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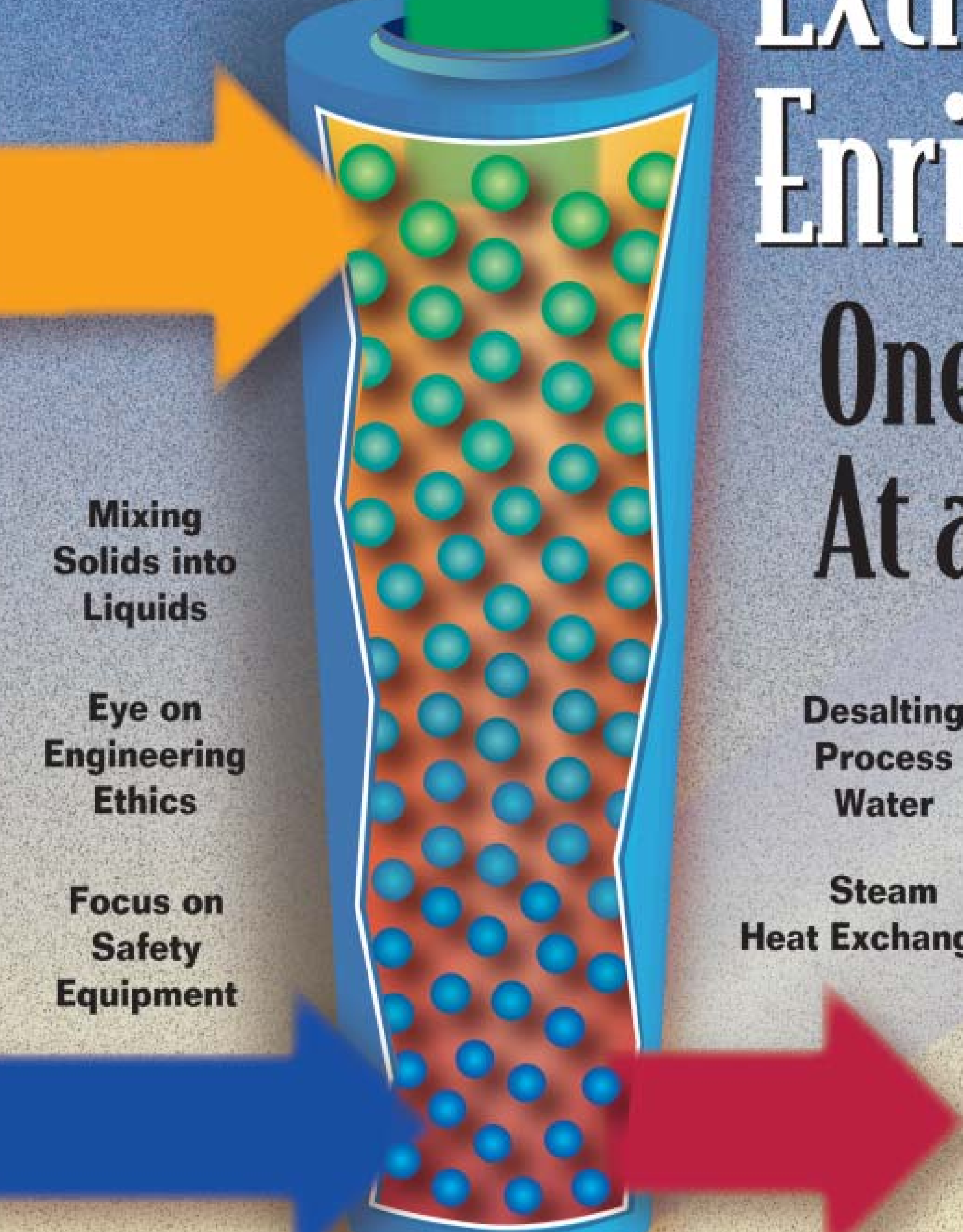

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Steam Heat Exchangers Are Underworked And Over-surfaced

An 'Extended Stall Chart' delivers effective condensate drainage

James R. Risko
TLV CORPORATION

One of the more difficult challenges facing process and maintenance engineers is to fully understand the steam-pressure dynamics in over-surfaced heat exchangers using modulating control with varying load conditions. And this challenge can be common because indirect heating by steam is often employed for heating process streams. Heat exchangers employed in this service are known as process heaters.

The stall chart, which compares steam pressure at various steam-heater turndown ratios with the system back pressure, provides a general overview of a given steam heating application. A basic understanding of this industry tool is necessary, and can be acquired from a variety of sources [1]. However, the basic stall chart assumes that the steam heater has not been oversized, which is usually not the case; heat exchanger area is generally over-surfaced for fouling factors and capacity considerations.

An effective alternative is the extended stall chart (ESC). Easy to employ, this plot readily accommodates oversizing.

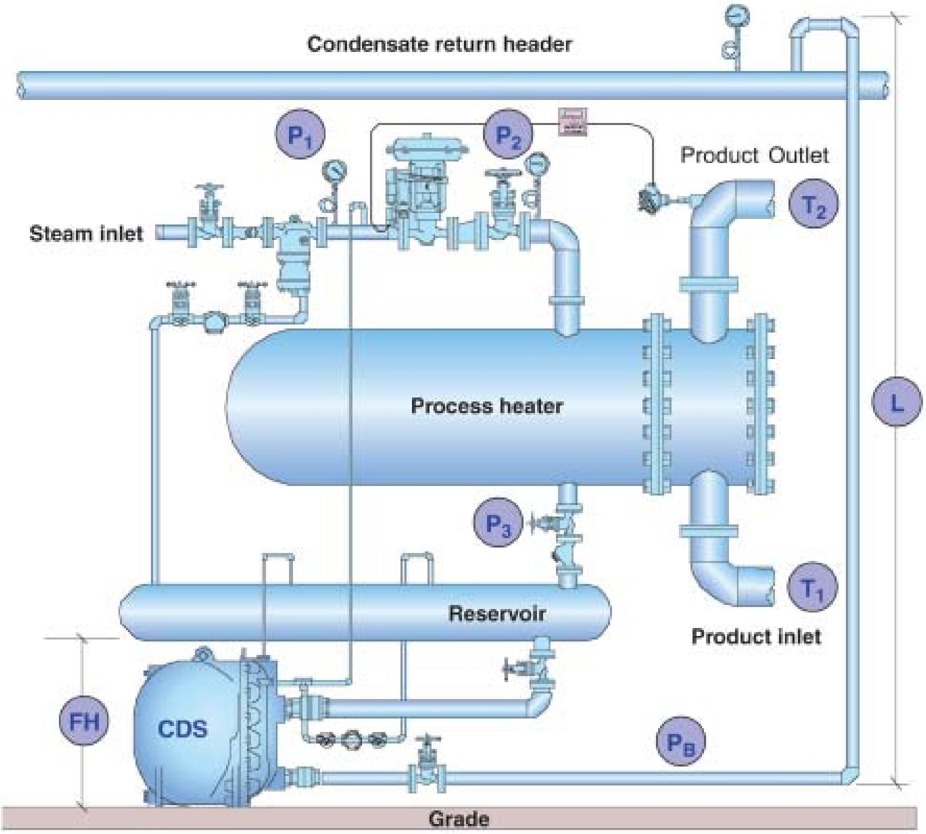

FIGURE 1. If the inlet pressure (P_3) to the condensate-drainage solution (CDS) drops below the back pressure (P_B), there will be a negative pressure differential across the CDS, and a "stall" condition will occur

Review of the stall chart

As the demand load varies in any heat exchanger using inlet-modulating steam control, the delivered steam-pressure profile will correspondingly change. As an example, consider the heat exchanger (process heater) shown in Figure 1. For this setup, the steam-supply pressure (P_1) can be relatively constant at a typical value of 150 psig. But the pressure (P_2) of the steam delivered directly to the heat exchanger by the control valve may vary greatly. That means the inlet pressure (P_3) to the condensate-drainage solution (CDS) will also vary considerably. (For simplicity, it is assumed that no pressure drop occurs across the heat exchanger, so $P_3 = P_2$).

If the pressure P_3 falls below the back pressure (P_B), there will be a negative pressure differential across the CDS. When this situation arises, the condensate cannot drain out, so it

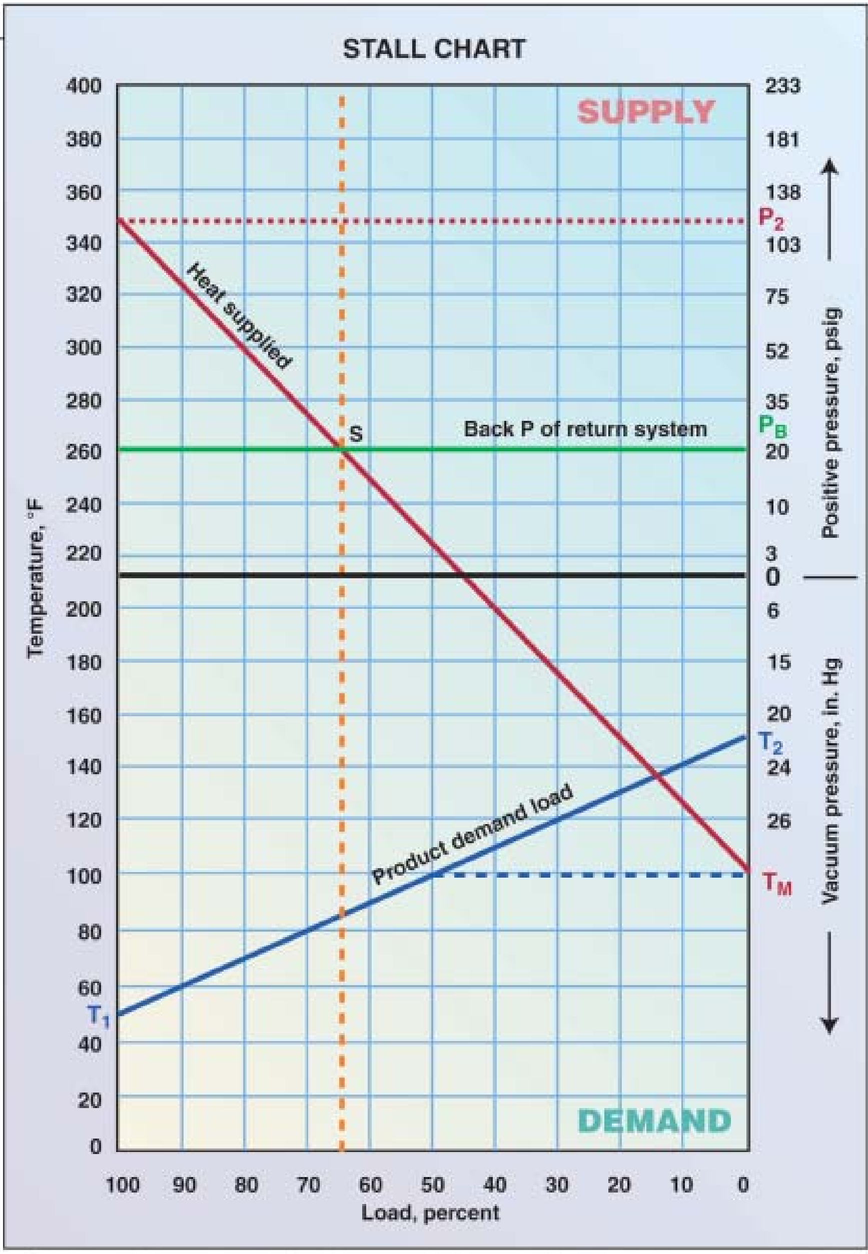

FIGURE 2. The stall point for this example, described in the text, occurs at 65% load

backs up into the steam side of the heater. This state of affairs is commonly refered to as a system "stall."

The first condition to understand when making the stall chart is that, even under full demand load, the maximum P_2 pressure will be the P_1 pressure minus the control valve pressure drop. If, for this example, the control valve pressure drop is 25 psi, and the steam-supply utility line loss equals 10 psi, then the delivered-steam pressure (P_2) will be a maximum of 115 psig.

Therefore, a P_2 of 115 psig is the pressure that should be converted to steam temperature and it is this value that is input into the stall chart as the steam profile at 100% demand, not the supply steam pressure, P_1, of 150 psig. The 115 psig value for P_2 is shown in the stall chart in Figure 2.

The second condition to review is the effect that varying load conditions have on the supply steam requirements for pressure and temperature. The control system adjusts the steam pressure and temperature to balance the delivered heat with the load. So, if the demand load drops, the steam pressure will also drop. Since less temperature is needed with decreased demand, lower temperature can balance the need and this causes the steam pressure to lower.

This can be seen by looking at the basic heat-transfer equation:

$$Q = (UA)(LMTD)$$

where *UA* is the characterizing coefficient (the product of the heat-transfer coefficient and surface area), and *LMTD* is the logarithmic mean temperature difference across the heat exchanger. Because the product *UA* is relatively constant, the steam temperature must drop when the load drops.

For this example, suppose that the back pressure (P_B) is 20 psig (solid green line) and that the product temperature increases from 50°F (T_1) to 150°F (T_2). The mean temperature of the process fluid, T_m, is 100°F, which is entered on the right. (Note that the values of T_m and T_2 are found on the left axis but plotted on the right axis.)

Control adjustments affect the steam-pressure profile, and the resulting steam pressure for a load percentage is recorded on the stall chart as the descending solid red line on Figure 2. It is formed by connecting the points P_2 (actually, its equivalent on the temperature scale) and T_M.

The stall point (*S*) occurs where the red and green lines intersect, or at at 65% load for this example. The dashed orange vertical line through the Demand section indicates the caution for a stall condition.

The demand load can also be graphically represented as a product temperature increase on the same stall chart as the ascending solid dark blue line, connecting the temperature points T_1 and T_2. And the equipment's heat-transfer capability from surface area is noted by the left hand side of the bottom hoizontal axis where the load condition is 100%.

To summarize, the basic stall chart actually represents three different environments in one. Those are:

- The product-demand load, shown by the solid blue line, usually starting in the lower left of the Demand section
- The heat supplied by the combination of steam supply and the equipment heat transfer surface, shown by the solid red line starting in upper left of the Supply section
- The back pressure of the return system, shown by the solid green line, usually drawn in the Supply section

Such a stall chart is relatively compact, due to the hypothetical situation where the demand heating requirement **exactly** meets the installed heat exchanger surface area. [In such a

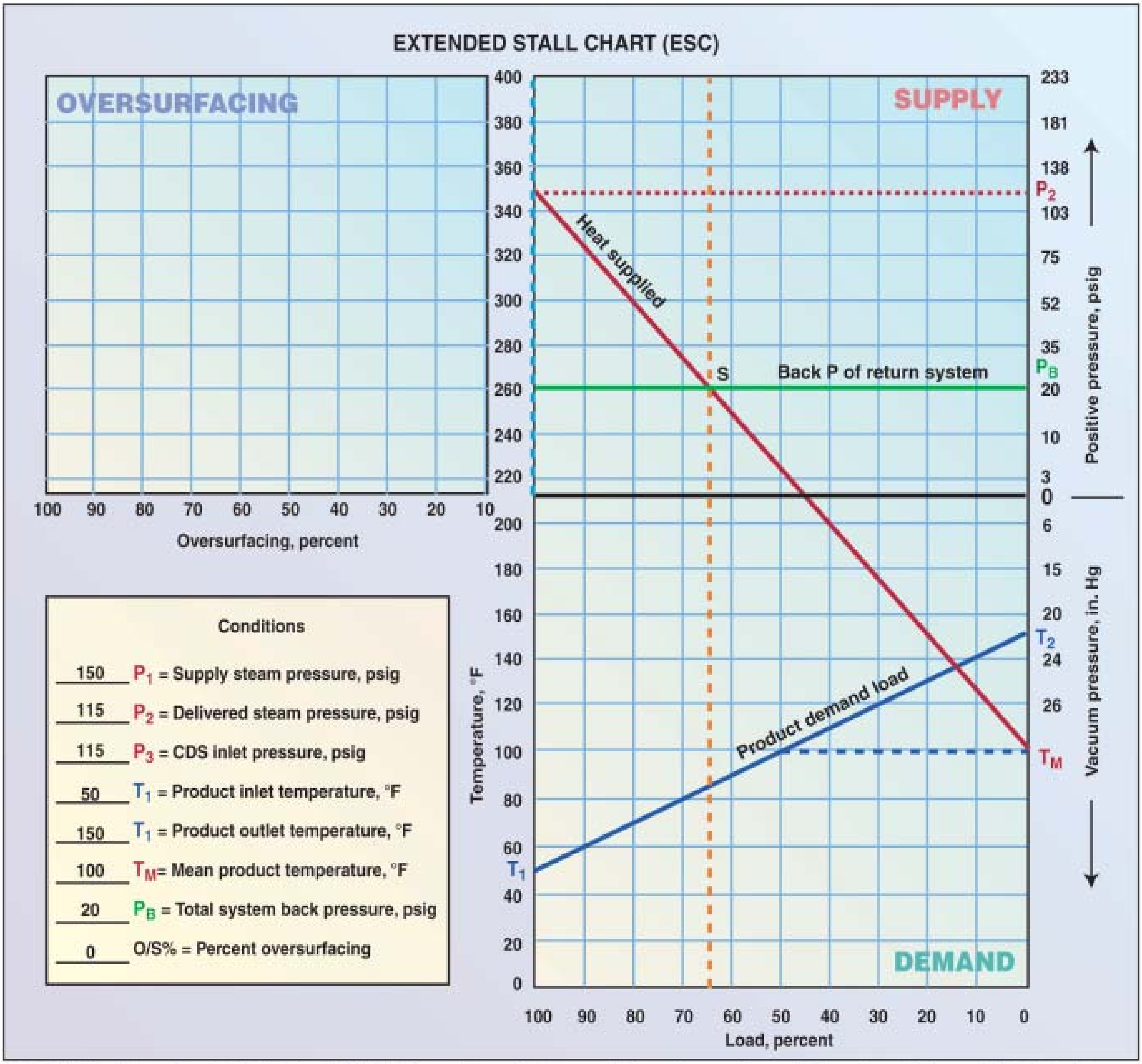

FIGURE 3. The extended stall chart (ESC) is formed by adding an additional, equally scaled quadrant (Oversurfacing) in the upper left-hand side. This new quadrant begins at P_B, as shown here. The surface area equal to 100% of the demand, with no over-surfacing, is indicated by the dashed light blue line on the left hand vertical axis of the Supply quadrant

case, $MC_p(T_2 - T_1) = Q = (UA)(LMTD)$, where M is mass flowrate and C_p is heat capacity at constant pressure, and the exchanger has no excess surface area.] While nearly impossible to achieve, the heat and surface area supplied are exactly equal to 100% of the demand, and the three environments are superimposed in the 100% scale stall chart shown in Figure 2.

The extended stall chart

Heat-exchanger area is generally oversurfaced for fouling factor and capacity considerations. The stall chart discussed above does not provide for recording the amount of over-surfacing. Therefore, a new stall chart is needed; one where over-surfacing can be graphically demonstrated in an additional quadrant to account for extra surface area.

This new, "extended" stall chart (ESC) improves the estimation of available pressure differential across the condensate-drainage device. The conditions of Figure 2 can be input and graphically demonstrated for comparison on the ESC (Figure 3). The surface area equal to only 100% of the demand, with no over-surfacing, is indicated by the dashed light-blue line on the left hand vertical axis of the Supply quadrant. So far, the results of Figures 2 and 3 look similar.

However, the ESC can be used to predict extremely valuable information. A leftward ascending line can be drawn from the point T_M on the right hand axis of the Demand quadrant through an intersection of the P_B line with the left hand axis of the Supply

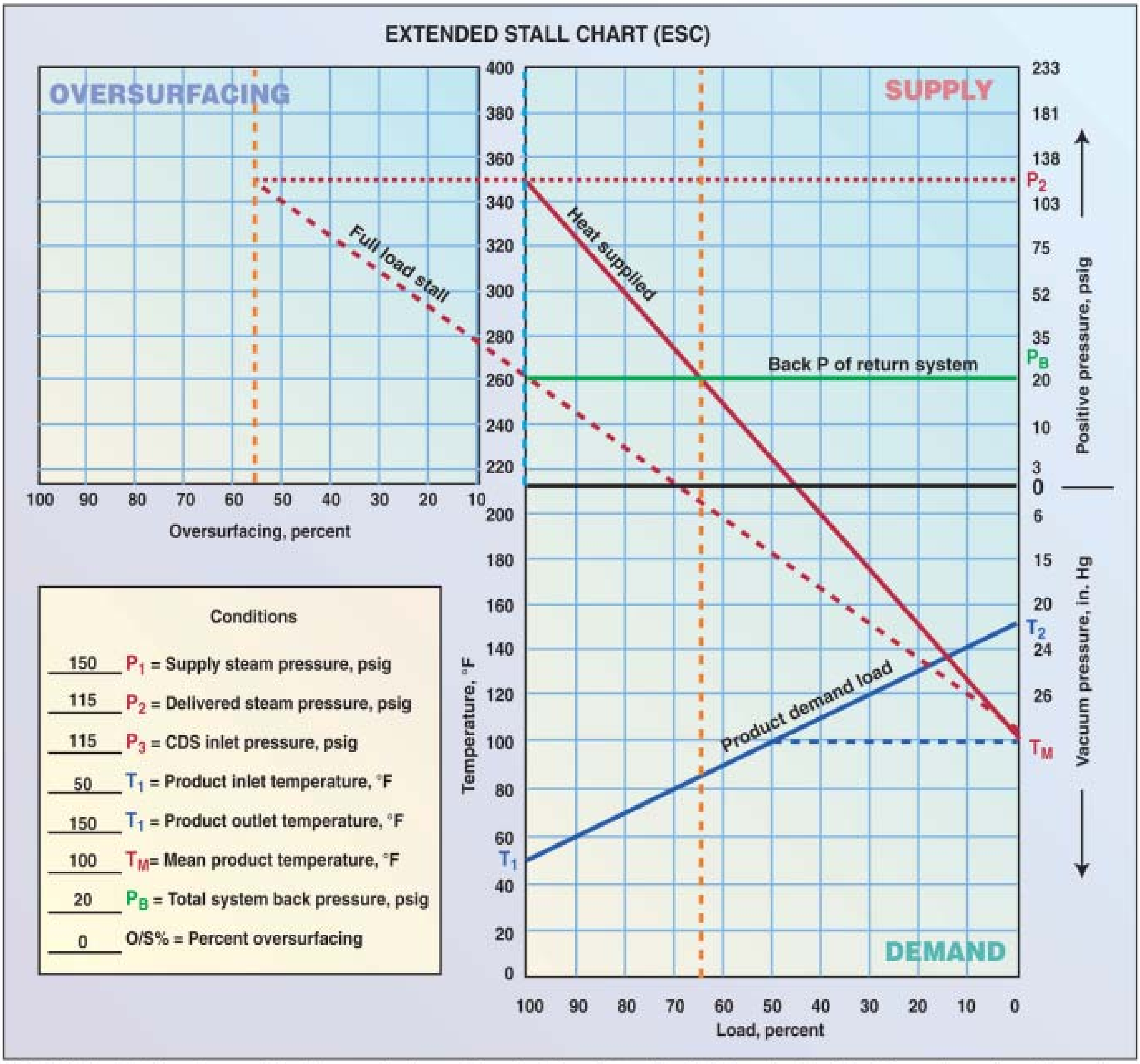

FIGURE 4. A leftward ascending line can be drawn from the T_M point on the right hand axis of the Demand quadrant through an intersection of the P_B line on the left hand axis of the Supply quadrant, and continue into the Oversurfacing quadrant to intersect with the P_2 pressure line

quadrant, and continue into the Oversurfacing quadrant to intersect with the P_2 pressure line. This is shown by the dashed red line in Figure 4.

The intersection of the dashed red line with the back pressure at 100% load provides a useful caution. It identifies the amount of over-surfacing and the pressure profile where the equipment is **always** under a stall condition. With this over-surfacing, the equipment will stall even with 100% demand, so this is called a full-load stall (FLS). By extending this dashed red line into the Oversurfacing quadrant, one can see in this example that 55% over-surfacing will lead to a FLS. Therefore, the amount of over-surfacing causing a FLS is shown with a vertical cautionary dashed yellow line in the Oversurfacing quadrant.

So, the ESC can be used to warn designers if the selected over-surfacing amount will lead to a FLS. Additionally, the ESC can predict the actual stall point more accurately than can the older style stall chart.

For example, suppose that the heat exchanger of the previous example is 40% over-surfaced. That supply capability of the heat exchanger now can be quickly drawn graphically in the Oversurfacing quadrant (the vertical dashed light blue line in Figure 5). Although the exchanger is over-surfaced, the demand does not increase. Therefore, the Demand Load (solid dark blue line) is input on the 100% scale, but the Supply Steam (solid red line) is input on the 40% over-surfacing scale.

The design impact is significant. When the design conditions were input

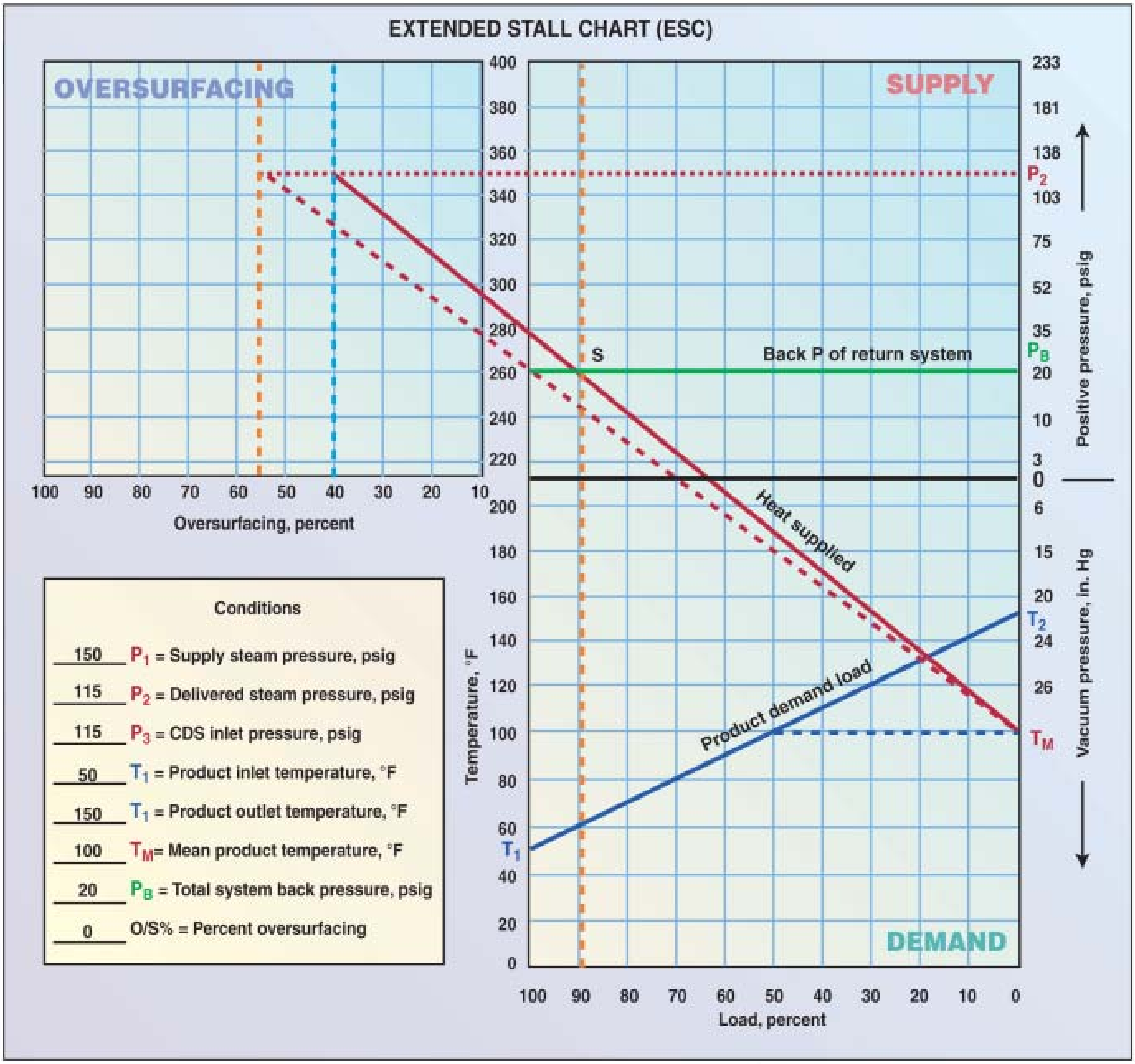

FIGURE 5. When the oversurfacing amount is considered, a more accurate stall point is estimated to occur at 90% of a full load condition

in Figure 2 or 3, the stall point was estimated to occur at 65% of full load. However, when the over-surfacing amount is considered, a more accurate stall point is estimated to occur at 90% of the full load condition. This knowledge guides the design engineer to more accurately select a proper CDS. With the ESC, correctly identifying particular equipment's propensity to stall will help eliminate poor process control, waterhammer, and stratification issues in more installations.

Conclusion

Over-surfacing must be considered when selecting condensate drainage solutions (such as traps, pump-traps, and level-pot control) for exchangers with modulating control. An over-surfaced exchanger is underworked and tends to lower pressure. So, the steam pressure drops and can stall at higher demand load than expected.

An engineer can predict the stall point with greater accuracy by the use of the extended stall chart. That key capability enables him or her to select the optimal condensate-drainage solution. Simply stated, the equipment's heat transfer and control performance will be optimized by selecting a steam trap or level pot control to drain condensate when a positive pressure differential exists, or a combination pump-trap for a negative pressure differential. ■

Edited by Gerald Ondrey

Additional Information:

For further information, please contact the author or TLV's Consulting & Engineering Services Department at (800) 858-8727. [800 "TLV-Trap].

Reference:

1. Risko, James R., "Steam heaters need complete condensate drainage," *Chem. Eng.*, pp. 114–119, July, 1996.

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