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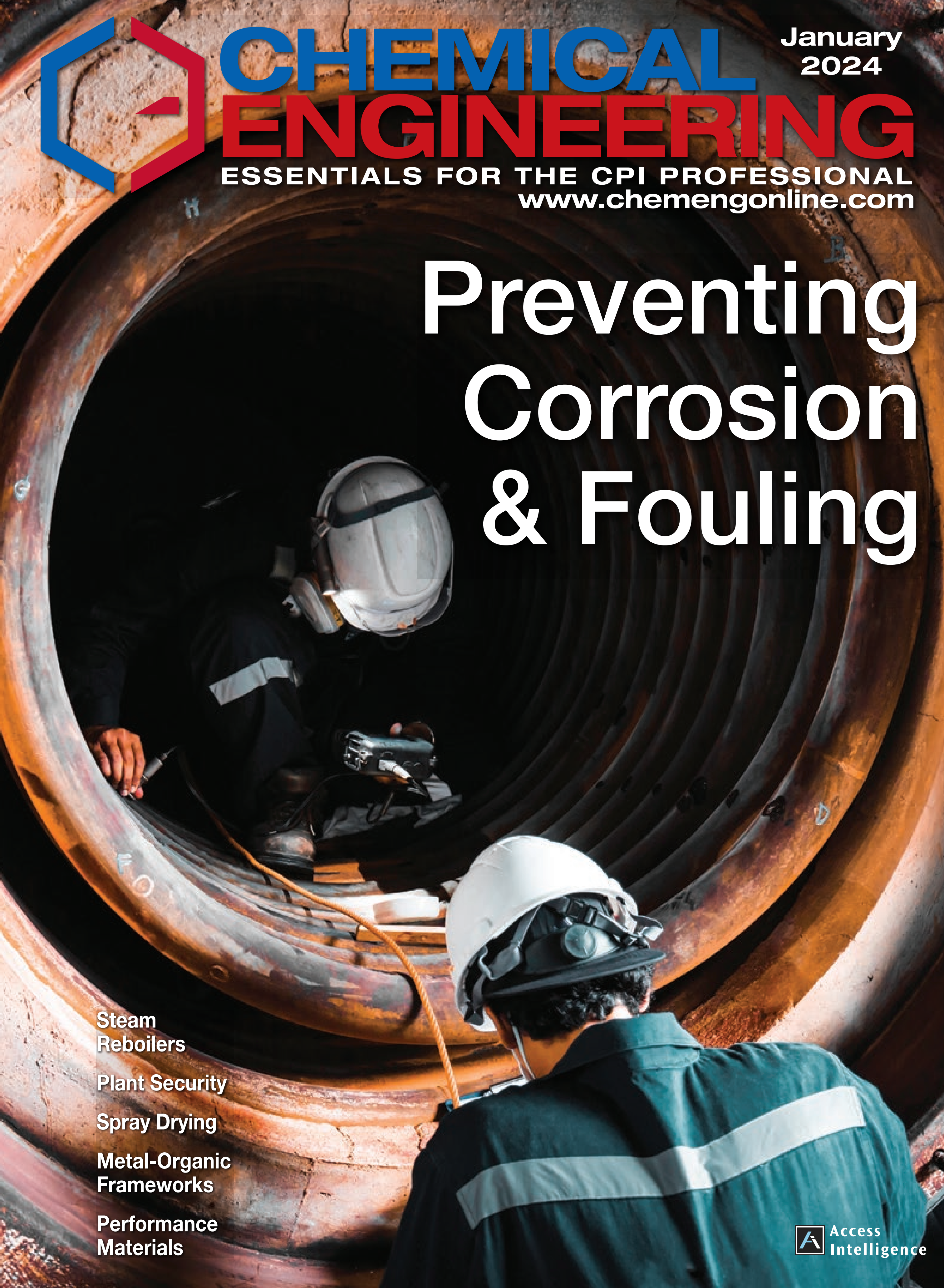

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Steam Reboilers: Condensate Vessel Balance to Reboiler is Important

Properly locating a simple 1–2-in. balance line can make all the difference in successful reboiler operation

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Consultant (retired president, TLV Corp.)

IN BRIEF

Steam reboilers are crucial to production in petroleum refineries and petrochemical plants, representing huge capital investment in distillation columns. Regardless of the investment made to have the best process design, it is common that misunderstanding and misapplication of a simple 1–2-in. balance line can create a reboiler bottleneck in the entire production system.

If your plant is experiencing issues with reboilers, it is possible that the cause is related to an improper balance. It may seem almost unbelievable, but this has been the case in many reviewed reboiler installations. This article provides some basic information first, then reviews two separate applications that suffered from improper balance: 1) a de-isobutanizer (DIB) reboiler with 30,000 lb/h steam/condensate load; and 2) a de-ethanizer reboiler with 17,000 lb/h load. Explanation of how balance lines were misapplied, how that created issues, and recommendations to correct are presented.

Issues and their causes

Steam reboilers are commonly controlled with inlet steam control (ISC) for more dynamic response, or outlet condensate control (OCC) for more steady-state operation. OCC applications maintain constant steam pressure on the reboiler and adjust the reboiler duty, but ISC reboilers reduce the steam pressure to adjust temperature to the process in order to equalize the supply heat to demand heat. For the purposes of this article, focus is given to ISC applications (Figure 1) [*1*].

Reboilers and heat exchangers with ISC can experience multiple production and reliability issues, and mostly the causes can be attributed to either: 1) a "stall" condition [2] or 2) improper balance (Figure 2).

A stall condition occurs with ISC reboilers when the reboiler inlet steam pressure (P_2) reduces to equalize the supply heat to process heat demand and the outlet steam pressure (P_3) becomes equal to or lower than the system back pressure (P_4) (that is, $P_3 < P_4$). With either a zero or negative pressure

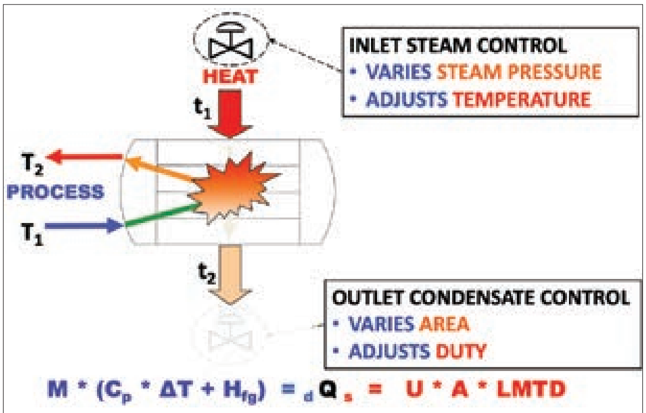

FIGURE 1. Reboiler steam or condensate controls equalize supplied heat to demanded heat by varying different factors

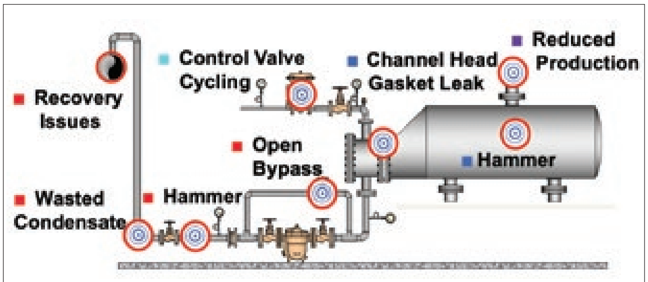

FIGURE 2. Each of the issues shown are commonly the cause of a stall or improper balance condition

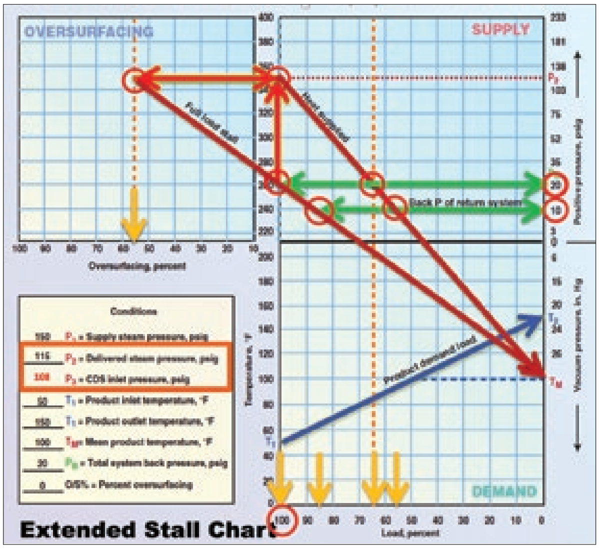

FIGURE 3. Stall points occur when the pressure profile line (maroon) intersects the back pressure line (green)

differential from the reboiler outlet (P_3) to the condensate return line (P_4), no condensate flow can occur and the system is stalled with condensate backing up into the heat-exchange surface. This condition can cause all of the issues shown in Figure 2.

An improper balance-line connection can also create a negative pressure-differential situation, but it differs in that the balanced/localized steam pressure at the condensate vessel/drum that connects to the reboiler outlet is higher than the reboiler's outlet pressure (P_3). This is explained later in the article.

Using the extended stall chart

The extended stall chart (ESC) estimates steam supply pressure for different load conditions and heat-exchange surface area (A) (from $Q = U{\cdot}A{\cdot}\Delta T$) (Figure 3). Effectively, UA "reduces" as the tube bundle becomes fouled, and the steam pressure rises to adjust supply heat to the process. The horizontal green line in Figure 3 represents equipment back pressure, and the four red circles where the burgundy line intersects the green line represent various individual stall points [*1, 3*].

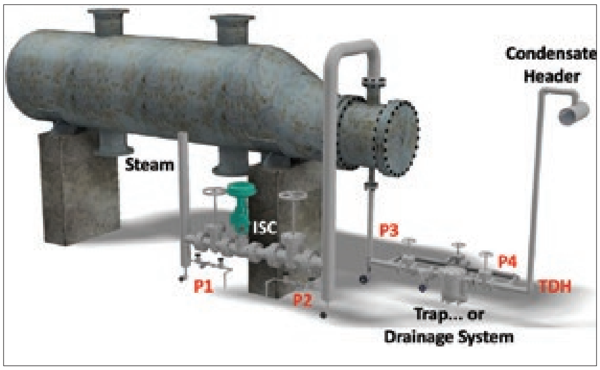

FIGURE 5. Four pressures (P_1, P_2, P_3, P_4) are needed to accurately recommend an appropriate drainage system

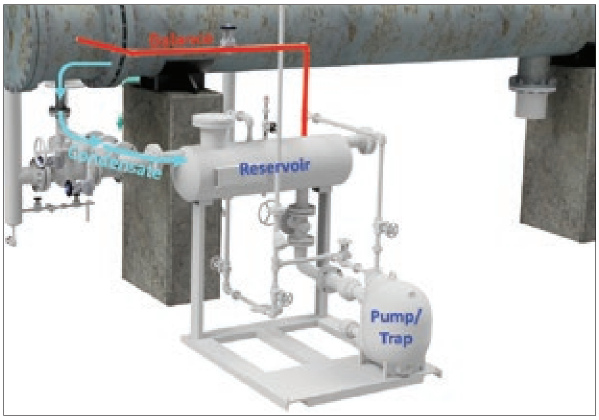

FIGURE 6. A proper condensate vessel balance line is needed so that incoming condensate can displace vapor without increasing vessel pressure

Essentially, if the process load always maintains positive pressure differential, $P_3 > P_4$, that is, pressure is always above the back pressure line for all load conditions, then only a simple device, such as a steam trap, is needed to help drain condensate from the steam space. Alternatively, a more complex drum and outlet control valve (OCV) arrangement can be used. However, if the pressure differential is sometimes negative, $P_3 < P_4$, then another type of drainage equipment is needed, such as a combination pump/trap system. Once appropriate data are entered into the ESC calculator [*4*], the anticipated stall point is identified and a recommended drainage device can be determined (Figure 4).

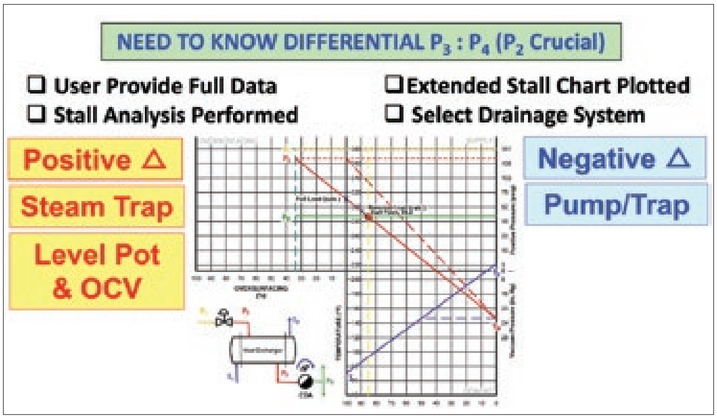

FIGURE 4. A steam trap or level pot/OCV drain system is used with positive differential pressure, and a combination pump/trap when differential pressure is sometimes negative

Four pressures, P_1, P_2, P_3 and P_4, are needed to perform an ESC calculation (Figure 5). The main determinant of stall is the pressure differential $P_3 : P_4$. However, P_1 is needed for the design in the event that full pressure might somehow reach the drainage equipment (such as a steam trap), and the P_2 pressure at full load is critical so that the appropriate pressure profile start point can be identified on the ESC.

Often, the actual P_2 and P_3 are not known because installations may not have pressure

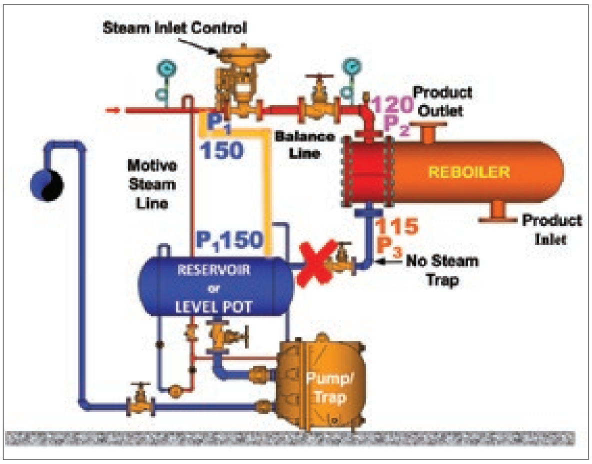

FIGURE 7. It is never recommended to balance from the P_1, inlet side pressure of the control valve

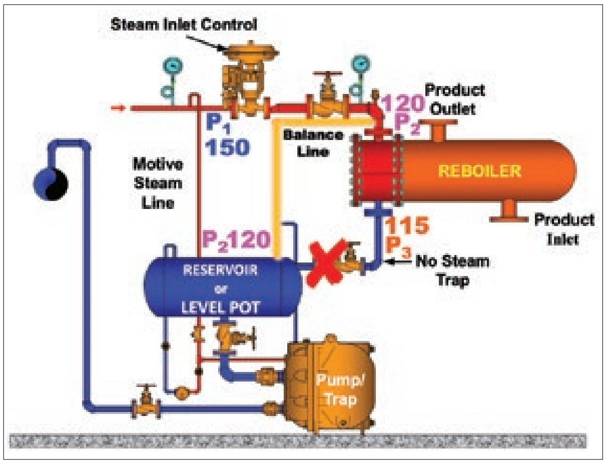

FIGURE 8. It is sometimes possible to balance from the P_2, reboiler inlet pressure, but generally not recommended

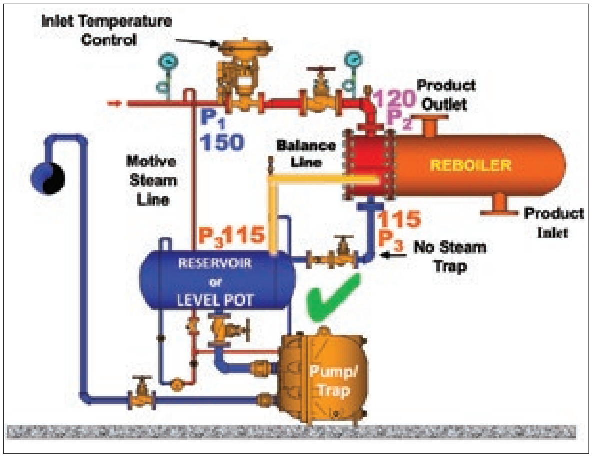

FIGURE 9. Balancing the vessel to the P_3, reboiler channel head enables unrestricted condensate flow

gages or sensors. It is crucial to know these pressures, so an appropriate method to obtain accurate readings is always recommended.

Vapor balancing basics

Balancing of a steam trap draining a reboiler is normally not necessary. However, it is required to balance either a condensate drum/level pot or reservoir when such vessels are part of the condensate drainage system.

Figure 6 provides some visualization of the need for balancing. A large body condensate vessel is often at least partially filled with steam, and when condensate enters it can compress the steam creating a higher internal pressure, thereby restricting additional condensate inflow. This can cause backup into the reboiler, which creates the issues previously outlined. When properly balanced, the vapor is displaced to the upper balance location as condensate enters the vessel body. It is important that the balance maintains the same vessel pressure as the condensate source so that flow by gravity can be accomplished.

Tube-side steam reboilers pose a special balancing challenge, and these generally horizontal installations are commonly incorrectly balanced. The red line, "Balance", in Figure 6 provides a visualization of some key aspects to balancing tube-side steam applications. In addition to avoiding low points and properly sizing the line, it is generally necessary that the line connects to the reboiler channel head, high on the outlet side after the pass partition/divider plate. In the case of combination pump/trap systems, this location is always recommended as a key requirement.

Conversely, balancing to shell-side steam reboilers is relatively easy provided that an appropriately sized tapping is located at the top side of the reboiler shell. The main items to consider are that there are no low points in the balance line where water can collect, the line is properly sized, and it is balanced to an appropriate top of shell location.

Balancing options

One practice, not recommended, is balancing the condensate vessel to the P_1 pressure located at the entrance to the ISC (Figure 7). This balances the full P_1 pressure to the vessel. P_2 represents the pressure downstream of the ISC — the pressure delivered to the reboiler, and P_3 is the outlet pressure from the reboiler — after subtracting tube pressure drop from P_2.

Even when the ISC is delivering the highest P_2, the outlet P_3 pressure of 115 psig cannot push condensate into the vessel, which is balanced to 150 psig. Balance to P_1 is expected to create a tremendous amount of backup into the reboiler, often causing operators to isolate the balance line, thereby removing balance from the system. The result of this action typically is that the vapor in the vessel becomes compressed (restricting condensate inflow), and the "work-around" is to open a bleeder valve to bleed off the pressure to atmosphere. This can create its own particular issue of pulling in air if the reboiler tube pressure goes into vacuum for low-load conditions.

Another not recommended practice is to connect the balance line to the P_2 inlet side of the reboiler (Figure 8). This brings P_2, a slightly higher pressure than P_3 (generally equivalent to or slightly higher than the tube

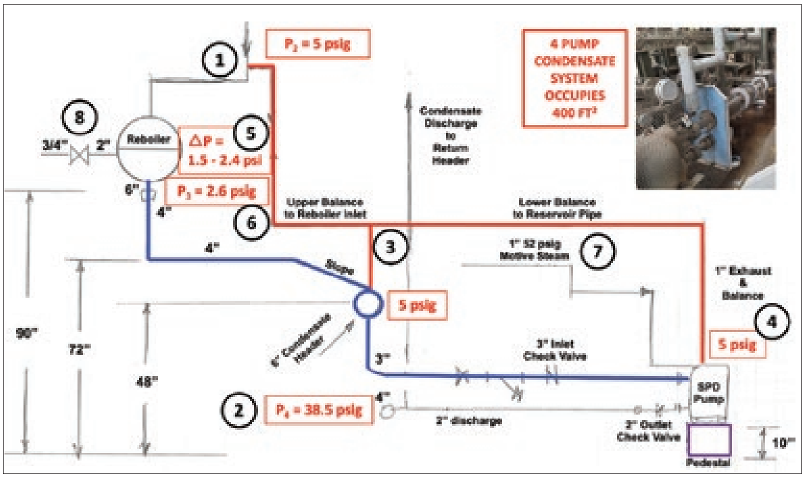

FIGURE 10. This de-ethanizer piping design had multiple hydraulic issues that prevented suitable drainage performance

pressure drop) into the condensate vessel (120 psig), against which the reboiler outlet pressure (P_3 = 115 psig) has to push to enable flow. It may work in some instances where there is sufficient fill head to create a water column high enough to overcome the pressure at the receiving vessel. In the case of this example, a water column at least 12-ft high would be needed. While this P_2 balance practice may work in some cases with level pot/OCV installations, it is not recommended for use with mechanical combination pump/trap systems.

Because drainage systems may change over time — particularly, for example, considering the potential need to use a pump/trap installation in the future when system back pressure elevates — the P_2 balance connection could require a major rework and is not recommended.

The recommended design practice for tube-side steam reboilers is to balance the condensate vessel to the outlet cavity of the channel head, on the side of the head and just below the pass partition/divider plate (Figure 9). A balance in this location brings the outlet pressure (115 psig) to the condensate vessel (115 psig) and enables flow to fill by gravity head.

De-ethanizer reboiler case review

The Figure 10 diagram provides insight into a de-ethanizer reboiler using four secondary pressure drainer (SPD) pumps/traps to drain condensate and discharge into the return header. Unfortunately, the system was improperly balanced and was not able to function, necessitating the waste of over 17,000 lb/h condensate to sewer for years (~18,000,000 gal/yr in drought area). A quick review of relative factors follows:

1. P_2 pressure = 5 psig
2. P_4 system back pressure (TDH) = 38.5 psig, so this system needs a pump solution!
3. P_2 pressure is balanced to a reservoir pipe
4. The reservoir pipe with P_2 pressure is balanced to the SPD pump
5. Reboiler high pressure drop = 2.4 psi
6. P_3 outlet pressure = 2.6 psig
7. Motive pressure to SPD pump = 52 psig, sufficient to pump against P_4 = 38.5 psig
8. The 2-in. channel head tapping is reduced to 3/4 in.

The question becomes, "Why was there difficulty when the SPD motive pressure of 52 psig was 13.5 psig higher than the back pressure (38.5 psig)?" Figure 10 explains the simple hydraulic issue that prevented this system from operating properly. The P_3 outlet pressure is 2.6 psig and the 6-in. condensate header acting as a reservoir had P_2 balance pressure of 5 psig. Condensate pushed by 2.6 psig cannot discharge into 5 psig unless the reboiler is 6 ft higher than the reservoir, but in this case, it was only 3.2 ft higher. This created a negative pressure differential, and hydraulically, the system could not drain as required.

The project engineer designed the system similar to how electric pumps could have been installed, but SPD pumps (as shown on pedestal) were used instead to avoid potential NPSHR (net positive suction head required) challenges posed by electric units. This electric pump design resulted in an installation footprint occupying over 400 ft^2 of the second level deck, and although the piping installation was of high quality, the improper balance and low-level piping removed the opportunity to pump the condensate.

There was another piping challenge to making a simple improvement to the system. The reboiler equipment designer had the correct idea and installed a 2-in. balance connection at the proper location on the channel head. However, the piping/process engineer reduced the 2-in. connection to 3/4 in. with a 3/4-in. valve instead of a 2-in. valve (Point 8 above). This made retrofit while operating a much more difficult task.

The recommended solution of a quad pump/trap package system, shown in Figure 11, occupies a much smaller 45-ft^2 footprint and could be relatively easy to install had the reboiler 2-in. channel head tap remained original size without reduction to the 3/4-in valve. Because the channel head tap was reduced, either a shutdown or hot tap on the other side of the channel head was required for retrofit. A basic recommendation is to use caution if considering to reduce the size of a channel head tap to be certain of its intended purpose and

DE-ISOBUTANIZER ISSUES*
P_2 not measured
Insufficient differential P_3 : P_4
Balance line size reduced
Balance line connects to P_2 steam
Insufficient differential P_3 : P_2
Isolation valve on balance line closed
Closure removes balance capability
Cannot back balance
No drum venting

*These factors were identified as potential causes of poor control performance potential detriment if reduced.

In addition to the environmental impact from wasted water, it should also be noted that dumping this amount of condensate requires an additional approximate 9,300 ton/yr of steam and 1,900 ton/yr CO_2 to be produced that could be avoided if just 100ºF condensate could be returned to the boiler.

De-isobutanizer reboiler case review

The two reviewed de-isobutanizers (DIB) on an alkylation column operated simultaneously, used 30,000 lb/h steam flow, and suffered from the erratic temperature control shown in the chart (top of Figure 12). There were 10 possible design-related causes to the poor performance (see box on previous page) which can be explained as follows, with reference to points shown in Figure 12:

1. P_1 pressure = varied 130–150 psig
2. P_4 system back pressure (TDH) = 43 psig, so there appears to be sufficient pressure to overcome with P_1 pressure
3. P_2 pressure = 50 psig
4. P_3 pressure = 45 psig
5. P_3 pressure confirmed by the 42–48 psig pressure reading
6. Balance line is connected to P_2, bringing P_2 pressure into the drum
7. 2-in. balance line is reduced to 1 in.
8. Balance line valve is shut off
9. The line is flooded — balance cannot occur through a flooded line
10. The system is “group-trapped” to a single drum/ OCV arrangement

With a P_1 of at least 130 psig against a P_4 of 43 psig, the design team must have felt there was sufficient pressure and adequate reboiler area to accomplish the process benchmark with minimal issues. However, the system’s P_3 low 42-psig pressure showed evidence of a stall condition, as well as other issues that prevented the desired performance.

Consider first that the balance line brings P_2 pressure of 50 psig to the drum, making discharge from the P_3 reboiler outlet pressure impossible at times without backing up condensate into the reboiler for needed head pressure from gravity to overcome the higher drum pressure. The site must have realized this issue because at some point they simply closed the isolation valve on the balance line, removing the 50 psig restriction to flow into the drum. However, since it is not possible to balance back to the reboiler through the flooded line routing condensate to the drum, this action then created a new issue. Once balance capability from the drum is removed, this causes a “pressure block,” as the drum vapor pressure is compressed from condensate displacing some drum volume. With no place to vent, the steam (and incondensable air) is compressed to higher pressure and restricts flow until some steam condenses — or until condensate backup into the reboiler gains additional gravity fill head to overcome the higher pressure.

While not the best practice, one potential mitigating

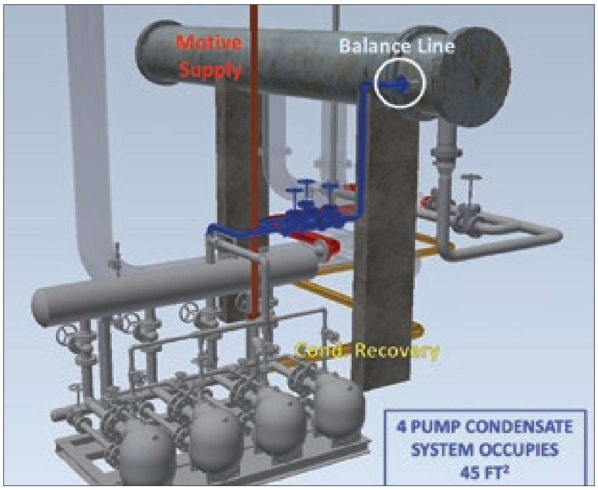

FIGURE 11. A package system mitigates piping errors and provides a much more compact drainage capability

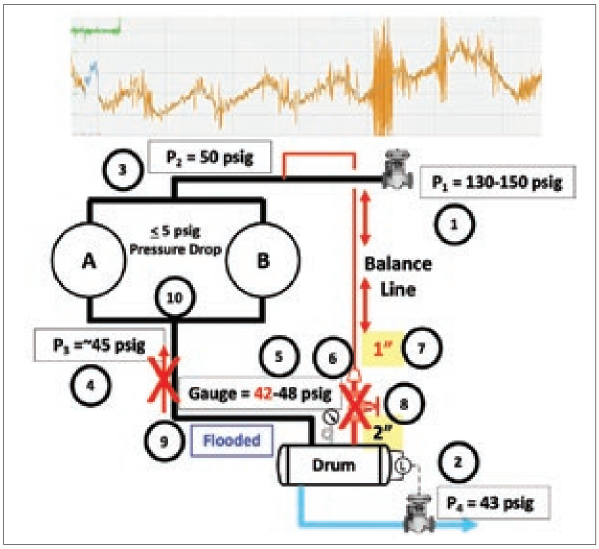

FIGURE 12. Ten potential design issues were identified that could have led to the poor temperature control

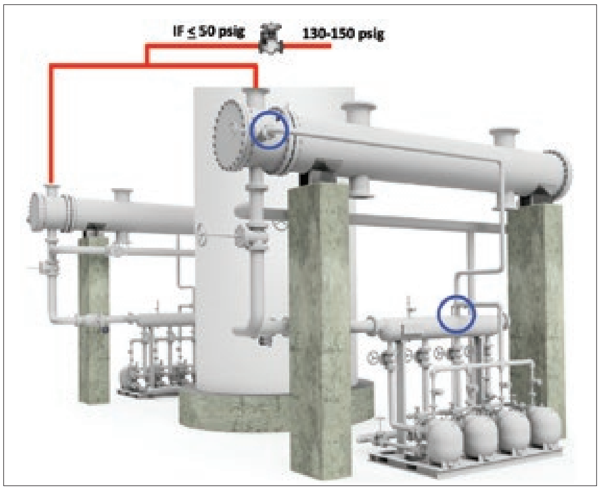

FIGURE 13. Individual quad combination pump/trap package systems can be retrofit to handle a stall condition

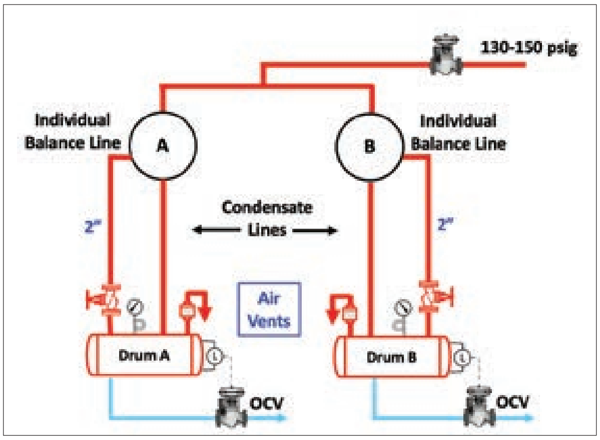

FIGURE 14. Individual condensate drum/OCV with air vents can be used in a non-stall application

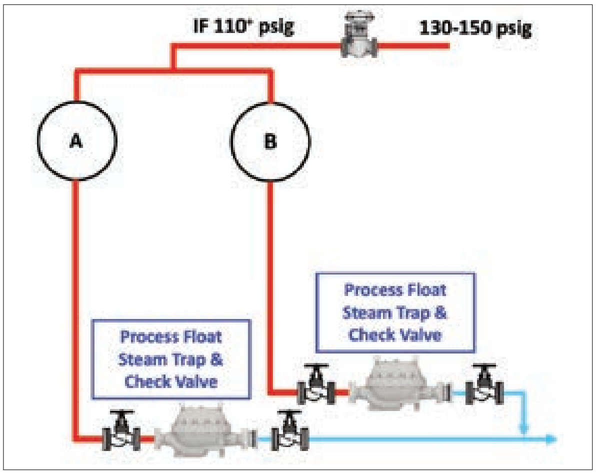

FIGURE 15. Individual steam traps with check valves are a lower cost recommendation for a non-stall application

action could have been to install a bleeder valve on the drum that could bleed off steam pressure and also incondensable air which can collect in the drum. Normally, an air vent would be recommended for a closed off system, but if a bleeder is used as a "Band-Aid" solution, then it can bleed both air and steam.

Even if the system had been properly balanced to the outlet side of the channel head just below the pass partition/divider plate, there was an additional issue of "group trapping" [*5*], indicated by Point 10 on Figure 12. This occurs when two or more condensing sources are discharged into a single condensate vessel or steam trap. Although the reboilers may look identical, there is commonly a different rate of condensation internally, which causes one of the reboiler's outlet pressure to be higher than the other. The higher outlet pressure becomes a restriction to the other's flow, thereby causing backup and erratic temperature control in that reboiler. This is why group-trapping condensing equipment is almost never recommended.

Because the equipment experienced stall conditions, quad combination pump/trap package systems were recommended. These require a proper channel head tapping for balance (as reviewed previously in the article), which fortunately existed on the reboilers with full size isolation valves to make the installation relatively simple to accomplish. To avoid the issues of group trapping, individual quad pump/trap packages were recommended for each DIB, with proper balance to the channel head (Figure 13).

Had the reboilers sufficient positive differential pressure ($P_3 > P_4$) and not been experiencing a stall condition, individual condensate drums with OCV could have been a recommended option, properly balanced to the channel head and with air vents installed on each drum (Figure 14). This would have been a costlier option than needed, because with positive $P_3 > P_4$ pressure differential, simple float-style steam traps and check valves would be an easier and less costly recommendation (Figure 15).

Closing thoughts

Properly locating a simple 1– 2-in. balance line can make all the difference in successful reboiler operation. Paying close attention to this detail during the design phase of a project can yield benefits throughout the entire operational life of the distillation column. ■

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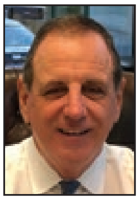

James R. Risko is retired from TLV Corp. (13,901 South Lakes Dr., Charlotte, N.C. 29873; Phone: 704-641-8959; Email: jimrisko@gmail.com), where he was president and responsible for U.S. and Canadian operations. He has over 47 years' steam-systems experience, authored more than 60 technical articles, provided webinars to over 3,500 attendees globally, and presented papers for the Kister Distillation Symposium, Distillation Experts Conclave, Fractionation Research Inc., American Fuel & Petrochemical Manufacturers (AFPM), American Institute of Chemical Engineers (AIChE), the Ethylene Conference, Refing Community (RefComm), International Pressure Equipment Integrity Assn. (IPEIA), IETC, eChemExpo, Assn. of Energy Engineers (AEE) World and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). He co-invented the world's first combination pump/trap and created the "extended stall chart" for draining stalled coils, heat exchangers and reboilers, the "drop-down loop seal" concept to help mitigate hammer in vertical risers of flashing condensate lines, and the two-bolt combined steam trap strainer-connector. A past chairman of the FCI, he has been selected to receive its 2024 Lifetime Achievement Award. Risko is currently an Advisory Board member of both the Texas Industrial Efficiency Energy Program (TIEEP) and the TEES Industrial Energy Technology Conference (IETC), an avid tennis and guitar player, and has three energy management certifications. He holds an M.B.A from Wilkes University, and two B.S. degrees, in mathematics/education and business administration/accounting, from Kutztown University.

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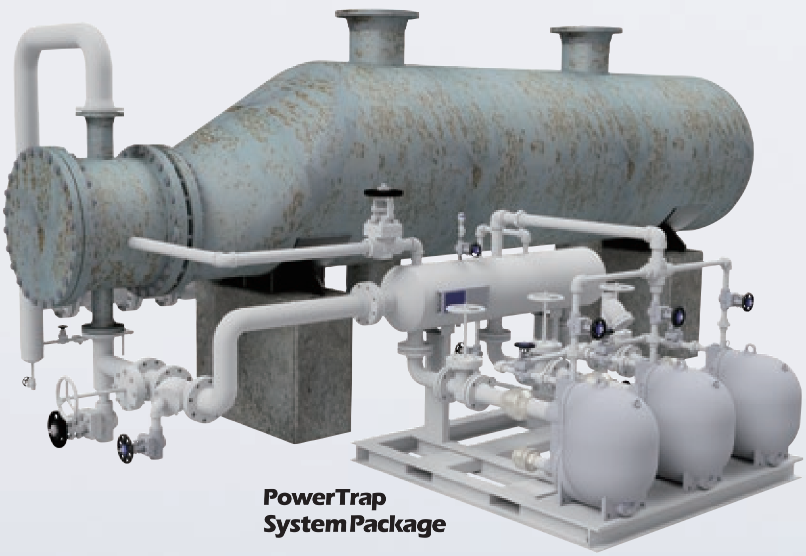

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