the water level in a boiler. With this arrangement, condensate is fed into the boiler in response to the water level in the pump receiver. The receiver is sized the same as a typical condensate transfer unit to provide one minute storage capacity based on the boiler steaming rate. The float switch in the condensate return unit starts and stops the pump in relation to the level in the receiver.

With this arrangement, the system surges occur in the boiler due to the change in boiler load. The boiler is equipped with an automatic water feeder to add city make-up into the boiler on low level to replace condensate lost in the system. Using a condensate return unit to feed a boiler has proven successful in small steam space heating applications. On larger installations, the boiler does not have an adequate storage volume to handle the system surges.

When a condensate return unit is used to supply a boiler that does not have an ade-

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quate storage volume, the make-up water valve on the boiler will add additional make-up water during start-up or heavy system steam demand. When the condensate is later returned, the boiler will flood and shut off on high water. This will cause a constant cycle of adding make-up water only to later flood the boiler. This problem may also occur when an older high water volume boiler is replaced by a low water content boiler. The practical system size limit for a condensate return unit feeding a boiler is approximately 8,000 sq. ft. E.D.R. or 60 boiler horsepower system size. The maximum system size will vary with different types of boilers having various storage capacities between high and low operating levels.

Boiler Feed Units

Systems larger than 8,000 sq. ft. E.D.R. or 60 boiler horsepower use a boiler feed unit to supply condensate to the boiler. The boiler feed unit consists of a storage receiver sized to store an adequate volume of water to handle the system surges or system time lag. The pumps are started and stopped to maintain the boiler water level in the boiler.

The normal boiler level control switch maintains a boiler water level within one inch differential. When a boiler feed unit is used, the fresh water make-up is added into the boiler feed receiver not the boiler. The boiler feed receiver must be sized large enough to prevent overflowing of condensate during system surges. The normal receiver sizing is to provide 5 minutes storage volume for systems up to 30,000 sq. ft. E.D.R. or approximately 200 boiler horsepower.

Larger systems should provide a minimum of 10 minutes storage volume. Large single story buildings requiring over 100,000 sq. ft. E.D.R. and campus complexes should provide a minimum of 15 minutes storage volume. Oversizing the boiler feed unit receiver does not affect the system operation, it only adds to the initial cost. However, undersizing the boiler feed receiver can cause an overflow of returned condensate which must be replaced with fresh make-up water. This wastes heat, make-up water, and chemical treatment.

Once you have decided a boiler feed unit is needed for the system, the following information must be determined.

- The unit load requirements
- The type of control system required
- The pump capacity
- The pump discharge pressure
- Select the basic unit
- Select the desired accessories

Determine the Unit Load Requirements

The load requirement is based on the boiler capacity, not the system capacity. The boiler is normally rated in boiler horsepower. It may also be rated in lbs/hr, square feet E.D.R., or BTU output. Convert this data to the boiler steaming rate, then convert this to gallons per minute using the relationships detailed earlier.

Select the Type of Control System Required

There are several choices in type of piping arrangements to meet various requirements. A simple arrangement is one (or two) pumps feeding one boiler. When the water level in the boiler drops, the pump control on the boiler activates the pump. When the water level in the boiler reaches the correct level, the pump control deactivates the pump. If the pump control is single level and a second boiler feed pump is included on the unit, the second pump can be manually operated as a standby.

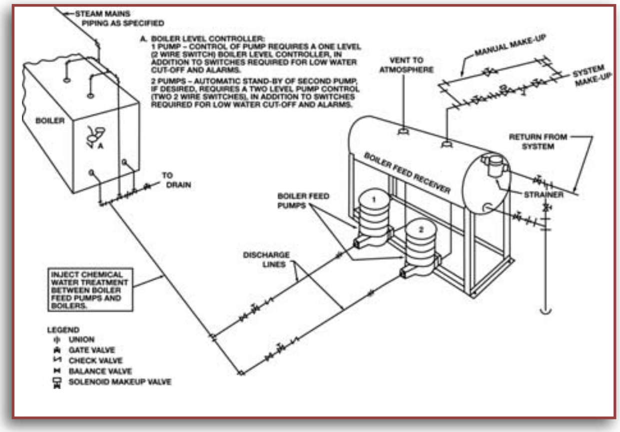

Figure 3. Automatically switching the lead pump after every activation cycle can ensure both pumps wear evenly and prevents the lag pump from sitting idle for long periods.

If the pump control can detect two separate levels, the second pump can be automatically activated as a standby if the water level in the boiler drops to the second level. Another option is automatic alternation which automatically switches the lead pump after every activation cycle. This ensures even wear on each pump and prevents the lag pump from sitting idle for long periods. (See figure 3)

One duplex boiler feed unit can feed two boilers. This arrangement has a dedicated

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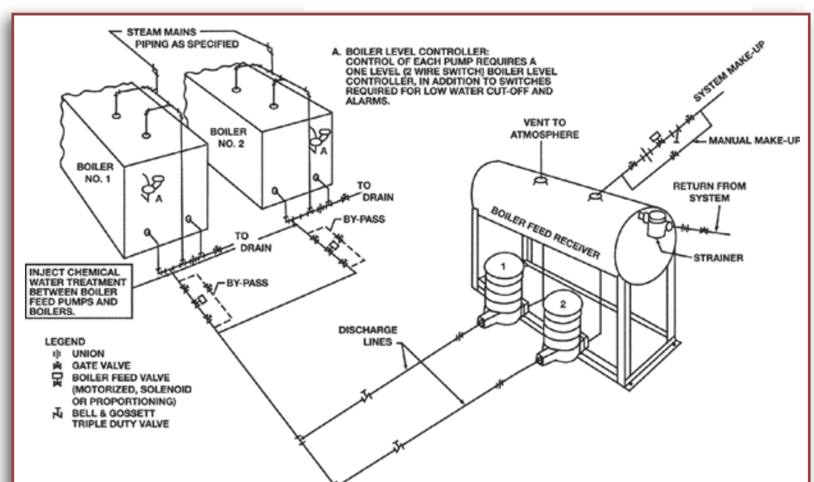

Figure 4. An example of a duplex boiler feed unit supplying two boilers.

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pump for a dedicated boiler. When either boiler requires water, the pump dedicated to that specific boiler will be activated. The two pumps can be manually switched to the other boiler by switching the pumps on the selector switches and manually closing and opening the valves in condensate piping. If the boilers are equipped with two-level pump controllers and boiler feed valves are installed between the pumps and boilers, the standby pumps can be automatically activated should the water level in the boiler recede to the second level. (See figure. 4)

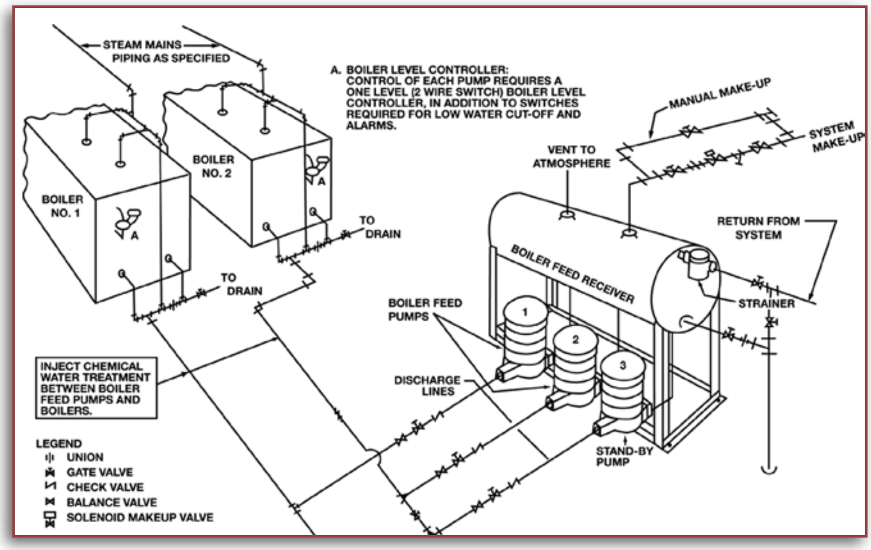

Figure 5. This is an example of two boilers being fed by three pumps.

A third arrangement is two boilers being fed by three pumps. Each boiler has a dedicated pump. The third pump is a dedicated manual standby. This arrangement may be expanded by adding one boiler feed pump for each additional boiler. Similar to the previous example if the boilers are equipped with two-level pump controllers and boiler feed valves are installed between the pumps and boilers, the standby pumps can be automatically activated should the water level in the boilers drop below the second level. (See figure 5)

These control system examples illustrate three common (but not the only) methods for linking the boiler feed unit to the boiler. Unlike a condensate unit, a boiler feed unit relies on external signals for pump control. When selecting the boiler feed unit, the number of boilers being fed, the number of pump control levels being monitored, if boiler feed valves are used, type of standby, and type of alternation, are all system dependent criteria that will affect the design of the boiler feed unit.

Calculate the Pump Capacity

The individual pump's capacity should be based on the boiler(s) they are required to feed. The pumps are normally sized for 1-1/2 to 3 times the boiler load. When boiler feed pumps are selected for continuous operation, they are normally sized for 1-1/2 times the boiler load.

Boiler Feed Pumps for intermittent operation are normally sized for 2X the boiler load. When there is a danger of pump cavitation or when turbine pumps are used, selecting the pumps at 3 x the boiler load is acceptable.

Calculate the Pump Discharge Pressure

The required discharge pressure for a boiler feed unit is calculated similar to a condensate unit. It is the sum of static head lift, friction losses in the piping, and the pressure in the boiler. In addition to the boiler pressure, a safety margin of 5 or 10 psig is added. For boiler pressures up to 50 psig, add 5 psig. For boiler pressures of 51 psig or higher add 10 psig for safety.

Select the Basic Unit

We know the required tank size, control system, and pump duty point. We now need to decide the type of unit. Things to consider are condensate temperature, materials of construction, and receiver location (underground, floor mounted, or elevated). Most manufacturers have preselected packages of receivers and pumps to meet a specific boiler load. These preselected packages are stated in E.D.R. served or boiler horsepower.

Select the Desired Accessories

Once the basic unit is determined, the options can be selected. A list of the typical options are as follows:

Gauge glass will permit visual indication of the water level in the receiver.

Thermometers help monitor the return temperature and provide indication when steam traps are not operating properly.

Discharge pressure gauges permit visual indication of the pump's performance and are useful in adjusting the balancing valves for maximum pump efficiency and to prevent cavitation.

A gauge glass, thermometer, and discharge pressure gauge are highly recommended options. They simplify installation and help monitor the system. They are used to troubleshoot system problems and are well worth the investment.

- A low water pump cut-off float switch may be added to prevent pump operation on low water level. This will prevent pumps from running dry which will damage pump seals. The low water cut-off option is not recommended for boiler feed units smaller than 100 gallons. On small receivers, the cut-off float switch will reduce the receiver's net capacity considerably.

- Alarm float switches and bells may be added to indicate abnormal conditions in the system.

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- Pump isolation valves permit pump service without shutting down the entire system and draining the receiver. These valves permit complete pump removal for bench test inspection or wear ring replacement.

- Manholes give access to the inside of the tank for inspection.

- Inlet basket strainers are connected between the return line (coming to the unit) and the receiver. This is the collection point for dirt and debris that form in the system. They have a large dirt pocket and easy access for easy maintenance. Strainers should never be installed in the pump suction piping. The additional frictional loss through the strainer would reduce the NPSH available to the pump and may cause cavitation.

- Sparge tubes or steam distribution tubes are submerged tubes that inject steam into the boiler tank to preheat the condensate. Preheating reduces thermal shock to the boiler especially when large amounts of fresh water make-up are added to the system.

- Corrosion inhibitor anodes are zinc or magnesium rods threaded into the tank. The anode metal is more "active" and creates a galvanic current flow. The anode corrodes and provides a protecting effect to the tank. In time the (sacrificed) anode will be chemically consumed and it must be replaced.

Pumps Designed for Handling Hot Condensate

Certain characteristics make a pump more desirable for handling hot condensate. Centrifugal and turbine pumps are commonly used for condensate handling.

A condensate pump should have:

- A low NPSHR

- A low sensitivity to sediment and corrosion

- A low inertia for frequent start & stops

- The ability to start after long periods of inactivity

- Generous running clearances to retain their original capacity after years of service

Earlier in this article we presented a brief description of NPSHA and explained that in all applications the NPSHA (available) must be greater than the NPSHR (required) for the application to function properly. We also stated that NPSHA is primarily determined by temperature. Elevating the receiver for additional static head may increase NPSHA. Once NPSHA is determined, a condensate unit must be selected with a lower NPSHR. Condensate pumps are designed with a low NPSHR. Their suction size is large for low friction losses. Their impellers are designed to minimize the pressure drop as condensate is pulled into the vanes. If the pressure at this point drops below the vapor pressure of the conden-

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CONVERSION FACTORS

- One Boiler Horsepower = 140 Sq. Ft. EDR or 33,475 BTU/Hr, or 34.5 Lbs./Hr Steam at 212° F.

- 1000 Sq. Ft EDR yields .5 GPM condensate

- To convert Sq. Ft. EDR to Lbs. Of condensate - Divide Sq. Ft. by 4

- .25 Lbs./Hr. condensate = 1 Sq. Ft. EDR

- One Sq. Ft. EDR (steam) = 240 BTU/Hr. with 215° F. steam filling radiator and 70° F. air surrounding radiator.

- To convert BTU/Hr. to Lbs./Hr. - Divide BTU/Hr. by 960

One PSI = 2.307 Feet Water Column (Cold)
One PSI = 2.41 Feet Water Column (Hot)
One PSI = 2.036 Inches Mercury
One Inch Mercury = 13.6 Inches Water Column

- Sizing Boiler Feed or Condensate Return Pumps:

If boiler is under 50 PSI, size pump to discharge at 5 PSI above working pressure.

If boiler is 50 PSI or greater, size pump to discharge at 10 PSI above working pressure.

- Size condensate receivers for 1 min. net storage capacity based on return rate.

- Size boiler feed receivers:

5 min. net storage for systems up to 200 Boiler HP.

10 min. net storage for systems above 200 Boiler HP.

15 min. net storage for systems that exceed 100,000 Sq. Ft. EDR or 700 Boiler HP.

- Size condensate pumps at 2 times condensate return rate

- Size boiler feed pumps at 2 times boiler evaporation rate or .14 GPM/Boiler HP (continuous running boiler pumps may be sized at 1-1/2 times boiler evaporation rate or .104 GPM/Boiler HP. When there is a danger of pump cavitation, or when turbine pumps are used, select pumps for 3 times the evaporation rate.

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sate cavitation will occur. Some condensate pumps include an inducer ahead of the impeller. The axial flow inducer develops a positive pressure at the eye of the centrifugal impeller, lowering the NPSHR. These specially designed pumps can handle condensate close to its boiling point.

Sediment and corrosion are prevalent in condensate return systems. Condensate return units are designed with a low sensitivity to both. Large strainers are installed on the receivers, keeping large particles out of the receiver. Typically the strainers are designed for easy cleaning with large dirt pockets to minimize maintenance. The pumps have generous running clearances and retain near their original capacity after years of service.

Condensate pumps are selected to return condensate at twice the system condensing rate. If a system sends condensate back at the rate of 10 GPM, the pump is sized to return it at 20 GPM. This enables the pump to return the condensate quickly and allows the pump to keep up during peak periods and start up.

During normal operation the pump is on a short start and stop frequency. One-minute pumping, two minutes stopped. Pumps that operate at a higher speed (3500 RPM) for a given duty point produce lower inertia loads on the pump shaft when compared to low speed (1750 RPM) pumps. However, there is a trade off: higher speeds produce more noise and require higher NPSHR. For most applications, the high-speed pump is preferred for lower cost and lower inertia loads.

Many condensate transfer units operate seasonally with long periods of inactivity. These units may sit unused for months. Pump materials are selected to reduce corrosion between the impeller and volute. Bronze wear rings are installed in the volute to minimize galvanic reaction.

In Summary

When selecting condensate transfer units, first collect all pertinent information about the application. Determine the total radiation being served or system size, the required pressure, condensate temperature, amount of make-up water added, and expected fluctuations in the load. This information will enable you to select the basic unit, the required receiver size and pump needed.

When selecting boiler feed equipment the process is similar; gather the necessary information about the system, and determine the boiler capacity, boiler operating pressure and returning condensate temperature. This information will help you select the basic unit, the receiver size, pump capacity, and type of control system.

Once the basic condensate transfer or boiler feed unit is selected, choose the options that meet your specifications for the specific application. Gauge glass, thermometer, and discharge pressure gauge are options that help monitor the system and aid in troubleshooting. Standby pumps, alternating controllers and high level alarms increase reliability.

Condensate transfer and boiler feed units are specifically designed for this duty. Properly selected and installed, these units will provide you with many years of trouble-free service.

This article was written by Bell & Gossett engineers and was originally published in the August 2001 issue of Engineered Systems magazine. Reprinted by permission.

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