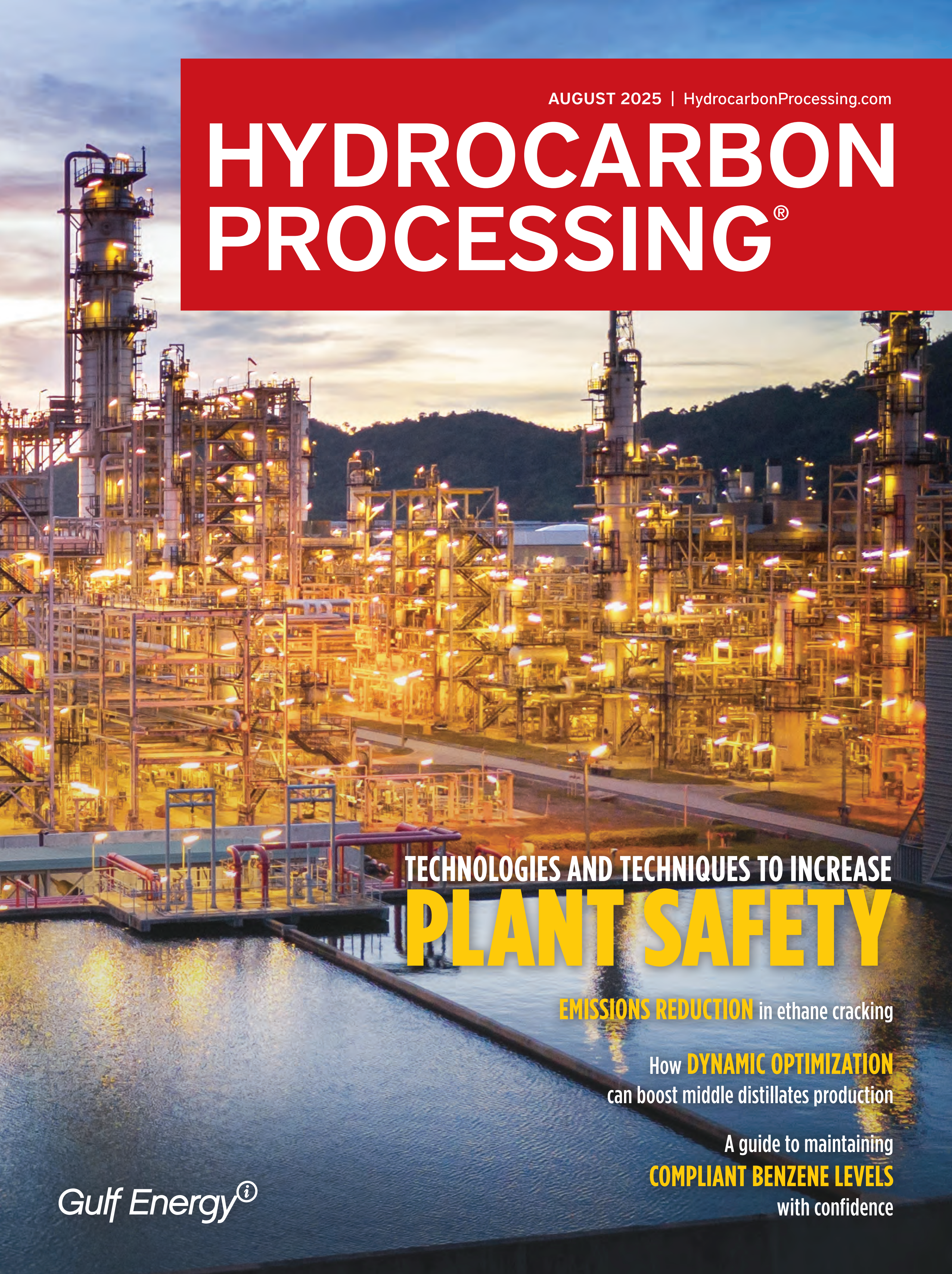

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PROCESS OPTIMIZATION

Draining inlet steam-controlled reboilers is a balancing act

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Effective condensate drainage is critical to optimized reboiler performance, but there can be numerous reasons why this goal is not always achieved. In those sub-optimal instances, reboilers can suffer from erratic process control, seal loss and lowered duty, equipment damage or steam blow-through into the condensate return header causing hammer or steam and condensate waste.

In a recent conversation with author Henry Kister, it was expressed that fewer issues can occur when the process reboil changes are less dynamic. In those applications, it can be common to use outlet condensate control (OCC) to adjust the flood level over the reboiler tubes to manipulate boil-up in response to column disturbances. However, OCC can experience challenges such as higher reboiler fouling due to higher temperature steam, control tuning difficulty from non-linear response of submergence area over the tubes, thermal stress and leaks at the channel head from the temperature difference of bottoms to steam, and tube corrosion from carbon dioxide (CO_2)—especially on horizontal reboilers.[1,2,3]

Less reboiler fouling, a more easily-controlled dynamic heat supply response and lessened bottom product degradation can often be achieved using inlet steam control (ISC), where steam pressure into the reboiler is adjusted to control temperature input as a key component to equalizing supply heat to the process's heat demand (**FIG. 1**). However, some users have reported condensate drainage issues from reboilers using ISC (specifically experiencing a stall condition), so understanding potential causes and mitigation for optimization are warranted. In consideration, methods to improve condensate discharge from ISC reboilers is the main focus of this article.

Overview comparing OCC and ISC designs. OCC on reboilers with less dynamic process changes can provide several capital benefits. Since these reboilers use the full upstream steam pressure that supplies the reboiler, the steam temperature is constant and high throughout the process: this can enable a smaller reboiler heat transfer surface area requirement. In addition to the potentially downsized reboiler, an inlet steam control valve is not required, as the outlet valve controls both the flow of steam and condensate through the reboiler.

The purpose of the outlet valve is to flow only condensate, so its size can be considerably smaller than an inlet steam control might be because an inlet valve must handle the much larger specific volume for steam that flows through it. The combination of a

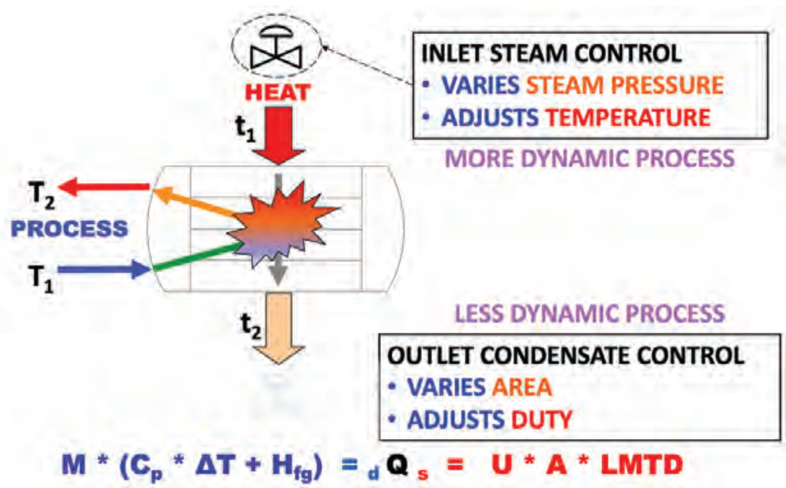

FIG. 1. Effective heat transfer requires that steam control schemes provide supply heat that can equalize to heat demand.

smaller reboiler, no inlet steam valve, no steam trap and a smaller outlet control valve (OCV) can provide significant capital savings, even when considering that a level pot is recommended to be incorporated into the OCC design.

Since the OCC design can be so cost-effective, the question might be why it is often not the best choice for more dynamic process change applications where ISC is used instead. It is important to note that OCC designs can have certain drawbacks, the most significant of which is higher tube fouling due to the higher steam temperature. In addition, control valve tuning can be difficult because of the non-linear response relative to whether the condensate coverage is being drained from the higher or lower regions of the reboiler.[1] Also, when the reboiler is heavily fouled, it is possible that OCC systems can experience seal loss and lose significant duty while discharging large steam blow-through into the return header—in one instance, the steam loss exceeded 28,000 lb/hr during peak periods of blow-through.

Generally, ISC reboiler schemes can experience a much lower fouling rate from lowered steam temperatures, are generally easier to tune the control system, and have a superior dynamic response to demand changes because the flow of steam over a fully exposed tube bundle surface occurs rapidly. As boil-up demand varies, the ISC valve changes steam pressure to adjust temperature to the logarithmic mean temperature difference (LMTD) equalization requirements. However, some of those pressure changes can result in a reboiler outlet steam/condensate pressure that is below the condensate header system P_4 back pressure, also called total dynamic head (TDH).

When this occurs, condensate often backs up significantly into the reboiler and creates numerous issues including erratic control, tube corrosion and fouling, channel head gasket leaks from thermal and hydraulic stress, with the added issue that operators may need to open a bypass valve to maintain process requirements. Opening a bypass line can result in a tremendous amount of steam blowing into the return header as well as a loss of reboiler duty. To mitigate this situation, an understanding of four pressures that can affect condensate evacuation from a reboiler can be useful.

Those pressures are P_1, P_2, P_3 and P_4, respectively representing the inlet steam pressure to the control valve (P_1), the delivery pressure from the valve outlet into the reboiler (P_2), the outlet steam pressure from the reboiler (P_3), and the back pressure or total dynamic head of the system that must be overcome to accomplish effective condensate drainage (P_4) (**FIG. 2**).[2,3,4]

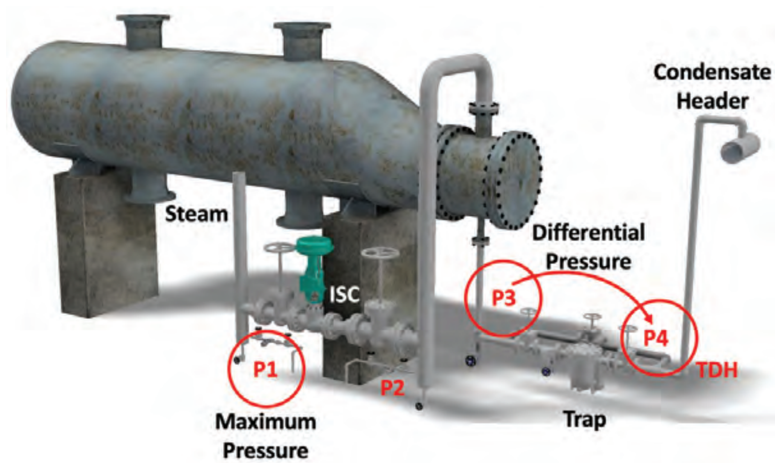

FIG. 2. These four steam/condensate pressures are important considerations to drain condensate from an ISC reboiler.

ISC reboiler drainage basics. It is common to use either a steam trap or OCV as a drainage device to discharge condensate from an ISC reboiler.[4] Essentially, the OCV is an electronic steam trap. For flow to occur through the drainage device, there must be a positive pressure differential, as shown by the $P_3–P_4$ arc in **FIG. 2.**

P_1 is also circled because the drainage device used must be suitable for this pressure should the system be put on inlet valve bypass and/or discharge condensate to atmosphere/grade instead of the return header. P_2 is the delivery pressure to the reboiler, which can adjust rapidly to provide the process temperature, and P_3 is the outlet pressure as a result of the pres-

FIG. 3. The author's preference is to use FT or FFT trap models for drainage where suited.

sure drop through the reboiler itself. P_3 is also extremely important because this pressure enables free drainage by gravity into the drainage device, whether that device is a steam trap, control valve or something else such as a pump/trap.

ISC reboiler drainage devices. In instances where there is always a positive pressure differential from P_3–P_4, condensate drainage can be accomplished by a steam trap, preferable a float and thermostatic (FT) or free float and thermostatic (FFT) type (**FIG. 3**).[4,5] Although some other trap types can be used successfully in certain instances, the author's personal preference is for FT/FFT models due to their ability to discharge condensate rapidly—in synchronization with supply steam—when they are properly sized and selected for the varying positive differential pressures and loads that can occur throughout the process cycles (**FIG. 4**).[6]

When using an FT/FFT steam trap for drainage, there are other considerations as follows for trap installation (unless the specific manufacturer recommends otherwise):

- Keep the trap close to the reboiler's vertical down drain line to mitigate against steam locking.
- Locate the trap well below the reboiler outlet flange to provide a response reservoir in the piping.
- Install a check valve after the trap to mitigate back slam damage from condensate falling backwards when discharging to an overhead or pressurized return.
- Note that FT/FFT traps have built-in air venting capability.
- If traps other than FT/FFT are used, it may not be possible to achieve both rapid, near immediate condensate discharge and air venting. Consult with the manufacturer for certified air venting and condensate subcooling data at rated load capacity in full accordance with the current ISO 5117 or ANSI PTC 39.1 standards in effect at time of selection.

FIG. 4. FT combination trap designs can discharge condensate immediately as it forms.

Saturated steam curve considerations. It can be useful to consider the impact of steam's pressure/temperature changes relative to heating demand as part of the LMTD, particularly with P_2 steam pressure at ~150 psig or lower. The slope of the saturated steam curve (SSC) is much steeper at low pressure (LP) or very low pressure (LLP) than at high pressure (HP) (**FIG. 5**).

Consider P_2 and examine the red temperature difference brackets (top, middle, low) on the top left-hand side of **FIG. 5.** A substantial pressure drop has to occur at HP P_2 relative to a smaller pressure drop to obtain a similar value temperature difference for LP or LLP steam. In the same figure, note the 45 psig back pressure line.

When P_2 is at full load HP (top blue horizontal Line A), the differential pressure against the back pressure (45 psig) is high. When the load percentage requirement for this application is lowest (blue horizontal Line B), the result is a P_2 delivery pressure (150 psig) that is still substantially above the back pressure (45 psig). That positive pressure differential for the range of temperature changes between Lines A and B equates to the possible successful selection of a steam trap or OCV with level pot for condensate drainage. It is possible to use those two pressure differentials for full load and low load to determine the trap or OCV capacity needed. To improve sizing selection, subtract the reboiler pressure drop from the differential pressure for high and low load to get the P_3 driving pressure against the P_4 back pressure.

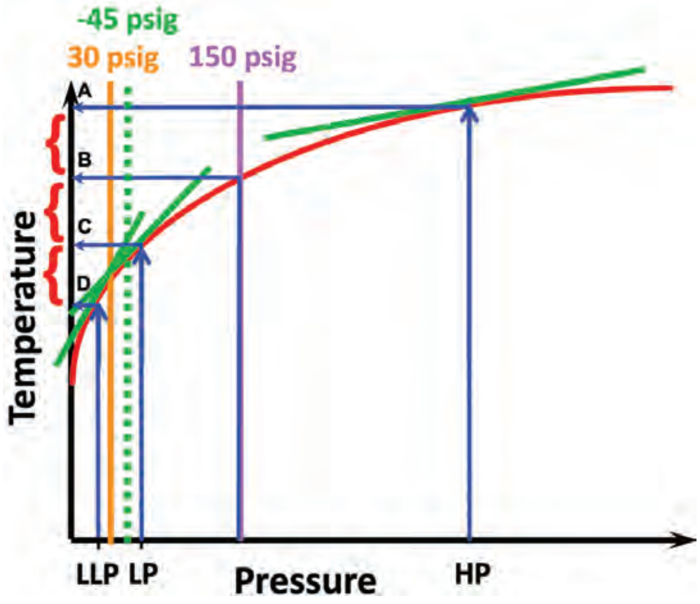

FIG. 5. The changing slope of the saturated steam curve can have an effect on P3–P4 pressure differential +/- value.

Now, consider the middle temperature bracket range of high/low loads shown by Lines B and C. The upper limit of 150 psig against the back pressure (45 psig) might initially cause design engineers to size a steam trap for the full load at a maximum differential of 105 psi (less reboiler pressure drop). However, that could create some drainage issues at the lower end of the load requirement, as the differential pressure between the vertical component of Line C to the back pressure (45 psig) is quite small. Although the trap or OCV can drain well at full load, reduced loads may cause condensate back-up into the reboiler, resulting in erratic control.

Next, consider the lower temperature bracket range indicated by Lines C and D. This initial full load P_2 barely has a positive pressure differential against the back pressure (45 psig)—when the lowest load occurs, the resultant P_2 (vertical component of Line D) is significantly below the back pressure (45 psig). Note that the P_2 pressure is positive, not in vacuum, but the pressure differential against the P_4 back pressure is negative. Condensate can be expected to back up into the reboiler and create a multitude of issues as outlined earlier.

There simply is an insufficient driving force to push condensate against the back pressure. In this instance, the P_2 pressure is positive; however, many instances have been seen of reboilers where the P_2 delivery pressure reaches vacuum to equalize the supply heat to the demanded heat, and these can be even more challenging to drain. When the P_3 pressure is equal to the back pressure, a "stall point" is reached as explained in the author's pioneering work for this phenomenon.

Although HP P_2 pressures generally do not create pressure differential issues in ISC reboilers, strict pressure differential consideration is recommended with P_2 pressures of 150 psig or less, and heightened awareness when LP or LLP P_2 pressure is used (**FIG. 6**).

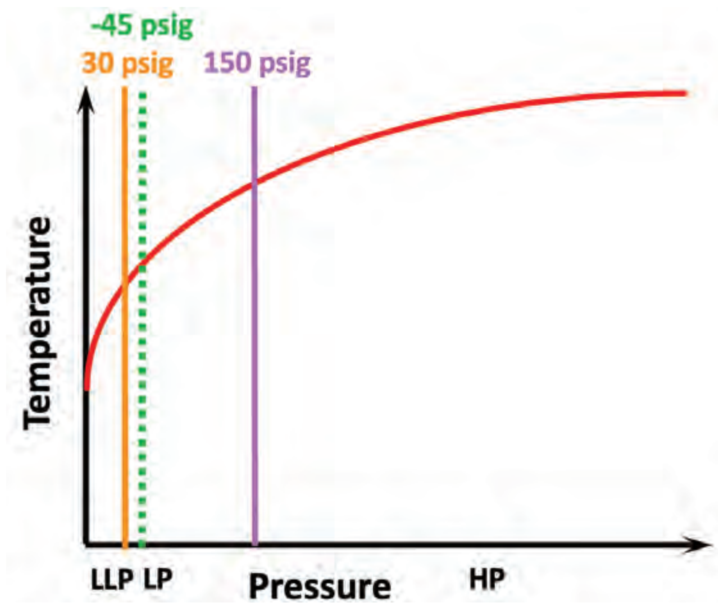

FIG. 6. ISC stall issues can be more prevalent when the P2 pressure is 150 psig or less, particularly when LP or LLP.

Method to estimate pressure differential. A commonly recommended method to determine P_2 pressure is to perform an LMTD calculation from which the supply steam temperature and resultant pressure can be determined. However, a potentially simpler and faster method is to use the extended stall chart (ESC) the author created for industry and published in 2004 (**FIG. 7**).[2–5, 7]

The first view of the ESC can be daunting, but it is well explained in several of the author's articles. For an easy understanding, examine the large red dot in **FIG. 7** labeled the "stall point." This estimates the percentage demand load where the P_3 steam pressure is equal to the P_4 back pressure. Note that an online calculator to estimate stall point and pressure differential is available for use at no charge.[8]

If the low load condition of the application is 85% of full load, a positive pressure differential is indicated by the two red circles shown above the vertical blue line on the left. In this case, a steam trap can be used if properly selected and sized because the differential remains positive.

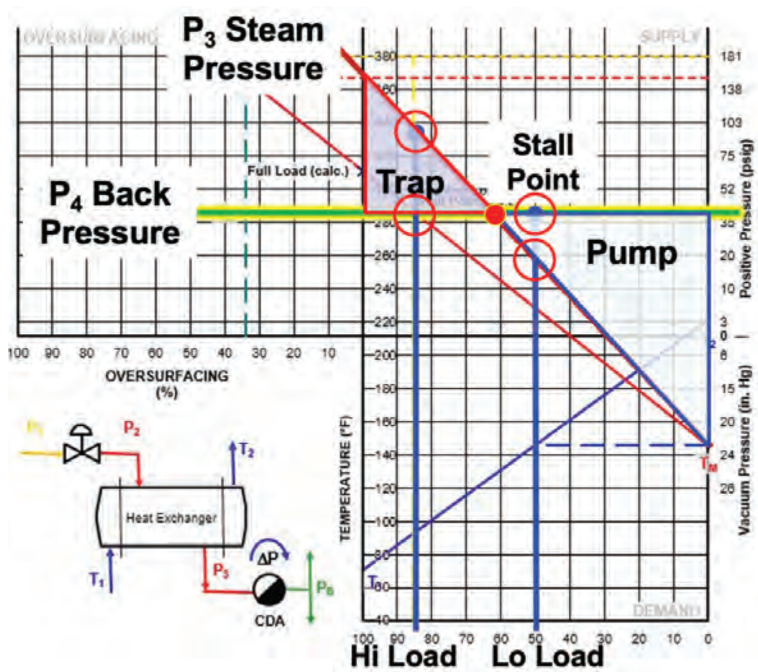

FIG. 7. The ESC can be used to determine available pressure differential, and can result in the selection of a trap or pump/trap.

If reading the pressure vertically up from the blue line on the right side of **FIG. 7** (50% load condition), it can be seen that the P_3 steam pressure is lower than the back pressure, which is a negative pressure differential condition. In this application, condensate should be pumped if it is to be recovered without backing up into the reboiler. Many LP and LLP applications require a pumping method for optimized reboil control.

If condensate does back up into the reboiler, the rising liquid level removes the effective steam heat transfer area. Then, the decreased area necessitates the steam pressure to increase. This can typically cause erratic reboil control with significant damage to the reboiler itself and is not recommended. This is why a pumping method is preferred.

Electric pumps have been used in some instances in combination with level pot/level control on the pump supply and head control valve on the outlet. This arrangement can be successful if properly designed, but the condensate temperature's effect on the net positive suction head available ($NPSH_A$) can be challenging for the pump's net positive suction head required ($NPSH_R$).[9]

Another method is to use a mechanical combination pumping and steam trapping unit, commonly referred to as a pump/trap or secondary pressure drainer Type 2 (SPD2). The pump/trap is preferred as it was the name this author used during pioneer work.

A cut-away view of the first type of combined pump/trap unit is shown in **FIG. 8.** The vertical line at the top of the pump filled in pink is the exhaust that enables vapor to flow out of the unit body. This allows condensate to enter through the top horizontal line filled in blue. A mechanical switching mechanism at the top of the unit is activated by the movement of the ball float as condensate level changes. When the float/liquid level is elevated high, the switching mechanism allows the body to be pressurized and higher-pressure motive steam enters through the top horizontal line filled in hot pink color. This action pushes condensate through the bottom horizontal check valve represented in blue fill color.

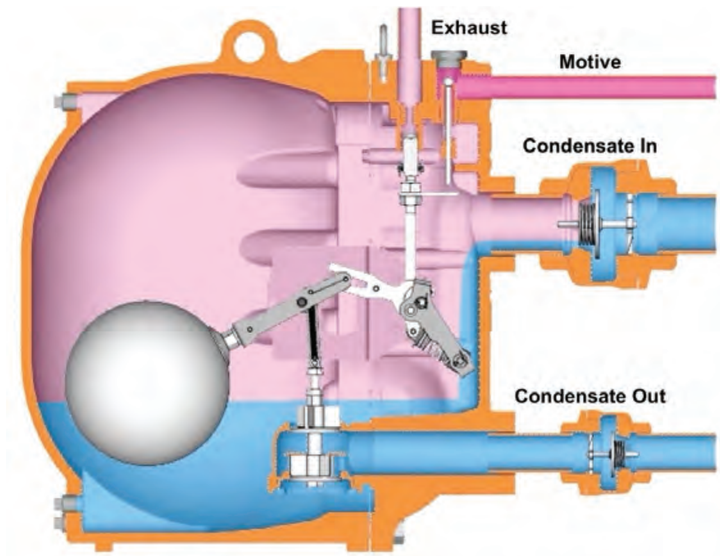

FIG. 8. A pump/trap combination unit has a steam trap to mitigate steam loss, and a pump to overcome higher back pressure.

Pump/trap installation considerations. A significant amount of condensate drainage issues occur when a horizontal, tube-side steam reboiler is LP or LLP ISC and its condensate outlet flange is close to grade. For a retrofit with a pump to mitigate problems, there may not be enough head for an electric pump, nor will it fill the head to promote gravity drainage into a pump/trap's necessary reservoir. To optimize the installation cost on new installations, it is recommended to have the reboiler's condensate outlet flange relatively high above grade (~80 in., depending on that pump/trap manufacturer) so that the least amount of pump/traps can be used with a ~60-in. (depending on the pump/trap manufacturer) fill height to the reservoir (**FIG. 9**).

Having an elevated reboiler enables a higher reservoir, which in turn accelerates condensate into the pump/trap body. This "acceleration head" shortens the condensate filling time and provides more discharge cycles to increase the pump/trap's discharge capacity, potentially lowering capital cost and complexity.[9]

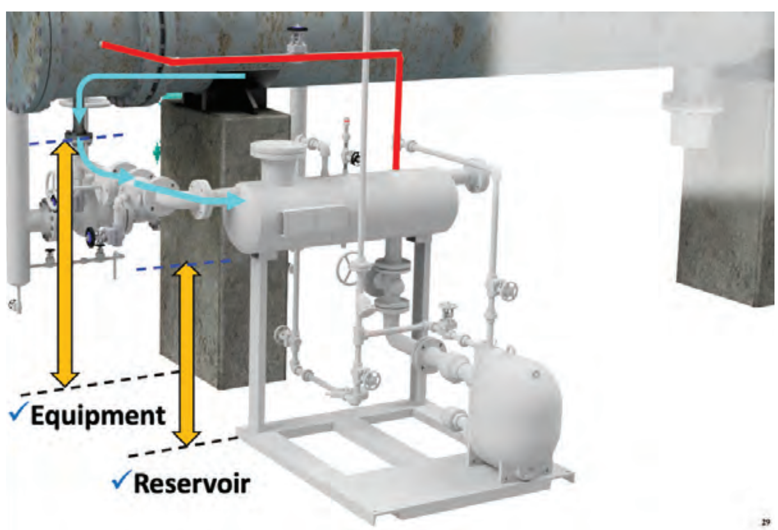

FIG. 9. A typical pump/trap system can be optimized with recommended equipment and reservoir elevation from grade.

The red line in **FIG. 9** is the vapor balance to the outlet side of the reboiler channel head. This allows exhausted motive steam to route back into the reboiler, and the vapor volume reduction enables smooth condensate flow into the pump/trap's reservoir.[2,3]

There are several notable design recommendations when using a pump/trap system package consisting of a reservoir, piping, valves, air vent and check valve (**FIG. 10**) (depending on pump/trap manufacturer):

- The balance line should not have any piping loop or reverse pitch that can pool condensate and choke balancing.
- The balance line from the pump/trap to the reservoir should not exceed a height of 10 ft.
- The balance line must connect to a vapor space that is the same pressure as the pump/trap condensate supply (P_3).
- Balance line valves should be kept at full port to minimize balancing restrictions.
- The balance line on horizontal tube-side equipment must connect from the reservoir to a properly-sized tapping on the outlet side of the channel head, just below the pass partition/divider plate (**FIGS. 10** and **11**).
- The reservoir must be properly sized to hold the condensate that backs up during the pumping cycle without adversely affecting the required vapor space for balancing from the pump/trap to the reservoir to the reboiler.
- An air vent on the reservoir is commonly installed to allow built-up air to be discharged to the atmosphere when the P_3 pressure is above atmosphere.
- A check valve is needed at the outlet of the air vent to mitigate against air infiltration when the P_3 pressure is below atmosphere.
- Condensate must free drain by gravity into the reservoir.
- The motive line enters the pump/trap from the side, not the top (to reduce condensate build-up between cycles).
- The motive line is drained by FFT or FT trap (to reduce condensate build-up).

In the conversation mentioned earlier in this article, it was discussed that issues with mechanical pump/traps may be caused by inconsistencies relative to the bullet points outlined above.

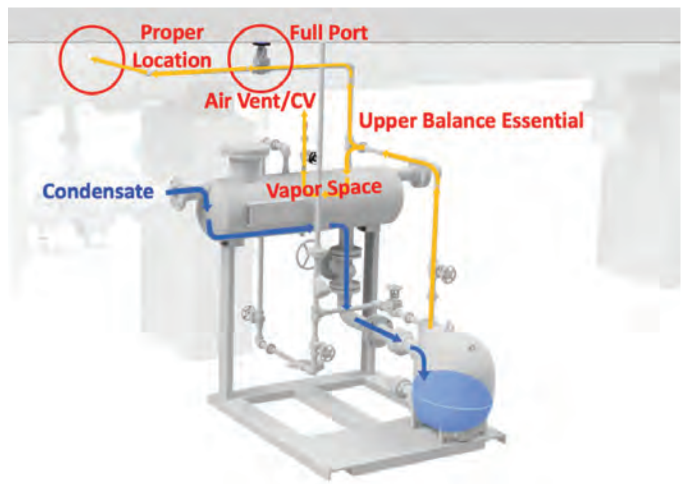

FIG. 10. To discharge against higher back pressure, one option uses a flash receiver and pump after the steam trap.

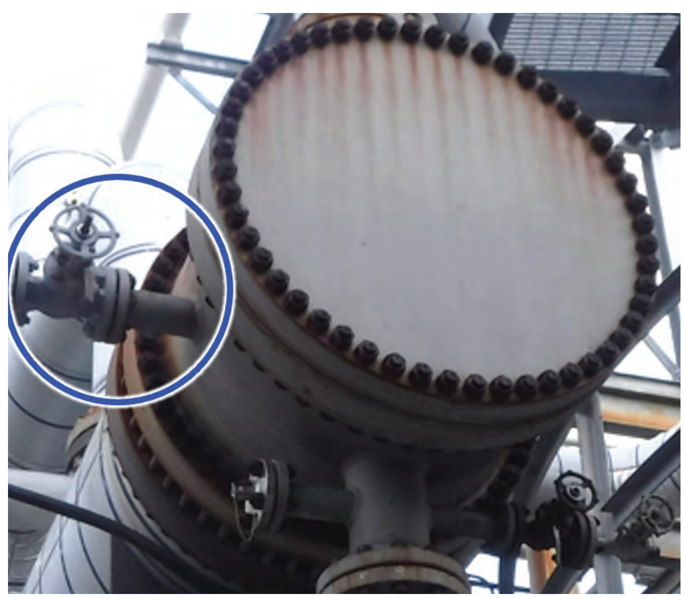

FIG. 11. Tube-side steam reboilers require an outlet-side, channel head large tapping for effective pump/trap operation.

An alkylation heartache and recommendation. One of the installations reviewed onsite involved an alkylation unit with two reboilers operating simultaneously side-by-side. The P_1 supply pressure was in the 130 psig–150 psig range and the P_4 back pressure was approximately 43 psig. At the onset, there seemed to be a sufficient pressure differential of ~87 psig to overcome the back pressure, but this system experienced drainage challenges. An investigation revealed multiple potential issues.[3,5]

The design had both reboilers discharging into a large drum with a single OCV to maintain level and discharge. However, the original balance line to the drum was pulled from the P_2 location which, when measured at the drum inlet, could result in a drum pressure that was higher than the reboiler's outlet P_3. This was expected to have interfered with drainage into the drum, resulting in backup into the reboiler until sufficient liquid head built up. In addition, the drum pressure sometimes fell below the P_4 back pressure, resulting in a stall condition.

There were other potential issues, including no air venting on the drum, and having two reboilers feeding into the same drum can create a group trapping and pressure imbalance issue.[5] While the single drum/OCV installation probably had a low installation cost, the site suffered for multiple years from the negative effect on the reboilers.

If the system always maintained a positive pressure differential, one properly sized steam trap with a check valve for each reboiler could have accomplished effective drainage. However, since a stall condition was anticipated, a more capital-intensive quad pump/trap system (**FIG. 12**) and a proper balance location to the channel head tapping (**FIG. 11**) were recommended for mitigation on each reboiler.

Takeaways. LP and LLP ISC reboilers can provide lower fouling and greater dynamic response, but often experience stall conditions. It can be useful to perform a simple ESC calculation to determine if further investigation is needed before finalizing design.[8] If a pump/trap solution is selected, the reboiler outlet flange height, proper balancing and location, reservoir height and volume sizing, vapor space, air venting and infiltration mitigation are useful components to consider. HP

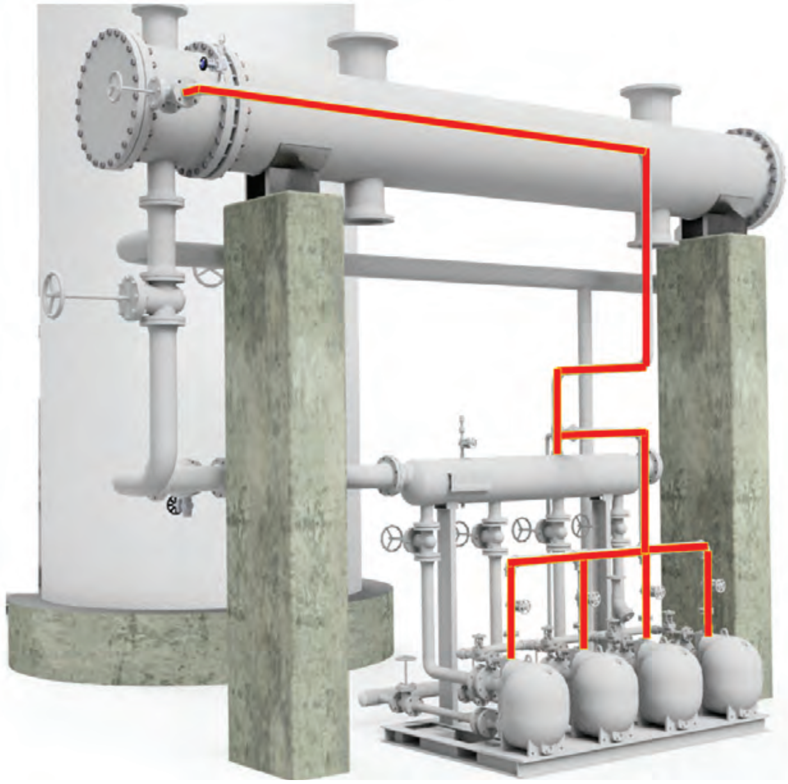

FIG. 12. This properly-balanced, quad pump/trap system was recommended to mitigate issues with an Alky reboiler.

ACKNOWLEDGEMENT

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