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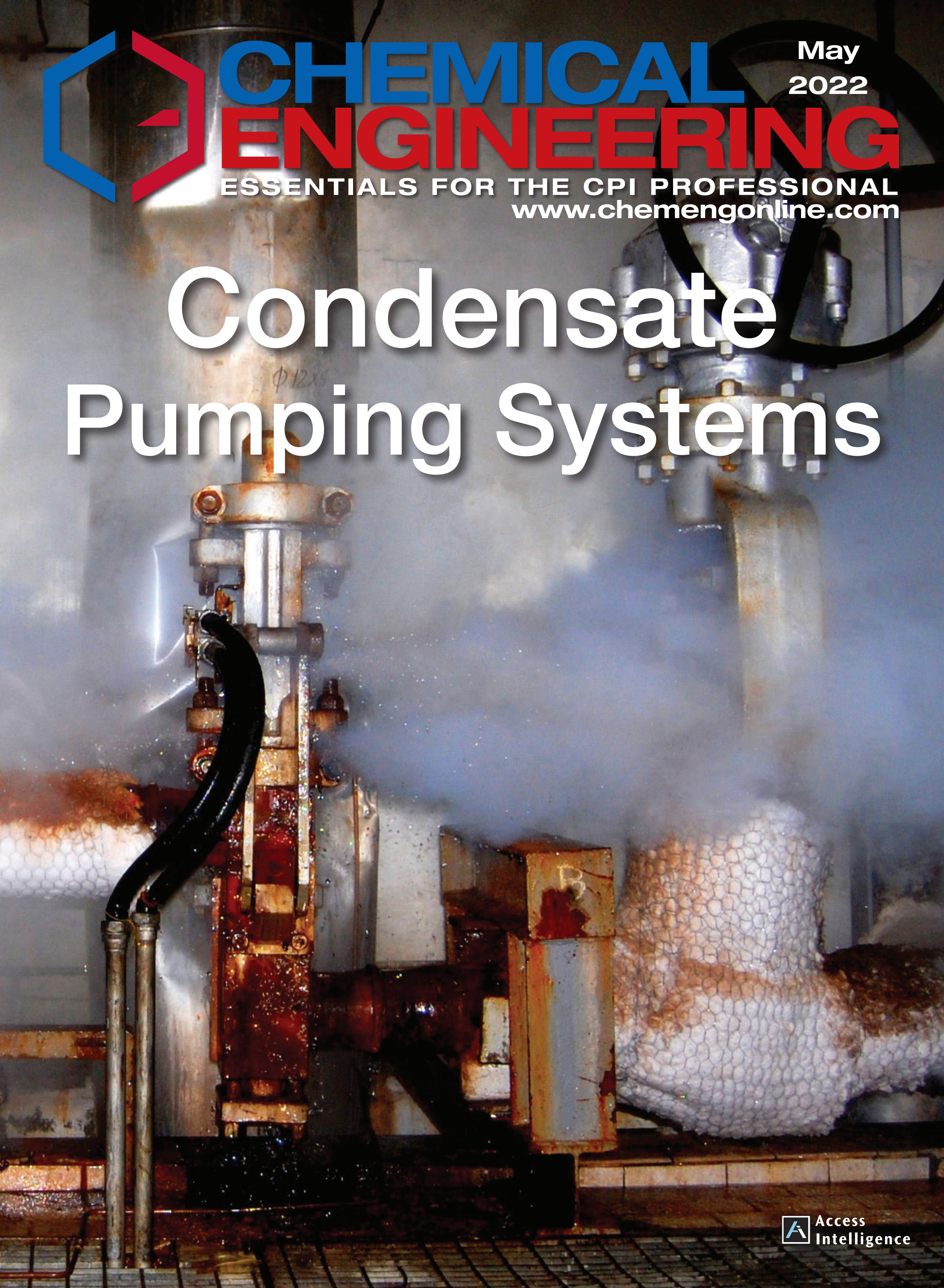
Condensate Pumping Systems



Access Intelligence

Vent Away Condensate Pump Frustrations In A Flash

The guidance provided here can help to mitigate problems occurring in pumping systems used for condensate recovery

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Condensate recovery is crucial to energy reduction and water conservation in a steam-using plant. It reduces effluent discharge and treatment requirements, as well as the chemicals and heating costs associated with preparing raw makeup water. Furthermore, having a greater percentage of high-quality condensate for boiler feed helps to reduce corrosion in the piping system [*1*, *2*]. Even with relatively simple condensate pumping systems like the one shown in Figure 1, condensate recovery can sometimes create complex challenges for plants.

A problematic pumping station, such as the one shown in Figure 2, is a result that may be all too common in some steam systems and can occur due to leaking seals or pump cavitation, ultimately causing condensate to overflow. Are all such instances due to normal wear, or have some been caused by poor design or insufficient system maintenance? Experience demonstrates that many comparable reliability issues can be avoided with improved design and system maintenance practices, but first it is necessary to identify probable causes and implement suitable mitigation action, preferably during the design stage, when possible.

FIGURE 2. This pump station exhibits severe spillage, creating a potential safety hazard and source of problems

IN BRIEF

How does cavitation occur?

Cavitation is normally a key factor, and engineers should first understand what causes this phenomenon in order to design around its potential occurrence [*3*, *4*].

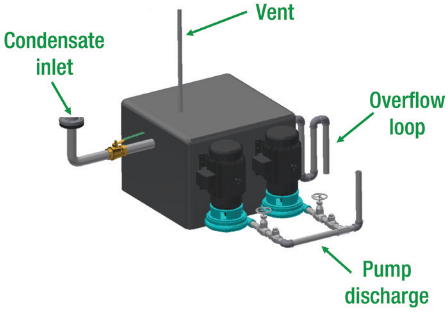

FIGURE 1. A simple condensate pump arrangement includes an inlet, receiver, vent, pumps and overflow loop

Figure 3 shows a centrifugal condensate pump that is experiencing cavitation issues. This situation happens when flash steam — formed from the re-vaporization of high-temperature condensate by the suction-side pressure drop — rapidly pushes away liquid volume in the impeller. Condensate is further accelerated by pump rotation, and this combination leads to impeller erosion. As a result, the vapor pockets, which are compressed by liquid flowing through the prop troughs, quickly collapse and cause an onrush of condensate into the void. This can cause more damage to the impeller and pump seals. Cavitation is typically not a singular event, but rather is ongoing throughout the causal conditions, resulting in capacity reduction or catastrophic failure of the condensate pump itself, or resultant spillage through leaking seals or the overflow.

This leads many engineers to ask how cavitation can be avoided. An understanding of both net positive suction head available ($NPSH_A$) and net positive suction head required ($NPSH_R$) is needed.

$NPSH_A$ is the resultant head at the eye (central point) of a pump's impeller. It is a function of all of the fluid variables acting on the inlet side of the pump. Those include positive head factors, such as pressure created by the inlet height of the condensate

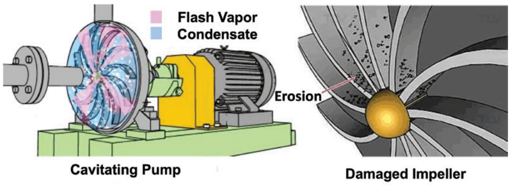

FIGURE 3. As the impeller spins, dynamic increase causes static pressure drop, which begins vaporizing the high-temperature condensate

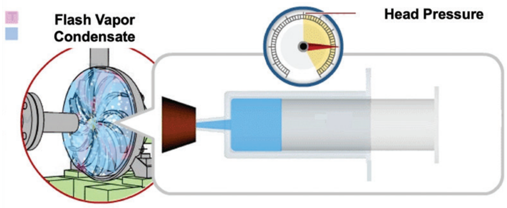

FIGURE 4. High head pressure ($NPSH_A$) mitigates condensate vaporization, maintaining liquid for pumping

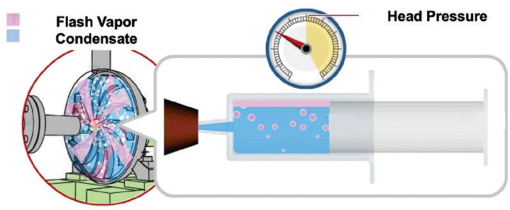

FIGURE 5. When $NPSH_A$ decreases due to high rotation, some liquid flashes into steam, thereby causing cavitation

column over the impeller and the surface pressure acting over that incoming condensate, as well as negative head factors like the vapor pressure of the condensate (how easily the condensate can vaporize) and inlet piping friction loss. Sufficient $NPSH_A$ is important to keep the condensate from vaporizing as it experiences a static pressure drop when the dynamics increase from impeller rotation (Figure 4). Although condensate may be in liquid form entering the impeller, portions can flash into steam vapor, causing cavitation when the $NPSH_A$ head pressure is reduced (Figure 5).

Pump selection

Pump manufacturers normally provide the specific $NPSH_R$ for reliable performance, which requires that the $NPSH_A$ always meets or exceeds the $NPSH_R$ to prevent cavitation [5]. $NPSH_A$ calculations can be relatively simple to perform, and one of the main values needed is the vapor pressure at the expected temperature of the condensate being discharged, as shown in Table 1.

Consider a hypothetical new installation that is designed to pump 210ºF condensate from an atmospheric receiver elevated 3 ft above the impeller (Figure 6). The temperature corresponds to a vapor pressure of 14.14 psia in Table 1, and assuming a minimal pressure drop of 0.2 psi for the inlet piping, the $NPSH_A$ can be estimated as 3.83 ft. With $NPSH_A$ known, it is just necessary to check the pump curve to determine if the $NPSH_A$ is suitable for the $NPSH_R$ of the selected model.

Suppose that the proposed pump has performance curves as shown in Figure 7. The pump is rated for 37.5 gal/min at 30 psi total discharge pressure (TDP). Since the TDP curve ends at 25 psi, if the pump resistance is less than 25 psi, it may burn out the motor. It can be seen at point D that this pump has an $NPSH_R$ of 9.5 ft, which is significantly higher than the $NPSH_A$ of 3.83 ft. Although the pump may meet the discharge rate and pressure, it can be expected to cavitate severely due to insufficient head to prevent the entering condensate from flashing as the impeller rotates. Typically, high-$NPSH_R$ pumps tend to operate at high speed (around 3,500 rpm), and lowering the rotation dynamics by using low-speed models (for instance, 1,750 rpm) can reduce the drop in static pressure. Such lower-speed pumps are commonly referred to as "low NPSH" models.

There can be several caveats when selecting low-rpm pumps to avoid cavitation. One is that these models, when selected for a certain TDP, tend to be more sensitive to changes in backpressure or total dynamic head (TDH), and another is that their cost can be substantially higher.

TABLE 1. ABSOLUTE VAPOR PRESSURE OF WATER AT VARIOUS TEMPERATURES [6]

Temperature, ºF	Pressure, psia
180	7.52
190	9.35
195	10.40
200	11.54
205	12.78
210	14.14
212	14.71
215	15.61
220	17.20
225	18.93

Given those potential concerns, it can be useful to consider alternative methods to prevent cavitation using lower-cost, high-rpm models or non-electric secondary pressure drainers instead, which are explained later in this article.

Consider a hypothetical electric pump with a curve similar to Figure 7 with insufficient $NPSH_A$. It is clear that the model shown in the pump curves will not be appropriate (since $NPSH_A$ is less than $NPSH_R$), so how can this be improved? When the $NPSH_A$ is insufficient, it is necessary to increase its value to use the high-rpm pump unit, and there are two possible methods to achieve this objective. The first is to increase the fill head by elevating the receiver, and this is often possible when the pump is located at a much lower level than the source of the condensate. The second option is to reduce the condensate temperature.

The example shown in Figure 8 illustrates that just elevating the re-

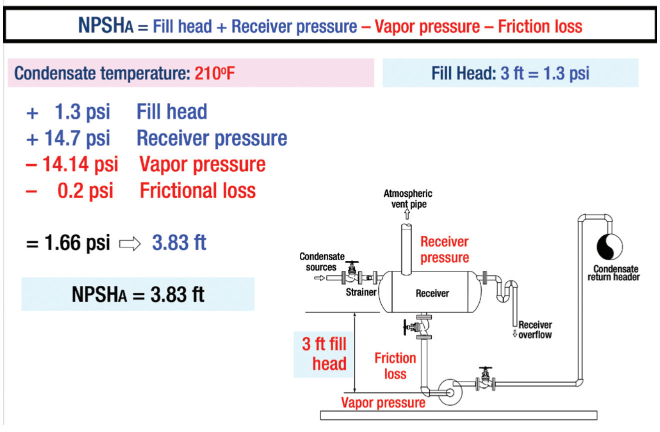

FIGURE 6. The $NPSH_A$ of 3.83 ft is calculated for 210ºF condensate with an atmospheric receiver and 3-ft filling height over the center point of the impeller

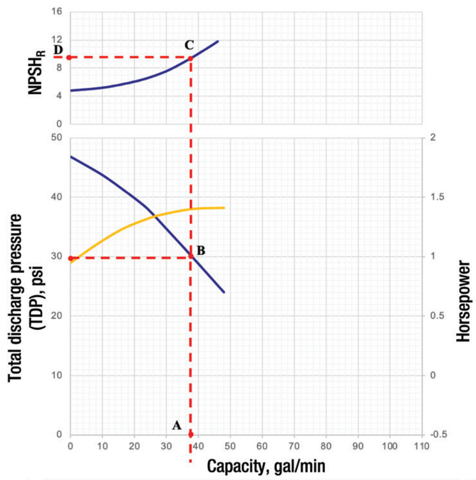

FIGURE 7. The NPSH$_R$ for this pump is 9.5 ft (point D)

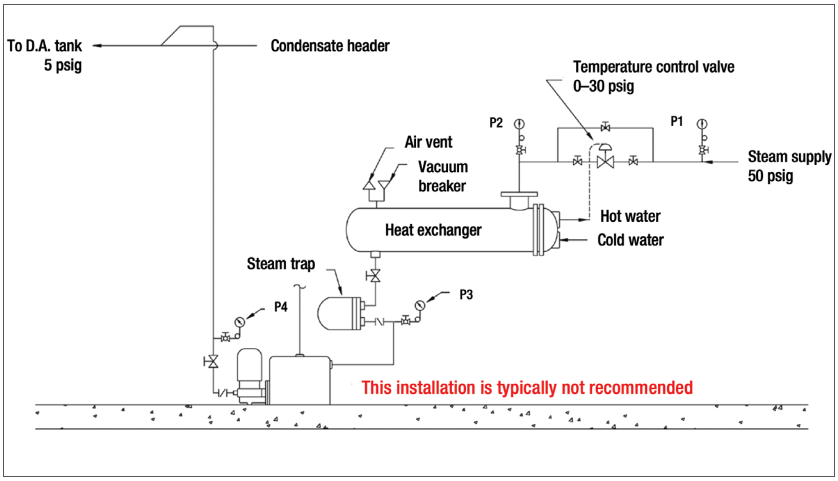

FIGURE 9. This particular design configuration is not recommended because its lack of a flash receiver can have a negative impact

TABLE 2. THE IMPACT OF DECREASING CONDENSATE TEMPERATURE

Condensate temperature reduced to 200°F	
New vapor pressure is 11.54 psia	
Calculation	
+1.3 psi	Fill head
+14.7 psi	Receiver pressure
–11.54 psi	Vapor pressure
–0.2 psi	Frictional loss
= 4.26 psi Corresponds to 9.83 ft NPSH$_A$	

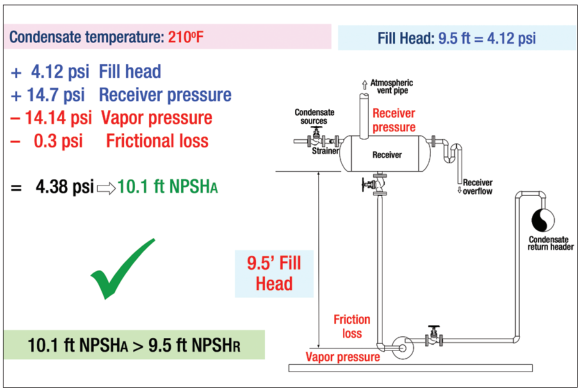

FIGURE 8. Increasing receiver height increases NPSH$_A$

ceiver by 6.5 ft — from 3 ft to 9.5 ft — increases NPSH$_A$ to 10.1 ft, which is more than sufficient for the NPSH$_R$ of 9.5 ft. Alternatively, keeping the receiver elevation at 3 ft, but reducing the condensate temperature by 10°F (from 210 to 200°F) increases NPSH$_A$ to an acceptable value of 9.83 ft, as outlined in Table 2.

Vent problems away

An example of a common application design is shown in Figure 9, with a heat exchanger discharging condensate that flashes when exiting the steam trap into a floor-mounted, electric condensate pump. The drawing is provided with the notice that this installation is typically not recommended. Since the receiver is clearly vented, why is this particular example not recommended? What is the potential cause for this pump to cavitate? This installation is similar to the pump shown in Figure 2 that experienced significant maintenance issues causing spillage. Figure 10 provides clarification about some of the issues with this layout, namely the role of the 1-in. pipe at the top of the installation. Other considerations for Figure 10 include the following:

- The small receiver collects condensate at the pump inlet
- The small vent equalizes internal pressure as water level rises and falls
- Condensate pressure and temperature are increased if flash is not vented before
- An increased temperature results in lower NPSH$_A$, potential cavitation, motor overheating and damage to pump seals

There can be a misconception about the vent found on condensate pump tanks like this floor-mounted example. That vent is sometimes considered by designers to be a flash steam vent, but in actuality, its purpose is to allow balancing of the tank to the atmosphere so that condensate can freely enter and replace the vapor space within the receiver. Commonly, the floor receiver's vent is too small to handle flash steam velocity appropriately — ideally to less than or equal to 50 ft/s, or at a maximum, 70 ft/s. Note that this selection depends on actual site procedures and recommendations from a knowledgeable engineer [*7*, *8*]. A correctly sized vessel should be added to the system to vent the flash steam prior to entry into the condensate pump receiver (Figure 11).

As can be seen in Figure 9, there is no separate flash vessel, and the hot condensate is discharged directly into the floor-mounted receiver. There are several issues with this approach — the first being elevated condensate temperatures and the second relates to insufficient filling

TABLE 3. VENT SIZE RESULTS FROM SELECTED ELECTRIC PUMP MANUFACTURERS

Pump manufacturer	Vent size, in.	Velocity, ft/s	Pressure drop over 12-ft pipe length, psi	Steam temperature, °F
1	1.25	715	4.8	227
2	1.5	526	2.1	219
3	2	319	0.6	214

head. This can cause pump damage and spillage of hot condensate to the grade, which creates potential for burns, slippage and freezing (if outdoors).

Consider the setup shown in Figure 12 for a pump selected to discharge 7,500 lb/h actual load from condensate formed with 100 psig steam. The flash steam amount generated can be as high as 997 lb/h. For this application, even a 4-in. vent would be too small and shows potential exit velocity of 84 ft/s. A 5-in. vent with 53 ft/s velocity might be acceptable for some engineers, but a 5-in pipe is an unusual size. As a result, a 6-in. vent pipe with 37 ft/s velocity would most likely be recommended.

Now, we can reference Table 3, which shows the provided vent size on floor receivers from three different condensate pump manufacturers, along with the estimated velocities for this amount of flash steam — note that the receiver vent sizes from all three pump manufacturers are too small to handle flash. Using the pump's floor receiver as a flash vessel could result in vent velocity as high as 715 ft/s, which is more than 10 times the recommended maximum exit speed. In addition, a pressure drop as high as 4.8 psi is estimated over a hypothetical 12-ft equivalent exit pipe length. The pressure drop builds up pressure in the receiver, and that can also have a detrimental effect on the $NPSH_A$.

Consider the example shown in Figure 13 with an elevated pressure of 2.5 psig, which corresponds to a 220ºF condensate temperature. Since the receiver pressure is no longer atmospheric, it is possible that the temperature can remain elevated. Notice how the $NPSH_A$ has decreased to 2.54 ft, even lower than the original 3.83 ft previously reviewed in Figure 6. Table 3 also shows that a vent pressure drop of just 2.1 psi can pressurize the receiver to maintain nearly the same temperature at 219ºF. This provides evidence of the need for a separate, properly sized flash vessel and vent.

Leaking traps, open bypass valves and blow-through of live steam through outlet control valves can further elevate pressure and temperature, severely impacting $NPSH_A$. Adding batch loads or new equipment not only requires greater pump-discharge rates, but also increases the flash steam amount that must be vented from the system. All of these factors can affect the pressure drop through a vent that is undersized for the additional load (as seen in Figure 13). Mitigation strategies to limit $NPSH_A$ reduction are described below:

- Maintain a healthy steam-trap population
- Close open bypasses
- Mitigate blowthrough on outlet control valves
- Check flash-receiver suitability for added condensate loads
- Install upstream flash tank or knockout pot
    - Flash steam velocity should be ≤ 10 ft/s
    - Flash vent should be ≤ 70 ft/s

Head off problems

Consider that the original problematic pump with an undersized vent could pressurize to 2.5 psig. Notice

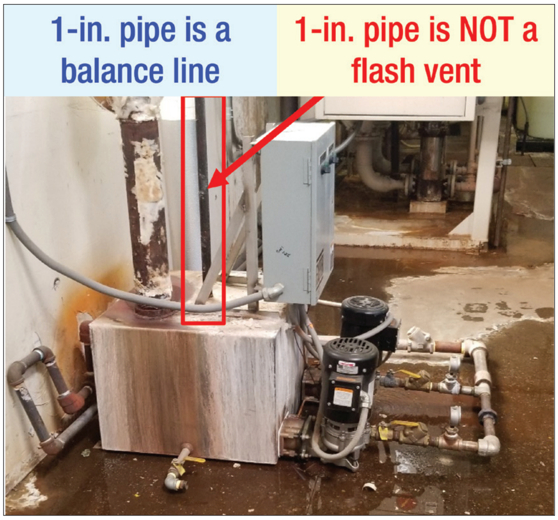

FIGURE 10. The 1-in. vent line is for balancing vapor to allow liquid entry into the receiver. It is generally too small to be used as a primary flash steam vent

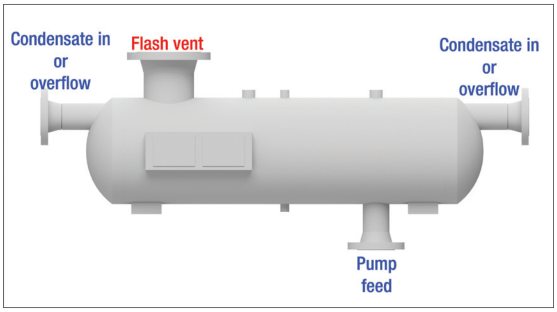

FIGURE 11. Implementation of a properly designed flash receiver is key to reliable condensate pump operation

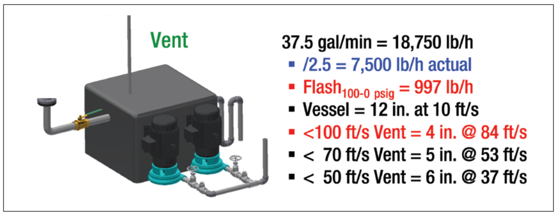

FIGURE 12. An appropriate flash-vent line size for the actual flowrate would be 5 or 6 in. [8]

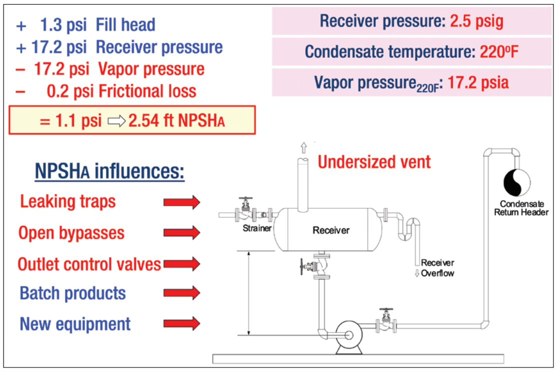

FIGURE 13. These five factors can decrease $NPSH_A$

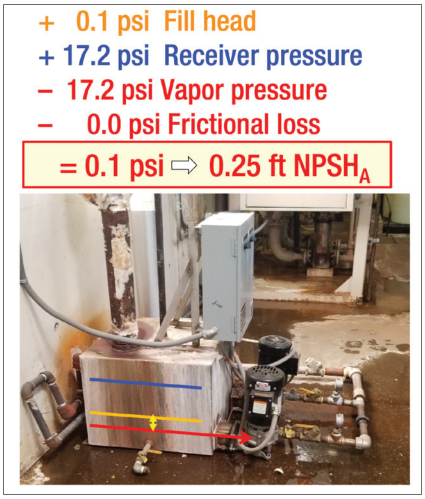

FIGURE 14. There is virtually no fill head on pumps with floor-mounted receivers

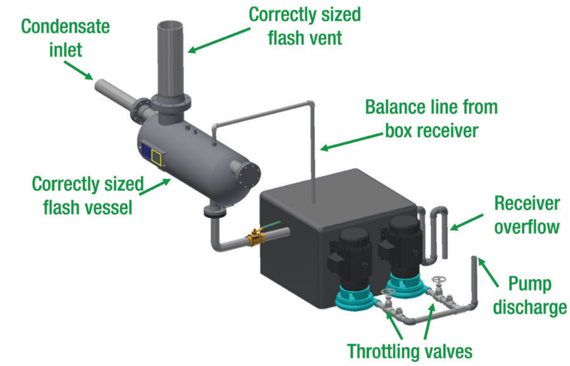

FIGURE 15. A flash vessel reduces condensate temperature and mitigates pressure buildup in the pump receiver

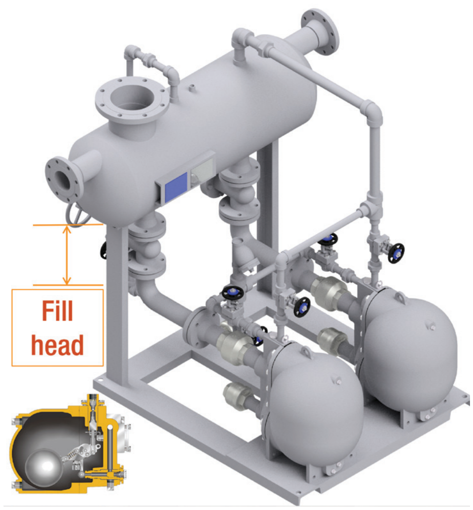

FIGURE 16. Non-electric pumps do not cavitate, but still require flash vessels for proper operation

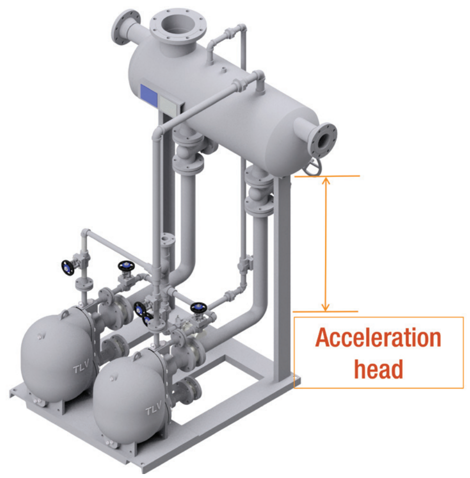

FIGURE 17. Elevating the receiver of non-electric pumps can increase capacity by filling the pump body quickly

the red, orange and blue lines displayed on the receiver in Figure 14. The blue line represents a high-level trigger point that alerts the pumps to operate, and the orange line represents a low-level trigger to stop pumping and thereby prevent losing the water seal over the pumps.

Then, note the distance between the orange and red lines. This low-level water height is the vertical head used to calculate $NPSH_A$. As such, floor pumps without a flash tank can pressurize and have a low $NPSH_A$.

There is so little fill head available (approximately 0.1 psi) to provide ample $NPSH_A$ to the pumps. Is it any wonder why these pumps experience issues whenever the condensate temperature is near-to-steam? This pump needs a vapor pressure of 10.68 psia from a non-flashing condensate temperature of 196ºF to avoid cavitation, but unless the load is extremely low (for cooling), it is unlikely, due to the undersized vent line.

Reliable system design requires key components, proper elevation, minimal leaked live steam infiltration, good flashing and effective venting, as seen in Figure 15. To mitigate cavitation, condensate pumps should first have the flash steam effectively handled in a properly sized flash vessel, then receive condensate from an appropriate height to provide ample $NPSH_A$.

Non-electric options

Non-electric secondary pressure drainers can be used in lieu of electric pumps. Figure 16 shows an example of a Type 1 secondary pressure drainer (SPD-1) that can provide effective condensate recovery without the use of electrical components [*9*,*10*,*11*]. They are mechanical pumps that use pressurized steam or air to discharge a certain displacement volume of condensate into the return header.

With no impellers to rotate and cause flashing, it is not possible for SPD-1 devices to cavitate during pump operation. Even so, for proper system performance, they do require a separate receiver as part of their installation to enable flashing of high-temperature condensate prior to pump entry. When properly designed, SPDs can provide a significant reliability improvement over electric pumping systems.

Although cavitation is not a concern with an SPD-1 system, there can be a benefit to installing its flash receiver at a higher elevation. This accelerates condensate flow into the pump and increases its capacity compared to the same unit if its tank were situated at a lower level, as seen in Figure 17.

The sizing and overall design of the flash tank/receiver, flash vent and balance line are also key to support reliable SPD-1 operation, so it is recommended to consult with the respective manufacturer of electric or non-electric pumps for design recommendations relative to their systems and in accordance with applicable recognized standards.

Turn flash into cash

There is a great deal of readily available information relating to the design of pressurized flash-recovery systems. These provide a great benefit, because often as much as 10% of flash steam can be recovered and used for low-pressure purposes. One key dependency for flash recovery to be valuable is a definite need for use of this supplemental steam elsewhere so that it reduces boiler load. If the boiler demand is not reduced, then the alleged savings do not materialize.

Another key dependency for implementation is to understand whether the elevated backpressure limits the process equipment performance or increases maintenance costs. If equipment performance or reliability are hindered, then those issues may preclude its use.

These questions can be reviewed by knowledgeable engineers who can perform appropriate design and steam-balance analyses to confirm if the anticipated benefits can be achieved.

However, even if it is not possible to install a pressurized flash-recovery system to use flash steam elsewhere, there is still the possibility to recover valuable portions of the flash that would otherwise be wasted to atmosphere.

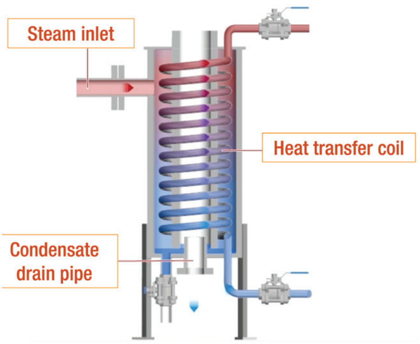

FIGURE 18. A vent condenser captures valuable treated water and some heat that would otherwise be vented out

The equipment to recover the treated water and much of the energy is a vent condenser (Figure 18). These condensers use a cool water stream, such as boiler makeup or process water (if available), to pull energy from the flash steam while condensing it to a recoverable high-temperature liquid. The result can reduce boiler load, capture valuable treated condensate, and also preheat a water stream where useful to elevate its temperature.

Many problems with condensate systems are caused by not handling the flash steam properly through a separate flash vessel, and the vent steam from that vessel contains value that should be recovered where economically feasible. Ref. 4 provides additional information regarding electric and non-electric condensate-pumping systems. ■

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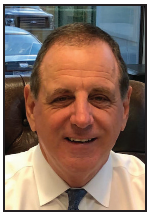

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