Boost Steam-System Efficiency by Improving Condensate Recovery

Pressurized condensate-return systems and flash-steam vent condensers offer opportunities for fuel cost savings in a plant's steam system. Here's how to take advantage

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FIGURE 1. Pressurized condensate tank systems, like the one shown here, can help maximize efficiency in a plant's steam generation

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Pressurized steam-condensate systems can provide plants with a minimum of between 15 and 35% savings in fuel costs when compared to conventional atmospherically vented steam-condensate systems. That is a tremendous opportunity for chemical process industries (CPI) facilities, since fuel prices have risen and are expected to increase even further. The pressurized condensate system should not be thought of as a luxury; rather, it should be considered a necessary component to maximize and increase the efficiency of a plant's steam system (Figure 1).

Unfortunately, it is not possible to implement high-pressure condensate return systems for all steam plants and all steam applications (see box, p. 37). Therefore, proper preliminary engineering assessment, design review and knowledge of the application are necessary to ensure a successful condensate system. In the examples discussed in this article, energy savings of $226,700 were achieved by implementing a 50-psig pressurized steam-condensate system. The project was implemented at a cost of $305,400, yielding a 1.3-year payback.

This article provides information on pressurized condensate systems and explains how to evaluate whether the technology could be a cost saver at your plant.

Pressurized condensate recovery

Pressurized condensate recovery systems operate continuously at pressures above 15 psig, and the condensate recovery system is not vented to the atmosphere. The pressure in the condensate system is sustained by the dynamics of the system or by a systematic control process loop. Typical condensate systems operate with backpressure because their condensate line is improperly sized for two-phase flow and because plants often neglect steam-trap stations blowing steam into the condensate line. These items alone can cause unwanted and uncontrollable pressure in the condensate recovery system.

A pressurized condensate-recovery sys-

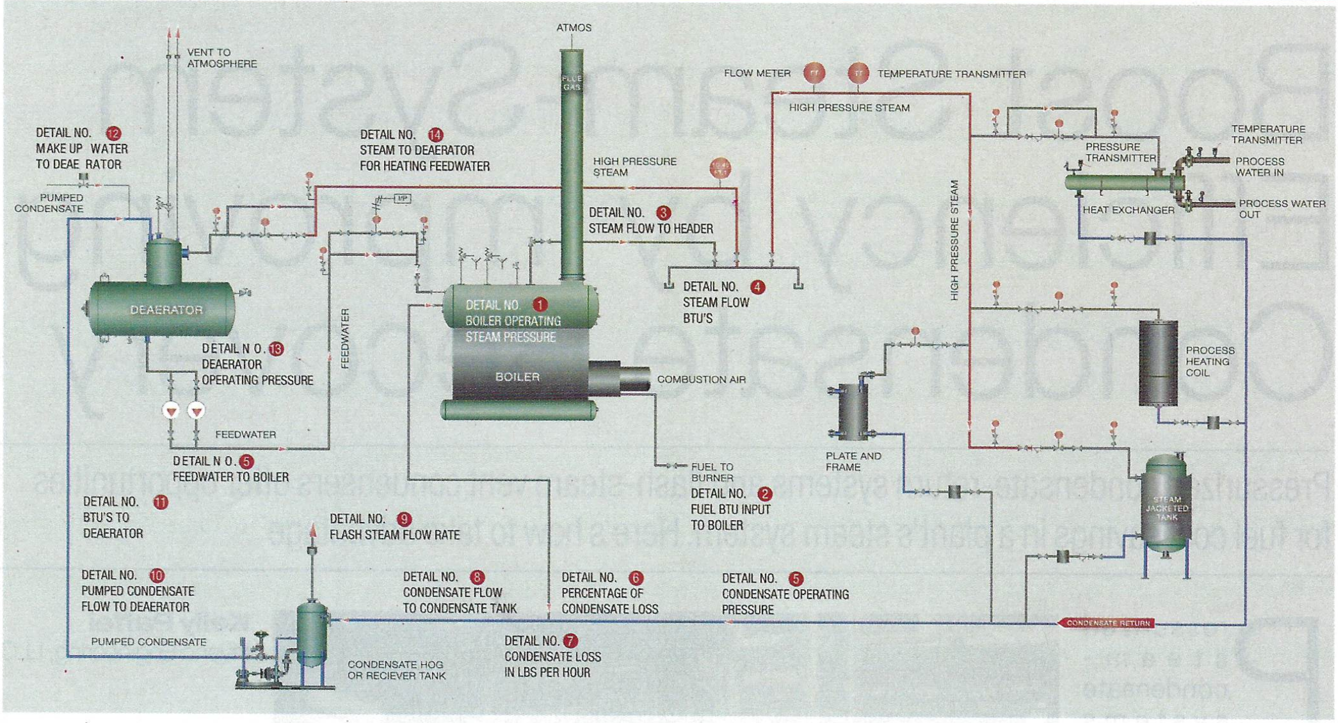


FIGURE 2. The diagram shows the layout of an atmospheric condensate system. Detail No. 9 shows where vented steam is lost

tem differs in that the condensate-return-line pressure is systematically controlled and managed to a predetermined set point that matches the peak performance level of the steam system process and integrates into the dynamics of the steam balance.

Four classifications of condensate systems are used in plants today:

1. Gravity or atmospheric condensate system (condensate line pressure is maintained at or close to 0 psig)
2. Low pressure (1 to 15 psig)
3. Medium pressure (16 to 99 psig)
4. High pressure (100 psig or higher)

Pressurized condensate system technology is not new in the steam world. These systems can be documented back to 1941. Though the technology may be considered old, it has been overlooked over the years due to relatively inexpensive fuel prices. As fuel prices have risen and, with them, the need for optimization to reduce overall operational costs, industrial plants are paying more attention to pressurized condensate systems, because they have proven to be a significant way to decrease expenses. In fact, these systems are considered to be among the top three items for optimizing a steam system, and have a very attractive payback for the investment. Figure 2 shows a steam system with atmospheric venting, while Figure 3 shows the same steam system with a pressurized flash-recovery line to the deaerator.

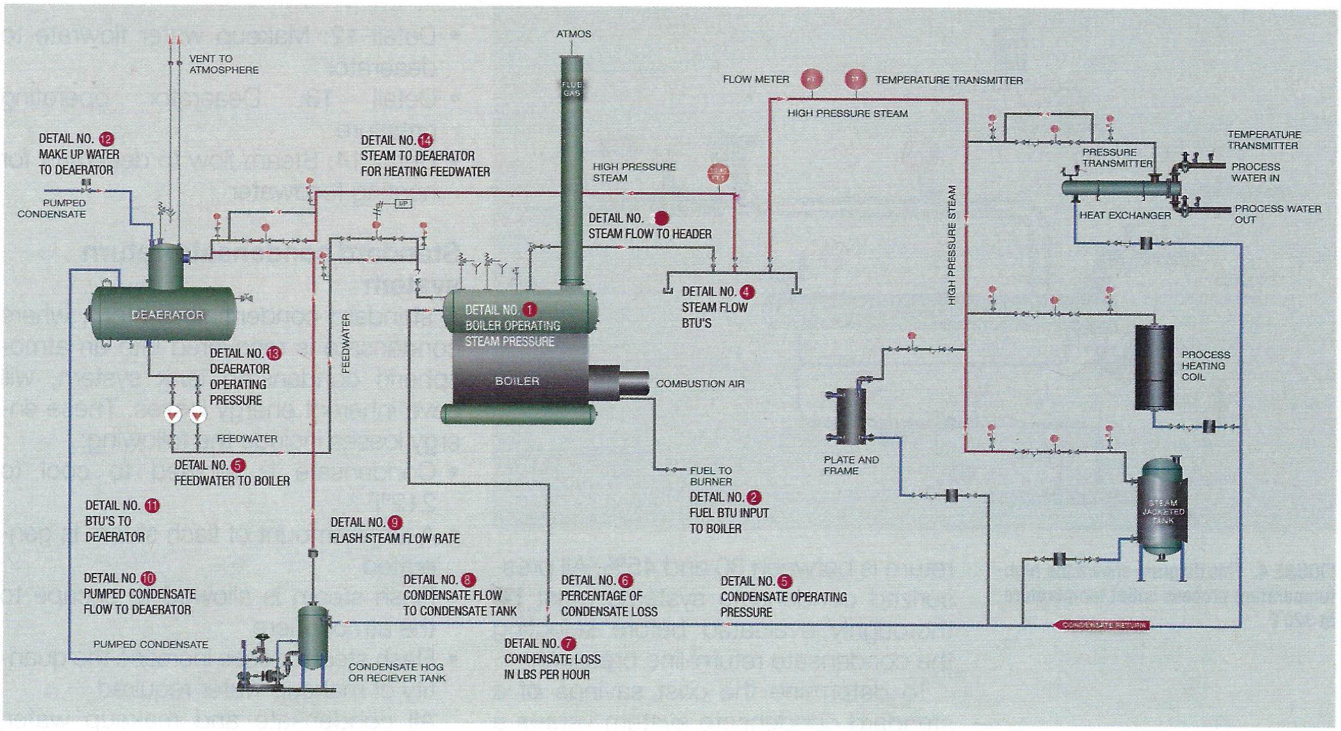
Increase efficiency and reduce costs

The best reason to use a pressurized condensate system is the remarkable energy savings that plants can often achieve with a low implementation cost. Any condensate that is not contaminated in a process application needs to be returned to the boiler to complete the steam system's thermal cycle and increase efficiency. Steam condensate contains a high quantity of sensible energy. If the sensible energy is not properly returned to the boiler operation, a large percentage, if not all, of this energy is lost.

Condensate that is returned to the boiler operation will require the condensate temperature to be raised to the saturated temperature of the steam boiler's operating pressure. To accomplish this task, energy is introduced at the deaerator and the boiler. The deaerator will add energy to heat the condensate to a temperature where noncondensable gases will be removed from the fluid. The boiler will add the energy for a phase change to occur at the boiler operating pressure.

The higher the temperature or pressure (direct relationship in steam) of the condensate being returned to the boiler plant, the less energy that is required to raise the temperature of the condensate back to the saturated temperature of the boiler operating pressure.

Theoretically, the most efficient system would be a condensate return system controlled at a pressure as close to the boiler operating pressure as possible. In a perfect system, the steam system would operate at 150 psi, and the pressurized condensate



system would operate at 149 psi. However, the limitation is the type of steam and condensate system. The plant must consider elements such as line sizes, distances, steam-trap station differential and elevations. With these variables in the system, a typical target for the pressure differential between the steam supply and condensate

FIGURE 3. A pressurized condensate return is shown in this diagram. The flash steam at detail No. 9 is delivered to the deaerator

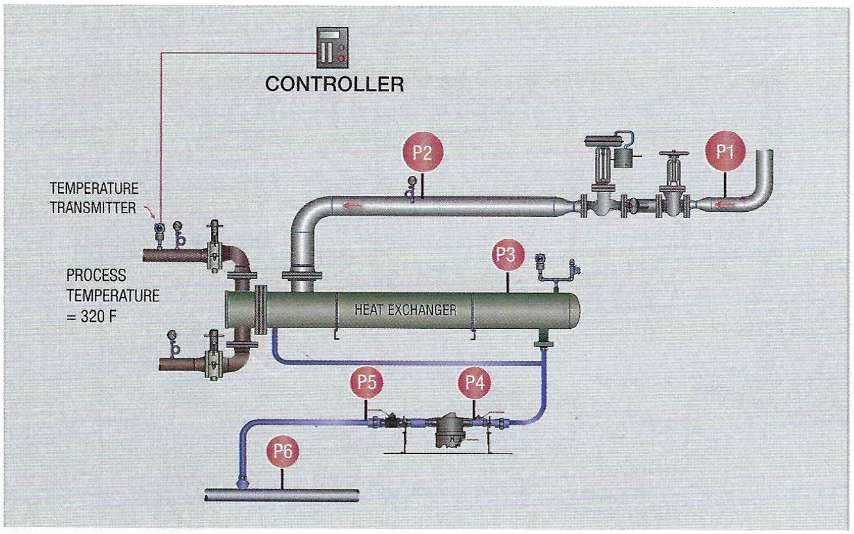


FIGURE 4. This diagram shows the high-temperature process outlet temperature at 320°F

return is between 30 and 45%. All pressurized condensate systems must be thoroughly evaluated before selecting the condensate return-line pressure.

To determine the cost savings of a standard condensate system versus a pressurized condensate system, it is important to review all operational parameters. Figures 2 and 3 both show the following elements of the steam and condensate system:

- Detail 1: Boiler operating steam pressure
- Detail 2: Fuel input into the boiler, Btus
- Detail 3: Steam flow output from the boiler, Btus
- Detail 4: Steam flow, Btus
- Detail 5: Condensate system operating pressure
- Detail 6: Percentage of condensate loss
- Detail 7: Condensate loss, lb/h
- Detail 8: Condensate flow to tank, lb/h
- Detail 9: Flash steam flowrate, lb/h
- Detail 10: Pumped condensate to deaerator
- Detail 11: Condensate Btus to deaerator
- Detail 12: Makeup water flowrate to deaerator
- Detail 13: Deaerator operating pressure
- Detail 14: Steam flow to deaerator for heating feedwater

Standard condensate-return system

A standard condensate system, where condensate is recovered into an atmospheric condensate tank system, will have inherent energy losses. These energy losses include the following:

- Condensate is allowed to cool to 212°F
- A large amount of flash steam is generated
- Flash steam is allowed to escape to the atmosphere
- Flash steam losses increase the quantity of makeup water required

All condensate and makeup water, which will become boiler feedwater, will require energy input to bring the energy level up to the saturated temperature of the boiler operating pressure. Reducing the differential energy levels (condensate and makeup water) to the boiler saturated energy level will increase the steam system's thermal cycle efficiency.

Steam process conditions

Table 1 shows values for an example steam application in a process plant. A steam requirement for the process application is rated at 24,000 lb/h (provides 24,000 lb/h of condensate). Condensate is drained from the steam process through a standard steam-trap station. The steam trap station discharges condensate into a vented condensate receiver system. When condensate is drained from the process at a

TABLE 1. DETAILS OF A TYPICAL STEAM APPLICATION IN A PROCESS PLANT

Application	Steam process
Steam pressure supplied to the process	150 psi (before a control valve) equivalent
Steam temperature	366°F
Steam pressure at the process	150 psi pressure
Steam flowrate	24,000 lb/h (minimum)
Operation	8,760 h/yr
Condensate line pressure	0 psig (vented to the atmosphere and mechanically pumped back to the boiler plant)
Cost of steam (per thousand pounds)	$5.24

TABLE 2. SUMMARY OF ENERGY LOSSES IN A TYPICAL VENTED CONDENSATE-RETURN SYSTEM

Summary of operational costs	
Boiler fuel cost (yearly)	$1,167,301
Flash steam losses	$162,043
Steam for deaerator operation	$64,657
Total energy loss cost	$226,700

The atmospheric system has a total energy loss of $226,700/yr as a result of flash steam loss, deaerator steam requirements to heat the low-temperature and makeup water, in addition to the cost of additional chemicals.

WHEN PRESSURIZED CONDENSATE RECOVERY IS NOT POSSIBLE: VENT CONDENSERS FOR FLASH-STEAM RECOVERY ON MODULATING STEAM SYSTEMS

The operational design of modulating steam systems requires the condensate to be recovered by a gravity (0 psig) condensate system, so pressurized condensate recovery is not an option. In these cases, a typical system will incorporate a condensate receiver that allows the flash steam to vent to the atmosphere. The venting of the flash steam ensures the condensate receiver is never pressurized. The use of vent condensers for flash-steam recovery in modulated steam systems is described below.

Flash-steam recovery in modulating steam conditions

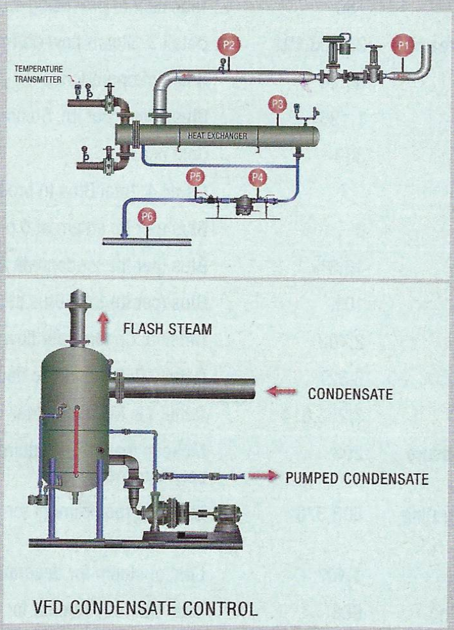
With today's energy pricing and the need to reduce emissions, a plant's steam/condensate systems cannot afford to vent flash steam to the atmosphere. To prevent the flash steam loss to the atmosphere, plants can install devices, such as flash-steam vent condensers in the flash-steam vent line.

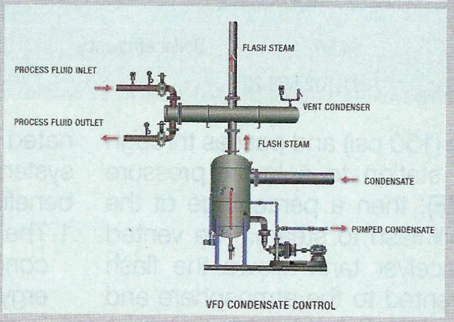
Depending on the installation costs, plants can usually recover the cost of a flash-steam vent condenser within ten operational months.

There are two main cost-saving benefits for a flash-steam vent condenser: it allows a plant to recover the flash-steam energy, which can be used to heat a fluid for a process; and it reduces emissions by recovering the flash-steam energy. The boilers will not have to produce as much steam, thereby lowering emissions from the boiler operation.

When condensate and flash steam (two-phase flow) is discharged from a modulating steam/condensate process, it means the process application has a steam-control valve that modulates the steam to the process. The control valve can operate from 0% (full closed) to 100% (full open) and anywhere in between (Figure 5, top diagram) The steam pressure after the steam-control valve and before the process heat exchanger can vary (P2 reading) depending on process conditions. The pressure at P2 can range from the full line pressure being delivered to the steam control valve (P1) all the way down to zero pressure.

In this case, the flash steam cannot be recovered in a pressurized flash tank, or a high-pressure condensate-return system. Instead, the condensate flow from the process has to be discharged into a condensate line with pressure at 0 psig (P5) and delivered to a vented condensate receiver tank that is operating at or close to zero pressure.





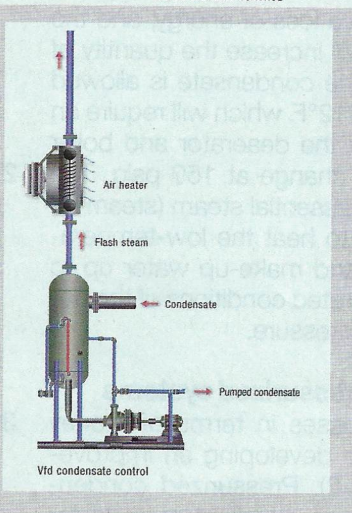


FIGURE 5. A modulated steam-condensate process has a control valve (top) and a receiver tank vented to the atmosphere (upper middle). A flash-steam condenser (lower middle) can be used to heat air (bottom)

Flash-steam vent condenser operation

The upper middle diagram of Figure 5 depicts the typical condensate-receiver-tank arrangement, where the flash steam is allowed to be vented to the atmosphere. The energy loss and emission factors today permit this loss in the system.

A flash-steam vent condenser is incorporated into the system to recover the flash steam by using an external heat exchanger (condenser), as shown in the lower middle diagram. The vent condenser (heat exchanger) will consume the flash steam by heating air, water or some other process fluids. The vent condenser is designed for the application to ensure proper operation. A standard shell-and-tube heat exchanger functions in this application. The process fluid consumes the flash steam and allows the condensate to drain back into the condensate tank. Therefore, the flash steam is consumed and the condensate is recovered. In the case of a modulating-steam process condition, the process steam system should use the lowest steam pressure, therefore producing the least amount of flash steam possible.

The shell-and-tube heat exchanger designed for a condenser applications is the typical heat-transfer design used in flash steam condensers. Other heat exchanger units that can be used are spiral, plate-and-frame, and fin-coil units (heating units for air or process gases). Materials and installation considerations will vary depending on the application. All vented condensers are engineered for the application.

Fluid for the condenser. To condense the flash steam, the condenser requires a fluid temperature of less than 160°F (general consideration). The fluid can be a liquid or vapor, depending on the application. If there is an insufficient quantity of cooling fluid for the flash steam in a liquid cooling system, then the plant should consider using a flash-steam bypass or some other method to prevent the cooling liquid from absorbing too much energy and changing from a liquid to a vapor and causing water hammer.

Heating air is another application for a vent condenser. The bottom diagram in Figure 5 shows the air passed over a tube fin configuration with the flash steam inside the tube. The lower temperature air condenses the flash steam, and the condensate is allowed to drain back into the condensate tank.

Pressure on the condensate tank. When choosing a vent condenser, the plant must select a design that does not create significant pressure for the condensate receiver tank. The flash steam vent line from the condensate tank to the condensing unit velocities should not exceed 900 ft/min.

Required information. For successful vent-condenser purchase, installation and operation, operators should know the following parameters:

1. Condensate flowrate (maximum, minimum and normal)
2. Flash steam flowrate (maximum, minimum and normal)
3. Cooling fluid flowrate (maximum, minimum and normal)

Before installing a condensate tank with a vent condenser, first locate and document the different flash-steam vent lines that are discharging to the atmosphere. Next, determine the flash steam lost to the atmosphere. Then calculate the projected energy loss and emissions reductions and determine what types of cooling fluids are available ❑

TABLE 3. STANDARD VENTED CONDENSATE SYSTEM OPERATING AT ATMOSPHERIC CONDITIONS			
EXAMPLE 1: OPERATION AT ATMOSPHERIC CONDITIONS			
Detail 1: Boiler operating at steam pressure (psig)	150	Total cost of producing steam at flowrate	$1,102,658.20
Detail 2: Fuel input to boiler: Btus required to produce steam	28,703,191	Detail 3: Steam flow (lb/h)	24,000
Cost of steam per thousand lb	$5.24	Hours of operation/yr	8,760
Btus (per lb): Total at 150 psig	1,196	Btus latent (per lb): Steam energy at 150 psig	857
Btus sensible (per lb): Condensate at 150 psig	339	Cost per Btu	$0.00000439
		Detail 4: Total Btus to process	28,703,191
Detail 5: Condensate line operating pressure	0	Btus (per lb) steam at 0 psig	970
Percentage of flash steam	16.3%	Btus (per lb) condensate at 0 psig	180
Detail 6: Percentage of condensate loss	10%	Btus (per lb) total Btus at 0 psig	1,150
Detail 7: Condensate loss (lb/h)	2,400	Detail 8: Condensate flow to condensate tank	21,600
Detail 9: Flash steam flowrate (lb/h)	3,527	Detail 10: Condensate flow rate (lb/h)	18,073
Detail 11: Condensate Btus to deaerator	3,255,814	Detail 12: Makeup water flow rate (lb/h)	5,927
Detail 13: Sensible energy in deaerator at operating pressure	208	Makeup water Btu requirement to achieve deaerator sensible energy level	877,191
Detail 15: Btus to increase condensate to deaerator operating pressure	503,378	Total Btu requirement for deaerator	1,380,568
Steam flow to deaerator	1,407	Cost of steam for deaerator	$64,657.45
Btus in the boiler operation to produce steam at operating pressure	988	Total Btu requirement for boiler fuel per year	207,710,033,609
Cost of fuel per decatherm	$4.30	Boiler efficiency	81%
Yearly boiler operating cost	$1,102,658.20		

given pressure (150 psi) and passes through a steam trap station to a lower pressure (0 psi at 212°F), then a percentage of the condensate will flash to steam. The vented condensate receiver tank allows the flash steam to be vented to the atmosphere and ultimately leads to a loss of energy, and the flash steam loss will increase the quantity of make-up water. The condensate is allowed to be reduced to 212°F, which will require an influx of energy at the deaerator and boiler to achieve phase change at 150 psig. The deaerator will use essential steam (steam off the main header) to heat the low-temperature condensate and make-up water up to the operating saturated conditions of the deaerator operating pressure.

Implementing pressurized systems

Quantifying the losses in terms of money is the first step to developing an improvement plan (Table 2). Pressurized condensate systems are an excellent method for reducing these losses by 75% or more, depending on the existing operating conditions of the steam and condensate system. Understanding the dynamics of the current system as well as the dynamics of implementing a pressurized system will lead to successful implementation.

In a pressurized condensate system, typical losses will be greatly reduced or eliminated by the dynamics of the pressurized system. Pressurized systems have several benefits, as follows:

1. The pressurized system will increase the condensate temperature or sensible energy level. The condensate temperature in the pressurized system is now at the temperature of the deaerator or higher. Therefore, the deaerator does not require essential steam (energy) to heat the condensate, saving essential steam.
2. Another benefit to pressurized condensate is that condensate has not been exposed to the atmosphere and has not absorbed any noncondensable gases. The condensate does not have to go through the deaerator process. In several types of installations, the condensate can be delivered directly into the boiler.
3. It will reduce makeup water usage. With the flash steam being recovered in a pressurized system, no flash steam is lost. Thus, the only need for makeup water is to replenish the deaerator's noncondensable vent losses. The makeup costs are negligible in a pressurized system. Reducing makeup water also will reduce boiler blowdown, thus reducing another energy loss in the boiler operation.
4. It will reduce the flash steam quantity that is generated, which will reduce the condensate pipe sizing requirements and re-

Before changing an industrial steam system into a pressurized condensate system, the first step is to ensure that the steam/condensate system and the steam processes will be able to operate under the new conditions

duce the condensate losses (1 lb of flash steam is 1 lb of condensate).

5. It will reduce the energy differential (condensate versus boiler operating condition). This will reduce the amount of fuel input into the boiler to raise the feedwater to the appropriate phase-change temperature.
6. It will enable the plant to use the flash steam from a pressurized system.

Before changing an industrial steam system into a pressurized condensate system, the first step is to ensure that the steam/condensate system and the steam processes will be able to operate under the new conditions. Condensate and flash steam (two-phase flow) discharging from a non-modulating or elevated-temperature process can operate in a pressurized condensate system.

A non-modulating steam condition refers to a steam system process where no control valve modulates the steam flow into the process to maintain a desired temperature or pressure. A process steam system that lacks a modulating steam-control scheme for the process provides a constant steam pressure to the process. Therefore, if the condensate recovery system has a controlled pressure, there is a constant pressure differential across the steam trap stations or condensate discharge control valve.

In a high-temperature process where the process temperature is higher than the pressurized condensate system, there will be differential pressure across the drain devices, such as the steam trap station or condensate discharge control valve. For example, as shown in Figure 4, if the process temperature

TABLE 4. SAME STEAM SYSTEM AS SHOWN IN TABLE 3, BUT OPERATING WITH A PRESSURIZED CONDENSATE SYSTEM: STEAM PRODUCTION COST IS REDUCED			
EXAMPLE 1: OPERATION WITH PRESSURIZED CONDENSATE SYSTEM			
Detail 1: Boiler operating at steam pressure (psig)	150	Total cost of producing steam at flowrate	$940,600.59
Detail 2: Fuel input to boiler: Btus required to produce steam	28,703,191	Detail 3: Steam flow (lb/h)	24,000
Cost of steam per thousand pounds	$4.81	Hours of operation per year	8,760
Btus (per lb): Total at 150 psig	1,196	Btus latent (per lb): Steam energy at 150 psig	857
Btus sensible (per lb): Condensate at 150 psig	339	Cost per Btu	$0.00000402
Steam flow from the boiler (deaerator and process)		Detail 4: Total Btus to process	28,703,191
Detail 5: Condensate line operating pressure	50	Btus (per lb) steam at 50 psig	912
Percentage of flash steam	7.8%	Btus (per lb) condensate at 50 psig	267
Detail 6: Percentage of condensate loss	10%	Btus (per lb) total Btus at 50 psig	1,179
Detail 7: Condensate loss (lb/h)	2,400	Detail 8: Condensate flow to condensate tank	21,600
Detail 9: Flash steam flowrate (lb/h)	1,687	Detail 10: Condensate flowrate (lb/h)	19,913
Detail 11: Condensate Btus to deaerator	5,323,644	Detail 12: Makeup water flowrate (lb/h)	4,087
Detail 13: Sensible energy in deaerator at operating pressure	267	Makeup water Btu requirement to achieve deaerator sensible energy level	604,841
Detail 15: Btus to increase condensate to deaerator operating pressure	0	Total Btu requirement for deaerator	604,841
Steam flow to deaerator	656	Cost of steam for deaerator	$0.00
Btus in the boiler operation to produce steam at operating pressure	929	Total Btu requirement for boiler fuel per year	181,579,443,953
Cost of fuel per decatherm	$4.30	Boiler efficiency	83.0%
Yearly boiler operating cost	$940,600.59		

is at 320°F, steam pressure to the process has to be higher than 75 psig. With steam pressure of 75 psig to the heat exchanger, P4 (in the example) will have a pressure of 70 psig or greater, and the condensate line pressure could operate at 30 psig.

Here are some examples of steam systems and processes that may be candidates for pressurized condensate return setups:

- Steam tracing
- Process ovens
- Process heating systems
- Steam line condensate removal steam trap stations
- Paper machines
- Rubber processes
- Press operations
- Reboilers
- Corrugators

Energy savings

Using the same example of an atmospheric condensate system and implementing a pressurized condensate system (increase the condensate pressure to 50 psig), the optimization results are as follows:

- Boiler fuel cost (yearly): $1,167,301 versus $940,601
- Flash steam losses: $162,043 versus $0.00
- Steam for deaerator operation: $64,657 versus $0.00

Implementation of a condensate system that is operating at 50 psig instead of 0 psig resulted in a savings of $226,700.

The new pressurized condensate system now operates as follows:

1. Condensate line now operates at 50 psig
2. Flash is operating at 50 psig with the flash steam going to the deaerator
3. Deaerator is operating at 50 psig
4. Condensate is directed to the storage side of the deaerator
5. The steam system is balanced and the steam-system thermal cycle efficiency is increased

Tables 3 and 4 provide details of the steam production costs and savings for pressurized condensate-return system (Table 4) versus the atmospherically vented system (Table 3).

Components required

Several components are required to implement a pressurized condensate system.

Pressure control system. A pressure control system controls the condensate pressure to a predetermined set point. The condensate pressure must be managed. One method is to use a backpressure control valve with a controller. An easier method is to use a flash tank discharging into the steam system that has a controlled steam pressure.

Flash tank or deaerator. Installing a flash tank system that delivers flash steam to a controlled steam system is an excellent way to operate the pressurized condensate system. One user of flash steam is the deaerator, which normally operates below 15 psig. Most steam systems have several operating steam pressures, so the flash steam can accept the cascaded steam.

Another method uses a thermocompressor to raise the flash steam's pressure and reintroduce it into the steam processes or deliver the steam into a plant steam-system, pressure-distribution system. Installing a new deaerator or using the current deaerator, which can operate at a higher pressure, is a third method of receiving the pressurized condensate. The deaerator is operated at a predetermined operating pressure that is the same as the pressure in the pressurized condensate system. The condensate temperature is already elevated, and there will be a reduced quantity of flash steam, which is normally consumed by heating the makeup water.

Pressurized condensate. Pressurized condensate does not have to be deaerated and can be pumped directly back into the boiler. Since the condensate has not been exposed to the atmosphere, it has not had the opportunity to take up any noncondensable gases.

Condensate-line sizing. Condensate-line sizing always needs to be checked to ensure that it has the proper design to operate in a pressurized operation. Typically, the condensate-line size required is reduced by the lower quantity of flash steam, which normally requires more area in atmospheric or very low-operating-pressure condensate lines. Velocities are also reduced due to the lower flash-steam quantity, thus eliminating the normal water-hammer issues with high condensate-line velocities.

Getting started

There are many reasons to implement a pressurized condensate system, if it is possible to do so, and little to no downside. The first step in moving toward this technology is for plant personnel or an outside firm experienced in pressurized condensate systems to conduct a steam and condensate assessment. The assessment will provide the knowledge of the benefits of pressurized condensate system and, more importantly, the cost of implementation. ■

Edited by Scott Jenkins

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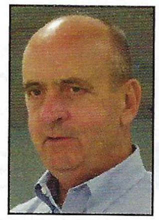

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