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SPECIAL SECTION:

WASTE PLASTICS RECYCLING

Optimize Reboiler Performance via Effective Condensate Drainage

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Reboilers, particularly those that use inlet steam control (ISC), can suffer from control and maintenance issues related to condensate backup. Observe these key design considerations to help debottleneck underperforming reboilers.

Reboilers that use an inlet steam control (ISC) valve arrangement can significantly improve the economics and control of certain distillation tower installations, particularly those with short time constants or broad load variability. ISC valve systems are intended to expose the full surface area of a reboiler to steam for effective heat transfer, which enables operation at lower steam pressure. Operation at lower pressure can reduce fouling, as well as corrosion that occurs when tube bundles are flooded. ISC valves improve control by enabling rapid adjustment of steam pressure to match process demand changes. The alternative, an outlet condensate control (OCC) valve arrangement, slowly varies the condensate liquid level to adjust the amount of reboiler surface area heated by steam *(1)*.

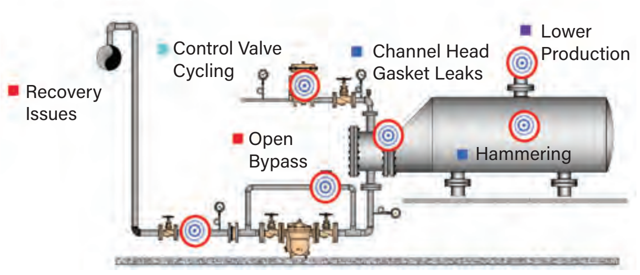
To achieve economic and control benefits, reboilers with ISC valves have to overcome potential operational pitfalls that can create bottlenecks in the system's drainage and hinder process operation, including:

• insufficient pressure to discharge condensate into the return header upon startup, under low demand, or when the tube bundle is relatively clean

• design uncertainty regarding the reboiler drainage system (*e.g.,* specifying the steam trap, pump/trap, level pot/control valve combination, or electric pump)

• insufficient understanding of balance requirements for level pots or pump/trap reservoirs that can cause reboiler evacuation issues, such as stall, backup, hammer, and corrosion.

Reliable reboiler systems require timely, almost instant condensate drainage from the steam space (Figure 1). Reboilers equipped with ISC and OCC valves have been



▲ **Figure 1.** Reboilers that are improperly drained can experience multiple reliability issues, which can create system bottlenecks known to experience condensate backup that can lead to corrosion, tube bundle damage, and condensate sewering (*i.e.,* condensate discharged to the sewer rather than the condensate return). These issues may occur in both horizontal and vertical reboilers. In addition, horizontal systems are prone to channel head gasket leaks.

Many of these problems can be avoided or mitigated through proper condensate drainage design. Reboilers that experience operational issues have often been improperly designed or installed, requiring corrective action to realize improvement. This article explores some reboiler operational issues related to condensate drainage, evaluates why certain problems occur, and provides key design considerations necessary to optimize reboiler performance.

Reboiler basics

Reboilers with ISC valves commonly drain condensate through a steam trap on the outlet side (Figure 2). This arrangement can provide mixed results, depending on the differential pressure across the steam trap. Consider that the pressures in the system are defined as:

- P_1 = pressure before the ISC valve
- P_2 = pressure exiting the control valve and entering the reboiler
- P_3 = exit steam pressure at the inlet of the steam trap after incurring pressure drop in the reboiler (plus head)
- P_4 = backpressure against which the trap must discharge.

The differential pressure across the trap is the difference between P_3 and P_4. If the differential pressure is positive, then P_3 is greater than P_4, and only a steam trap is needed to drain condensate. But if the differential pressure is negative, then condensate can back up into the reboiler, where it will be subcooled by the process liquid. When steam contacts the subcooled liquid, some of the steam collapses, which can cause thermal shock damage to the reboiler.

Since P_1 is generally much greater than P_4 (*e.g.,* P_1 may be 150 psig and P_4 may be around 20 psig), it is natural to wonder how the differential pressure could become negative. To answer this question, it is worthwhile to review the reboiler heating process, and the control systems used to equalize the heat supply to demand.

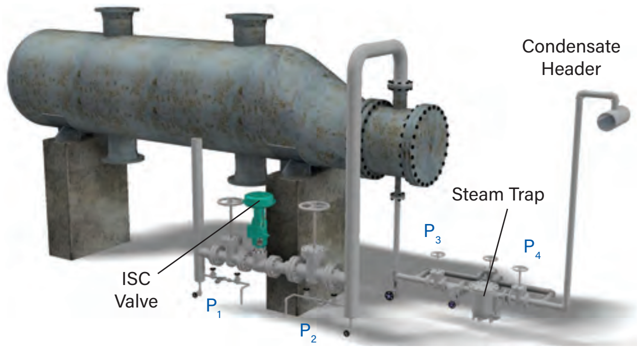
Heat supplied by the reboiler (Q_s) must match the reboiler heat demand ($_dQ$), otherwise the bottoms liquid will be over-reboiled (producing too much vapor) or under-reboiled (producing too little vapor). Over-reboiling tends to introduce heavies into the tower top, while under-reboiling tends to increase lights in the tower bottoms. The reboiler heat balance is represented by:

$$M \times (C_p \times \Delta T + H_{fg}) = {}_dQ = Q_s = U \times A \times LMTD \qquad (1)$$

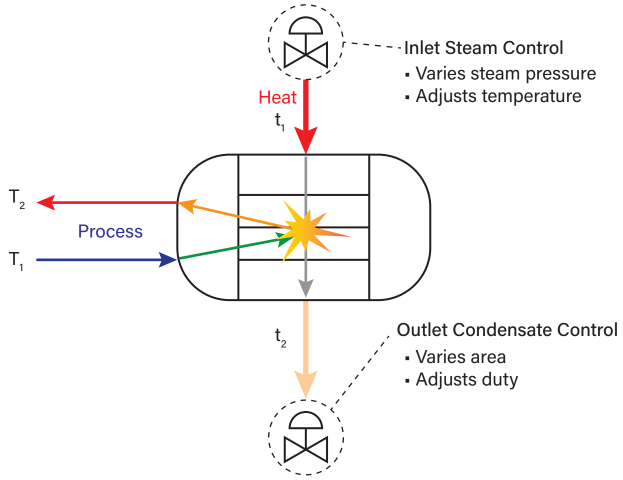
where M is the mass of the liquid, C_p is the liquid specific heat, ΔT is the liquid temperature rise, H_{fg} is the heat of vaporization, U is the heat transfer coefficient, A is the reboiler tube area, and $LMTD$ is the log mean temperature difference.

Heat transfer in OCC vs. ISC configurations. OCC and ISC are the two main control schemes for reboilers (Figure 3). The OCC method varies the unflooded steam-condensing area to adjust the heat duty. The flooded tube area cannot transfer heat of vaporization; it provides heat only by subcooling the condensate until it reaches the process temperature, beyond which it can actually pull heat from the process. Because heat exchange by sensible heat has a dramatically lower heat value and transfer coefficient than steam heat exchange, it can be ignored in reboiler calculations, and only the latent heat is considered.

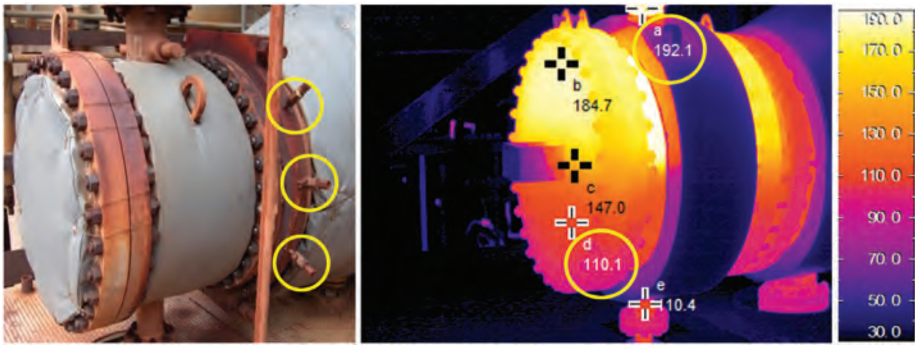
OCC horizontal or vertical reboiler systems often experience instability and operational issues, tube corrosion, or steam blow-through (in which a significant amount of steam passes into the header). The channel head gasket in horizon-



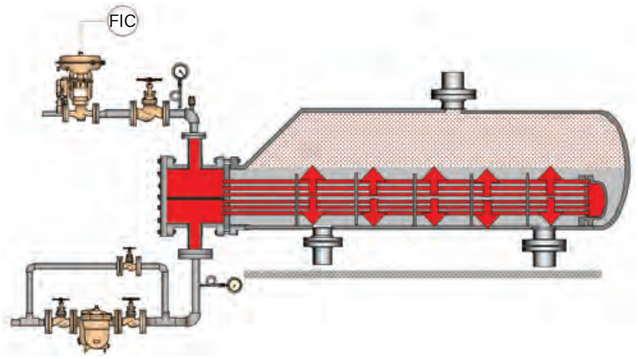
▲ **Figure 2.** Reboilers with inlet steam control (ISC) typically drain condensate through a steam trap.



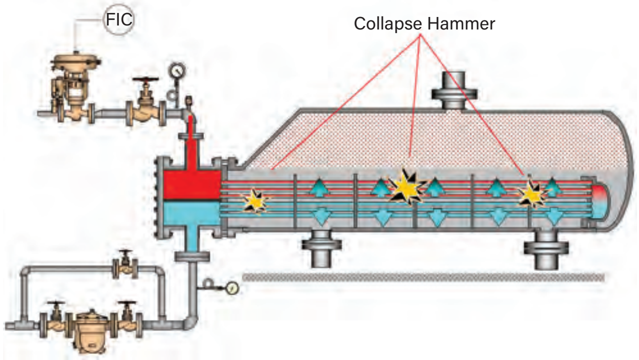
▲ **Figure 3.** Effective reboiler control requires that the heat supplied to the process equals the heat demanded by the process.



◀ **Figure 4.** Leak collars can indicate damage from temperature stratification and condensate backup issues in OCC reboilers. The circles on the left photo show the leak-sealing injection points for a damaged gasket. The circles on the right image highlight the significant temperature drop — stratification caused by condensate backup.



▲ **Figure 5.** ISC reboilers that heat without condensate backup experience fewer maintenance and control problems.



▲ **Figure 6.** Reboilers that experience condensate backup can suffer from a type of hydraulic shock known as collapse hammer.

tal reboilers may be damaged if the equipment is flooded by OCC. Therefore, an ISC arrangement can provide better reliability for horizontal reboilers, but the condensate must be quickly drained. Vertical shell-side steam reboilers may experience fewer issues related to temperature stratification and hydraulic/thermal shock than horizontal tube-side steam reboilers. A possible benefit of OCC reboilers is their consistent, high steam pressure, which can prevent backflow contamination of process fluid into the steam system in the case of a tube leak *(1)*. However, higher temperatures on the tube side may increase fouling in systems with temperature-sensitive liquids. It is typically easy to visually identify operational issues in an OCC system (Figure 4).

ISC systems vary steam pressure to match heat supply to demand. Varying the steam pressure adjusts the steam temperature and the mean temperature difference between heat and product flows. As a result, ISC reboilers can use the lowest pressure steam, provided that the resulting — possibly negative — pressure differential across the condensate drainage system can be overcome.

If a tube leak occurs, low pressures in ISC reboilers can allow process contamination into the heating system *(1)*. A check valve installed in the steam line between the ISC valve and reboiler entry can mitigate process fluid backflow into the steam supply line, but process contamination of condensate will still occur. A contamination alarm and mitigation system should be implemented when appropriate for these systems.

Whether using medium- or low-pressure steam, ISC valves can reduce the steam pressure to produce a vacuum condition that equalizes the supply heat to demand when the tube bundle is unfouled and the demand is below peak. This can create a negative pressure differential that prevents condensate from draining, allowing it to back up into the system. When the load is near peak or when the tube bundle is sufficiently fouled, the steam pressure is higher and a positive pressure differential will exist across the steam trap. This enables steam to circulate throughout the tube bundle without condensate backup (Figure 5).

How do ISC reboilers stall? When demand load decreases, or when the tube bundle is relatively clean and oversurfaced (*i.e.,* when the fouling factor is overstated and *U* is higher than expected), the large heating capability triggers the ISC valve to throttle, reducing the steam pressure and corresponding temperature to match the heat supply to the heat demand. At a certain turndown value (in both horizontal and vertical reboilers), the steam pressure equalizes with the backpressure, stalling the condensate flow inside the equipment. When heat demand is at or below this threshold value, the differential pressure across the steam trap is zero, and no flow will occur.

During a stall, condensate backs up into the reboiler and the condensate becomes subcooled, increasing corrosion and the possibility of hydraulic shock from a phenomenon known as collapse hammer. Collapse hammer occurs when entering steam contacts colder condensate, which rapidly collapses steam pockets; the condensate rushes into the void created by the collapse, creating hammer as condensate hits metal components (Figure 6). Hammer from stalled condensate can cause significant problems with the channel head gasket in horizontal equipment, especially while the gaskets are also experiencing rapid thermal changes (subcooled condensate to steam).

Extended stall chart load analysis

Extended stall charts *(2)* can help to assess various load vs. backpressure scenarios to allow engineers to identify when a stall is likely. A stall occurs when the exit pressure, P_3, decreases to equal the condensate-side backpressure, P_4.

Consider three hypothetical scenarios:

• Scenario 1: P_1 = 150 psig; P_4 = 10 psig; 55% oversurfacing (Figure 7)

• Scenario 2: P_1 = 150 psig; P_4 = 20 psig; 0% oversurfacing (Figure 8)

• Scenario 3: P_1 = 150 psig; P_4 = 20 psig; 55% oversurfacing (Figure 9).

Extended stall charts (Figure 7–9) are developed by first plotting the process demand (blue line), which rises left to right from 100% load (T_1) to no load (T_2). For simplicity, the arithmetic mean temperature (T_M) is substituted for *LMTD* and plotted on the right axis. The P_4 backpressure (green line), estimated as a consistent backpressure, is plotted at the intersection of the oversurfacing value. Next, the P_3 steam pressure exiting the reboiler is also plotted from the oversurfacing value (dashed red line). The resulting pressure profile of the supply heat is plotted by connecting the P_3 value to T_M (solid red line). The intersection of the red pressure profile line with the green P_4 line is the estimated stall point.

Scenario 1 shows an estimated stall point at 86.4% of full load when discharging against a low backpressure of 10 psig (Figure 7) *(2)*. As long as the load is always above 86.4% of full load, a steam trap with a check valve on its outlet (to mitigate possible damage from accelerated backward condensate flow to the trap, *i.e.,* backslam) can serve as drainage. This is the lowest-cost installation and can be effective when there is little load variation.

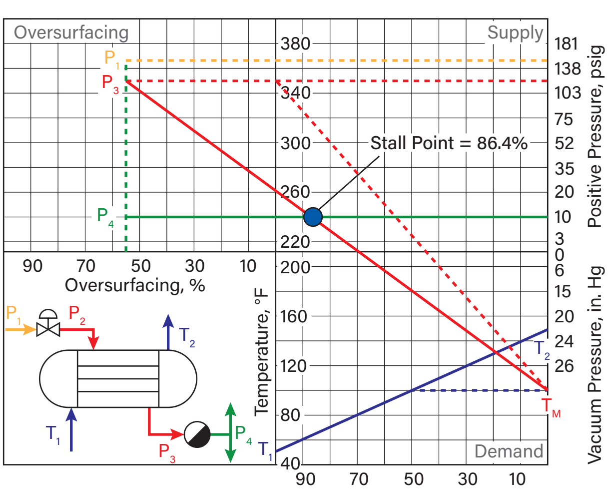
In Scenario 2 (Figure 8), two dynamics have changed:

• the equipment has fouled, which has the same effect as reducing the heating area to just meet 100% of demand, with no oversurfacing

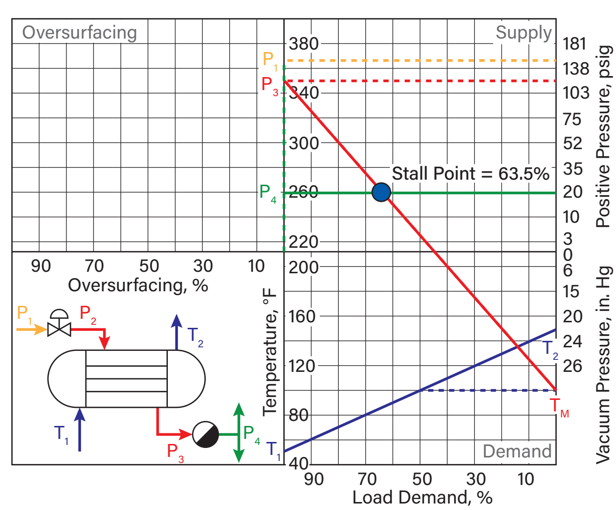
• the system backpressure, P_4, has increased to 20 psig.

These two factors decrease the stall point to 63.5%. When tube surfaces are fouled, a stall condition is less likely to occur, and the process can perform well for multiple months against high backpressure. Months of good performance can cause owner/operators to lose focus of the importance of maintaining low system backpressure. After the tubes are cleaned or replaced, the ISC valve throttles to decrease the steam pressure due to the improved heat capability, and the system may suffer from condensate discharge issues against the high backpressure.

In Scenario 3, the tube bundles have been cleaned or replaced, but the backpressure remains high at 20 psig



▲ **Figure 7.** When the tube bundle is oversurfaced, stall can occur at 86.4% of full load, even against low backpressure (10 psig).



▲ **Figure 8.** When the tube bundle is fouled, stall will only occur at less than 63.5% of full load, even against elevated backpressure.

(Figure 9). At the higher heat transfer coefficient of the clean surface, the P_3 exit pressure equalizes with the elevated backpressure, P_4, at a stall point of 98.4% of full load. Therefore, the equipment can experience stall anytime the load is not near maximum. An increase of only 10 psi backpressure caused the stall point to move from 86.4% (Figure 7) to 98.4% of full load.

The analysis of these three scenarios illustrates the critical importance of maintaining low condensate system backpressure. Backpressure may increase from the original design for several reasons, such as:

- an open condensate bypass on ISC equipment is connected to the same condensate header as the reboiler outlet steam trap
- the steam trap population is not proactively managed, allowing a significant amount of steam to pass into the header (*i.e.,* steam blow-through) *(3–5)*
- OCC valves on some heating equipment are suffering from steam blow-through *(1)*, particularly systems that do not have level pots
- system dynamics have changed (*e.g.,* a new condensate tie-in with significant added flow has been connected to the header)
- a nitrogen blanket was added to mitigate hammering in the condensate return line.

Design for handling stall

A stall condition is often misunderstood as something to be avoided, which overlooks the opportunities stall conditions can afford. Stall conditions allow for the use of the lowest possible steam pressure, and often enable the use of low-pressure vent steam for heating. Some reboiler operations have a high steam flow demand, and substituting low-pressure steam for medium-pressure steam can significantly improve the steam energy balance, which is critical to improving the energy intensity index (EII) or energy efficiency index (EEI) of a facility. Low steam pressure can also reduce fouling in systems with temperature-sensitive product streams.

While the lower pressure steam can be advantageous in ISC arrangement, a method to pump the condensate and overcome a potentially negative pressure differential across the outlet drainage device may be needed.

Flash receiver and pump. One such method is to install a separate pump after the steam trap (Figure 10). The differential pressure across the trap may be too low to discharge condensate to a return header that may be, for example, 35 ft above at 20 psig pressure or more. However, it is most likely sufficient to discharge 2–3 ft overhead into a horizontal condensate flash receiver that is atmospherically vented and then pump the condensate to the return header. Condensate in close proximity to the condensing source and flash vessel can be around 212°F. To avoid cavitation, a non-electric, secondary pressure drainer (SPD1) pump is preferred. Depending on the amount of flash steam and the production unit location, a method to handle flash steam (*e.g.,* a vent condenser) may be needed.

Combination pump and trap. Rather than install a separate steam trap and condensate pump to discharge against

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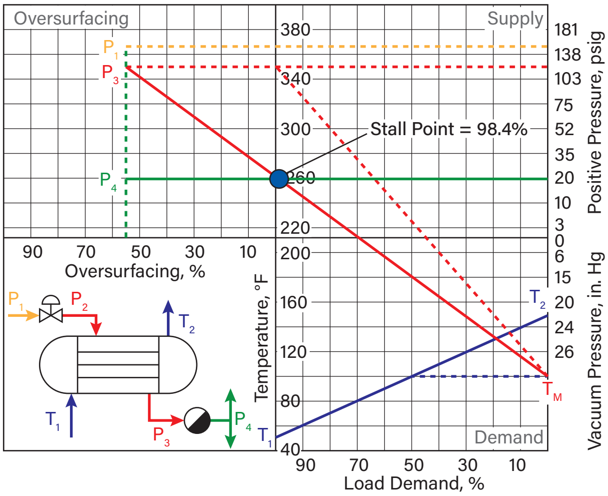
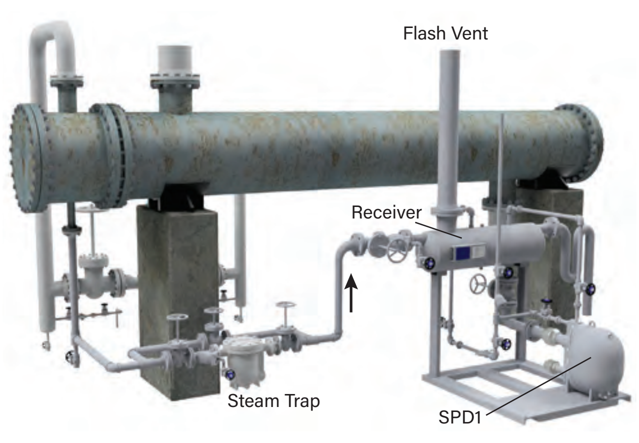


▲ **Figure 9.** When an oversurfaced tube bundle is clean, elevated backpressure increases the stall point to 98.4% of full load.



▲ **Figure 10.** One method to discharge condensate against high backpressure is to use an atmospherically vented flash receiver and pump (SPD1) after the steam trap.

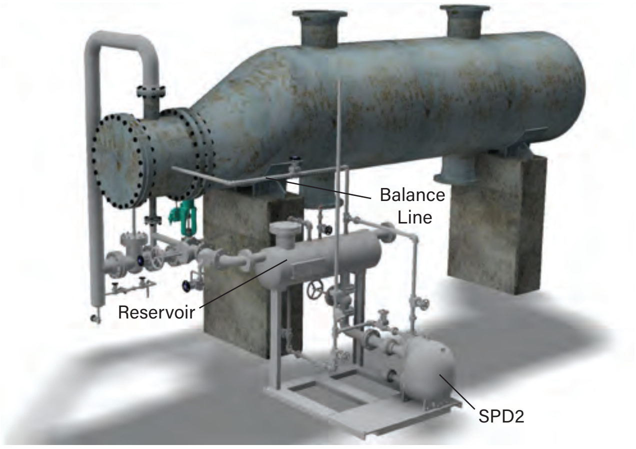
high backpressure, another option is to use a combination pump and trap in the same body, a so-called pump/trap (SPD2), downstream of a reservoir. The loads of condensate that must be drained from reboilers can be high, so it is common to have a dual-orifice trap arrangement (Figure 11). The float assembly in Figure 11 is a mechanical actuator. When high level in the reboiler is reached, the actuator simultaneously opens a motive valve to input high-pressure steam that discharges the condensate against the high backpressure, as well as closes the exhaust valve so that the body can pressurize. At low level, the actuator closes the motive valve and opens the exhaust to allow the pressure of the internal vapor to equalize with that of the condensing source; the exhausted motive steam still has heat to contribute to the heating process.

Figure 12 shows the layout of a pump/trap assembly that drains a kettle reboiler via gravity flow from the reboiler outlet to the reservoir. The reservoir that is connected immediately upstream of the pump/trap is different from a flash vessel. It is not at atmospheric pressure and does not produce any flash steam due to its direct connection to the condensing source.

A pump/trap is connected to the reboiler condensing source in two ways: via the reboiler condensate outlet piping and what is known as a "balance line" — a connection that links the vapor space of the reservoir to an appropriate location in the reboiler, which will allow this vapor to reach the tube bundle (Figure 12). The pump/trap exhaust contains uncondensed motive steam that is first balanced with the horizontal condensate reservoir (a closed system vessel) and then to an appropriate outlet-side vapor space location on the reboiler. The reboiler will have the same pressure as the pump/trap, allowing the vapor within the pump/trap to balance with the vapor in the tube bundle.

In order for the balance line to function correctly, the pump/trap must have the lowest elevation of all the reboiler components. The pump/trap and the reboiler must have a pressure differential of zero to enable gravity flow of condensate into the pump/trap and, at the same time, allow the exhausted motive vapor to reach the tube bundle to be properly condensed. If the pressure in the pump/trap during the filling stage is not equal to that of the reboiler, it can have the same effect as stuffing a rag into the exhaust of a car, causing the car, or in this case the pump/trap, to stall. Free exchange of exhausted steam into the condensing source vapor space at its outlet pressure must occur to allow

▲ **Figure 11.** A pump/trap assembly contains a mechanical actuator system. When the reboiler reaches a high level of condensate, the actuator opens a motive valve that inputs high-pressure steam to discharge the condensate.



▲ **Figure 12.** A combination pump/trap assembly (SPD2) with a closed reservoir can be used to discharge condensate against high backpressure.

▲ **Figure 13.** Condensate outlet piping that is 80 in. above grade is preferred, but it is still possible to drain reboilers on low-fill installations with an outlet at 30 in. by using multiple pump/trap units in a package design (as shown here).

condensate to displace the vapor and enter the pump/trap body. This is one of the reasons why it is necessary to connect the balance line from the reservoir's vapor space to a very specific location on the reboiler in order to obtain proper operation *(6)*.

Low-fill pump/trap assemblies. Preferably, the pump/trap package system should be installed more than 80 in. below the reboiler condensate outlet flange. This accelerates gravity flow into the pump/trap reservoir, and it can reduce the number of pump/trap units required. However, in some instances, particularly existing systems, the condensate outlet piping may be close to grade. It may still be possible to use a pump/trap assembly with a specialized, low-fill design (Figure 13). If the pump/trap assembly cannot be utilized in systems with very low elevations, then a separate steam trap and pump can be installed.

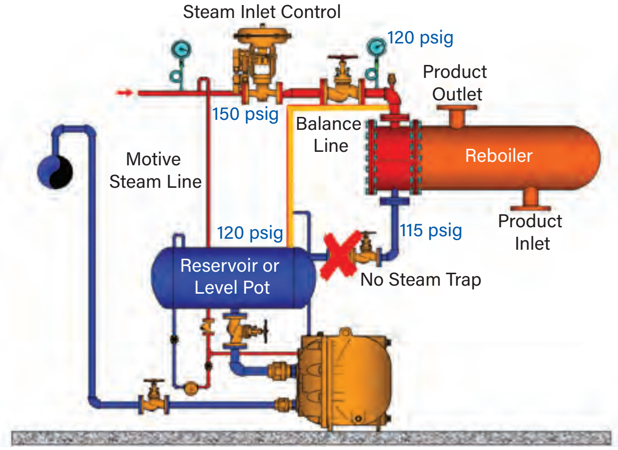
Balancing a tube-side steam reboiler

Imbalance issues can occur in pump/trap installations when the balance line is installed incorrectly. As mentioned in the previous section, the balance line must be routed to an appropriate outlet-side vapor space location on the reboiler. Commonly, balance lines are installed in three locations:

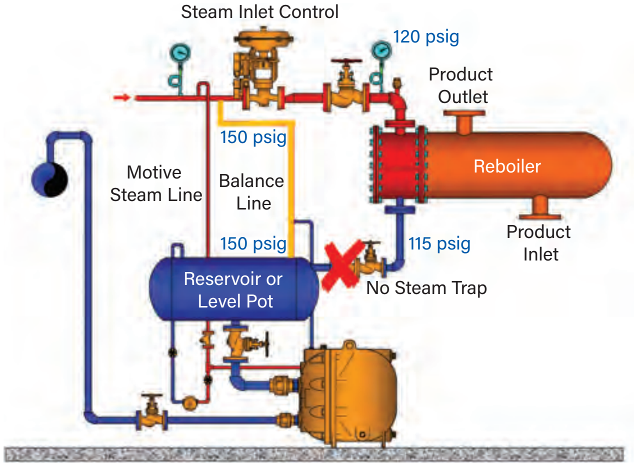
- before the ISC valve (Figure 14)
- between the ISC valve and the reboiler inlet (Figure 15)
- at the steam outlet of the reboiler (Figure 16).

Only one of these installation locations — at the steam outlet of the reboiler — is recommended.

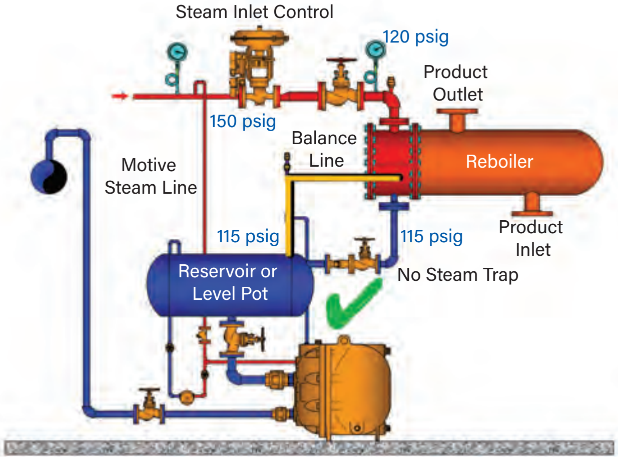
Consider a reboiler with hypothetical pressures before and after the ISC valve of 150 psig and 120 psig, respectively, and 115 psig at the reboiler outlet. In Figure 14, the balance line (yellow) is connected to the ISC valve inlet side, which equalizes the ISC steam pressure and reservoir at 150 psig. After incurring pressure drops through the ISC valve and reboiler, the highest possible pressure at the outlet of the reboiler is 115 psig (before throttling for reduced demand). At this pressure, condensate cannot flow into the reservoir, which is at a pressure of 150 psig. Since 2.31 ft of height is required to create just 1 psi of head pressure, getting the condensate to flow into the reservoir would require a minimum vertical drop of 81 ft to create sufficient hydraulic pressure, which is not feasible in this scheme. If the P_3 pressure decreases due to lower load, the height difference increases. For example, if demand change reduces P_3 to 50 psig, an improbable height of greater than 231 ft is needed to produce the required head pressure to allow con-



▲ **Figure 15.** When the balance line is connected at a location between the inlet steam control (ISC) valve and the reboiler inlet, the outlet pressure from the reboiler is too low (115 psig) to drain condensate into the reservoir (120 psig).



▲ **Figure 14.** The reboiler outlet pressure is too low (115 psig) to drain condensate into the reservoir (150 psig) when the balance line is connected upstream of the inlet steam control (ISC) valve.



▲ **Figure 16.** The reboiler outlet pressure is equal to the pressure of the reservoir (115 psig), thereby enabling condensate to drain via gravity.

densate to drain. The result is significant condensate backup into the reboiler.

In Figure 15, the balance line is connected to a location between the ISC valve and the inlet to the reboiler. The reservoir pressure is 120 psig, which is higher than the reboiler outlet pressure of 115 psig. Although this negative pressure differential is not as severe as in the scenario presented in Figure 14, condensate will still back up into the reboiler *(6)*. Getting condensate to flow into the reservoir would require a vertical drop of 12 ft or more, which is often not available.

Figure 16 shows the proper balance location, in which the balance line is connected to the outlet-side steam space of the reboiler. The vapor space at the outlet side of the reboiler is at the same pressure as the condensate outlet, allowing condensate to flow into the reservoir. For tube-side steam reboilers (typical of horizontal designs), if the elevation difference between the reboiler and the reservoir level is small, the balance line must be connected to the channel head. This enables the pressure to equalize with the vapor space, allowing the exhaust steam to condense in the tube-bundle space.

Due to often-undersized tapping on the channel head, some engineers try to balance a pump/trap to the reboiler condensate outlet piping, but this normally does not work. The condensate outlet piping is too small and the flowrate is too high to enable exhaust steam from the pump/trap to counterflow up into the tube bundle. As a result, the balance line must be connected to the channel head at a high location on the outlet side of the pass partition, and that tapping must be of a sufficient size to allow for unrestricted balancing. The reservoir vapor space is an excellent location to include an air vent/check valve combination to enable venting while restricting the inflow of air (avoiding a vacuum condition).

Key balance and motive sizes

Manufacturers may have different requirements for their pump/traps. Table 1 provides some of my preferred design criteria to facilitate proper pump/trap system breathing. A pump/trap has to "breathe in" motive steam and "breathe out" exhaust steam without significant restriction. Piping that is too small or piping loops in the motive or exhaust lines can severely degrade operation. A reduced port valve, in either the motive or exhaust line, or balance tapping that is too small at the reboiler condensing source connection (shell tapping for shell-side steam, channel head tapping for tube-side steam) can cause poor system performance.

Table 1. Proper balance and motive line sizes are essential for effective pump/trap breathing.

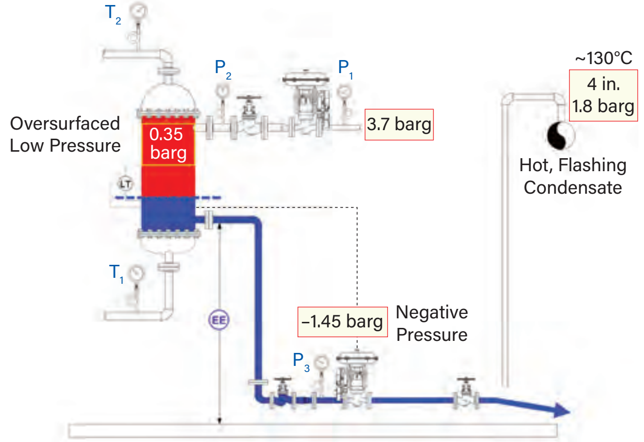
Number of Pump/Trap Units	Balance Line, in.	Motive Line, in.
1	1	1
2	1.5	1.5
3	2	2
4	2.5 (or 3)	2
5	2.5 (or 3)	2.5 (or 3)

Proper breathing of a pump/trap means that the motive steam is without pipe or valve restrictions or condensate buildup, and the exhaust steam can freely balance without restriction or buildup. The main causes of poor pump/trap performance in reboiler operation are improper balance and motive line sizing, connecting the exhaust to a location other than the condensing source vapor space, and loop seal/reduced flow valve restrictions in either line. Failure to meet operational expectations is often not an equipment sizing issue, but rather a breathing issue. Consult the pump/trap manufacturer before ordering a new reboiler or heat exchanger. The manufacturer can advise of the proper vapor-space tapping connection size and location to enable correct pump/trap installation.

Add a spare pump/trap to mitigate interruptions

It is recommended that the reboiler outlet flange be more than 80 in. above grade, which can reduce the number of pump/traps required to recover the condensate. This cost savings can be reinvested to mitigate process interruptions.

Because every mechanical product will require service at some point, consider installing an extra pump/trap to operate as a functioning spare and prevent process interruptions. If the minimum number of pump/traps are installed to drain a reboiler and one stops working, condensate may need to be discharged to grade, the pump/trap may have to be bypassed (further pressurizing the return and decreasing the reboiler duty), or the process may need to switch over to another reboiler. Investment in a spare allows site operators to check



▲ **Figure 17.** The low steam pressure (0.35 barg) in the reboiler was insufficient to drain the condensate into the condensate header, which was at a pressure of 1.8 barg.

the performance of each unit at regular intervals by opening a small, strategically located drain valve connected to the pump/trap. Because it is unlikely that multiple units will require concurrent service, the malfunctioning pump/trap can be repaired while the reboiler remains in operation.

A vertical thermosiphon reboiler review

Much of the previous discussion has focused on horizontal reboiler design with tube-side steam. This section shifts the focus to a vertical reboiler that uses shell-side steam and an ISC arrangement. This system uses a level pot (*i.e.,* a vertical vessel that commonly precedes an outlet control valve) and an outlet control valve as the steam trap.

In one such vertical reboiler system, the condensate return header's P_4 backpressure was 1.8 barg and its flash-steam temperature was 130°C; the P_1 inlet pressure was 3.7 barg, and the reboiler was highly oversurfaced (Figure 17).

Although P_1 (3.7 barg) was high, the overly large surface area of the reboiler caused P_2 to drop drastically (0.35 barg). The pressure from P_2 of approximately 0.35 barg (plus head) was not adequate to discharge into the P_4 backpressure of 1.8 barg. The original design engineer must have assumed a P_1 of 3.7 barg would be more than adequate to discharge into the expected P_4 backpressure. However, the site encountered such severe water hammer that the condensate was dumped to grade for more than 10 years.

In an attempt to bring the system back to a functional state, the site changed the level transmitter that controlled the drain control valve to create a very high flood line in the reboiler (Figure 18). High flooding reduced the steam condensing area, which elevated the P_2 steam pressure to 2.2 barg to supply the required heat to meet demand. This resulted in a positive pressure differential of 0.4 barg, which is more than adequate to discharge condensate into the header. However, the high oversurfacing of the reboiler and the high flood line caused the condensate at the bottom of the reboiler to significantly cool. The condensate became further subcooled in the level pot to the point that the outlet temperature was approximately 92°C. Discharging 92°C, nonflashing condensate into a condensate header full of flash steam at 130°C produced substantial collapse hammer that was so severe that the site had to discharge the condensate to grade again. In addition, locating the flood line near the P_2 steam inlet connection was a source of instability and another undesirable aspect of this design.

To resolve the operational problems and mitigate water hammer, a pump/trap assembly was designed and recommended for the system (Figure 19). A pump/trap assembly would allow a return to the original conditions in which the steam vapor heats as much of the tube surface as possible. The P_2 pressure drops to 0.35 barg, and the balance line equalizes that pressure to the reservoir pipe/tank. Condensate flows from the reboiler into the reservoir and pump/trap, but it cannot initially overcome the negative pressure differential. However, once the condensate level rises in the pump/trap, it activates the 3.7 barg steam as the motive source to pump a positive displacement of condensate (8 gal/cycle) into the return header. Since the condensate flashes near 105–108°C, the flash creates a cushion while discharging into the flash steam header at 130°C. In this arrangement, the system is able to handle the oversurfacing and stall condition without creating hammer or condensate backup into the reboiler.

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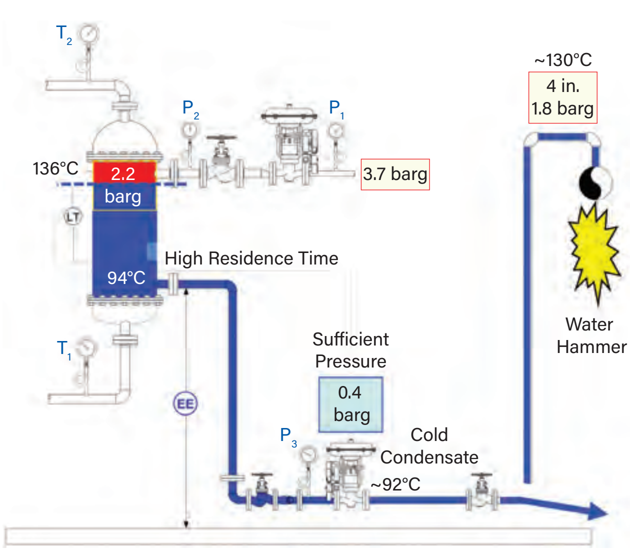
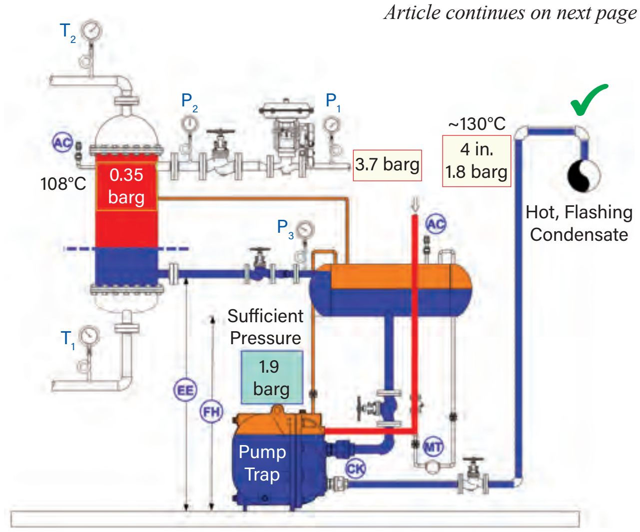


▲ **Figure 18.** High flooding elevated the steam pressure (2.2 barg) and increased the pressure differential, but decreased the condensate temperature to 92°C. When the cold, nonflashing condensate discharged into the 130°C flash steam header, it created water hammer.



▲ **Figure 19.** Low reboiler steam pressure (0.35 barg) requires motive steam (3.7 barg) within the pump/trap to discharge condensate into the return header.

Discharging nonflashing condensate into flashing condensate return lines

In scenarios where the condensate can be significantly subcooled and nonflashing, hammer can occur. There are several potential options that could resolve this issue, but they should be evaluated and designed by a knowledgeable engineer.

The condensate could be discharged into the side of the main header, rather than the top where it might more readily collapse flash steam. Other design considerations include:

- multiple side entry insertion points to reduce input buildup at a single location
- globe valves to restrict flow velocity
- check valves to prevent reverse flow
- slanted entry points, rather than insertions at a right angle to the main header, to facilitate integration of liquid into liquid without crossing into the flash steam flow.

A bottom feed into the main header could be suitable for some installations. However, all of these options could create severe collapse hammer in the condensate header, particularly if steam were to be injected through the connecting line into the liquid condensate. Therefore, to ensure safe operation, all of these design concepts must be carefully evaluated and reviewed, and a knowledgeable engineer must perform an appropriate hazard and operability (HAZOP) analysis. These concepts should never be used with OCC, because the control valve may blow steam into the system and cause severe damage. CEP

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Development Background

My first work with identifying and naming the stall phenomenon began in 1978 while reviewing a damaged heat exchanger as a member of the Philadelphia Chapter of Operating Engineers. After just one year of operation, the lower section of the tube bundle had so many leaks that it resembled Swiss cheese. I became determined to understand why condensate could not elevate out of an exchanger and how to mitigate it to prevent severe corrosion.

The stationary condensate reminded me of the Piper Cherokee aircraft that I trained/soloed on in 1975. During flight, it was necessary to stall the aircraft and then safely pilot out of the situation, inspiring the name for this condition.

In a short period of time, it became evident that pressure exiting the control valve and entering the reboiler (P_2) and the exit steam pressure at the inlet of the steam trap after incurring pressure drop in the reboiler (P_3) could frequently fall below the backpressure (P_4) as demand load decreased. This phenomenon could be anticipated by charting the stall point. On the first graph I created, I noted: Positive pressure differential only requires a trap and negative pressure differential only requires a pump, but varying pressure differential requires a pump/trap combination.

After understanding the cause, it became possible to solve stall conditions by matching a separate SPD1 pump with an oversized float trap on the outlet (to account for the higher-than-average flow discharge rate). Later, the dream of combining both mechanisms in one body was realized in a pump/trap SPD2 model.

To ultimately improve the evaluation process, the extended stall chart used in this article was published in 2004. Since that time, it has been used all over the world to anticipate and solve stall in oversurfaced exchangers by charting the stall point and incorporating pump/trap technology for applications with varying positive/negative differential pressures.

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