

# Steam reboiler system operations

Basic heat exchange principles are used to explain gas plant thermosiphon reboiler hydraulic constraints. Field measurements help clarify “off-design” operations that were not apparent and were causing high condensate levels

Ken Weston *CITGO Petroleum Corporation*

Steve White *Process Consulting Services Inc*

Process equipment performance is sometimes baffling. An FCC gas plant thermosiphon reboiler installed at CITGO Petroleum Corporation’s Corpus Christi, Texas refinery showed symptoms that indicated hydraulic constraints. High condensate levels occurred – the flow control valve went 100% open even though the steam flow rate was less than 15% of design. It appeared the exchanger would not meet its design duty due to condensate hydraulic limits.

Field measurements and further analysis using fundamental engineering principles showed high condensate levels were a result of inherent operating characteristics and not problems with design or operation. Further testing confirmed the exchanger met its design duty. Basic heat exchange principles will be used to explain the observed steam reboiler operation.

## FCC stripper reboilers

A supplemental steam reboiler was installed in the deethaniser (stripper) to eliminate flaring during startup. In normal operation, the FCC deethaniser strips most of the hydrogen sulphide ( $H_2S$ ), ethane, ethylene and lighter hydrocarbons from the debutaniser feed. Sufficient reboiler heat is needed to reduce the ethylene content to acceptable levels, because ethylene reacts with benzene in the downstream cumene unit to form ethylbenzene, a contaminant in the cumene product. During startup, the stripper reboiler’s duty must be high enough to prevent non-condensibles from reaching the downstream equipment. Figure 1 shows the process flow scheme of CITGO’s deethaniser reboiler system, including the supplemental reboiler.

During normal operation, the stripper reboiler’s duty is relatively high and shell-side operating temperatures vary between 190°F and 260°F, making it a good low- and medium-temperature heatsink. Although some stripper reboilers use steam for heat, most utilise

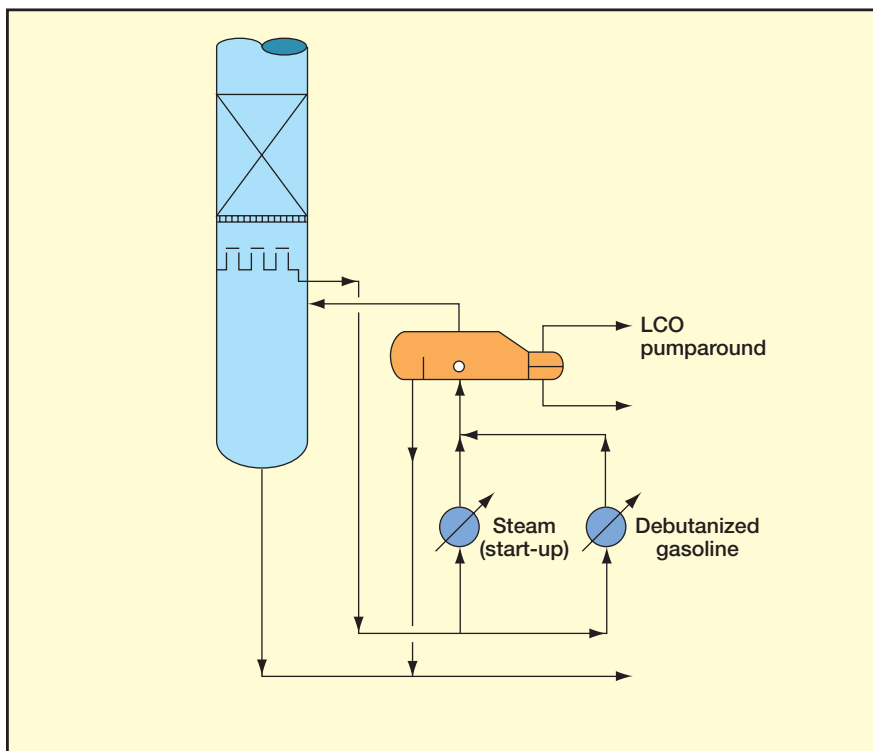


Figure 1 Reboiler system

main column pumparound or product rundown. CITGO’s design uses a thermosiphon in series with a kettle reboiler to supply reboiler heat. During normal operation, the supplemental reboiler is operated at a very low duty.

Debutanised gasoline product supplies about 60–65% of the total reboiler duty, with LCO pumparound providing the remainder. Since the liquid leaving the bottom tray in the stripper column is only 190–205°F, gasoline product heat is exchanged in the first reboiler, heating the stripper’s bottom tray liquid to 220–235°F prior to feeding the kettle reboiler. The kettle uses main column LCO pumparound heat between 450°F and 465°F, with the outlet temperature varying from 240–260°F. Throughout startup, there is little heat available from either debutanised gasoline or LCO pumparound due to low stream

temperatures. As a result, the supplemental steam reboiler was added. While this is increasingly common, adding a third reboiler is fraught with design challenges and care must be taken to ensure system hydraulics are not compromised.

## Reboiler fundamentals

Thermosiphon reboiler performance is governed by basic heat transfer and hydraulic principles. Heat transfer theory includes the heat transfer coefficient, exchanger surface area and log mean temperature difference (LMTD). Computer modelling tools such as Heat Transfer Research Institutes’ (HTRI) IST program are used to design heat exchangers and there are many hydraulic system design programs available. Yet when problems occur, field temperatures and pressure measurements are key to identifying

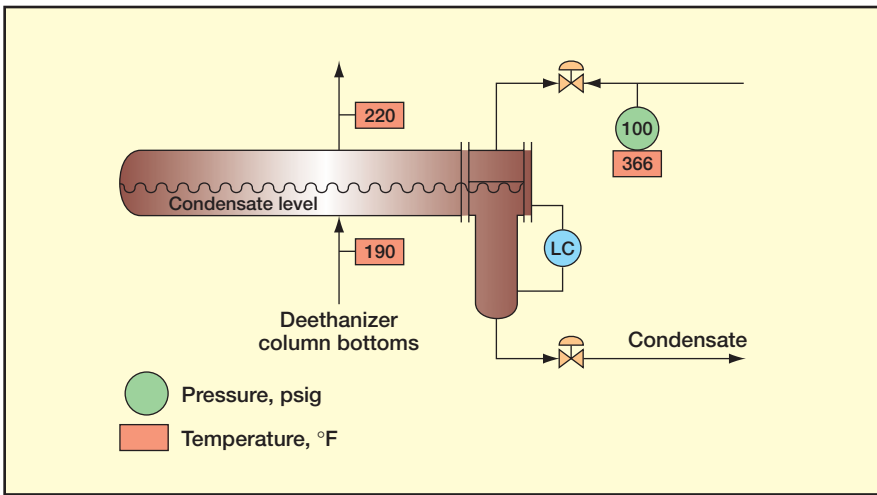


Figure 2 Reboiler operation

root cause performance. While computer models are essential for design, field measurements help explain off-design operations that may not be apparent.

Steam reboilers exchange heat by condensing steam at the pressure needed to meet the process duty. The amount of heat exchanged is a function of the heat transfer coefficient, exchanger surface area and the LMTD of the shell- and tube-side streams. Once an exchanger is installed, both the surface area and mechanical configuration are fixed. Although the heat transfer coefficient is a function of many process variables, actual performance largely depends on whether the exchanger is clean or dirty. When the exchanger is clean, the heat transfer coefficient is high. A clean exchanger requires a low LMTD to satisfy Equation 1.

$$Q = U A \text{ LMTD} \quad \text{Equation (1)}$$

- Q = btu/hr Exchanger duty
- U = btu/h-ft<sup>2</sup>-°F Heat transfer coefficient
- A = ft<sup>2</sup> Exchanger surface area
- LMTD = °F Log mean temperature difference

Conversely, when the exchanger is dirty, the heat transfer coefficient is low, and the exchanger LMTD must be higher to meet the desired duty. Equation 2 shows how the dirty heat transfer coefficient is calculated. Since fouling is the largest resistance to heat transfer in most refinery services, it plays a major role in exchanger performance. A clean steam reboiler requires much lower condensing temperature than a fouled exchanger. Thus, the condensing pressure of the steam is much lower.

$$\frac{1}{U_D} = \frac{1}{U_C} + R_F \quad \text{Equation (2)}$$

Where:

- U<sub>D</sub> = heat transfer coefficient, dirty
- U<sub>C</sub> = heat transfer coefficient, clean
- R<sub>F</sub> = overall fouling factor (Ft<sup>2</sup> °F Hr / Btu)

A stripper reboiler's heat transfer coefficient (U-value) can be as high as 130 btu/hr-ft<sup>2</sup>-°F, but when it is fouled it may be as low as 65 btu/hr-ft<sup>2</sup>-°F. The exchanger LMTD varies from start-of-run (SOR) when the exchanger is clean to end-of-run (EOR) when it is fouled. When a high fouling factor is used for design, the exchanger is over-surfaced for start-of-run conditions, thus the exchanger LMTD must be very low.

In a steam reboiler, understanding the mechanism that adjusts exchanger LMTD is essential to appreciate the observed symptoms. Shell- and tube-side temperatures both affect exchanger LMTD, but during normal operation shell-side process temperatures change relatively slowly and are primarily dependent variables. At startup when the unit is transitioning to normal operation, temperatures are variable until normal operation is reached. In this case, field tests were performed during normal operation so the shell-side process temperatures were stable and did not vary. Thus, only steam conditions can be used to adjust the exchanger LMTD.

Figure 2 is a schematic of the reboiler showing some operating temperatures and pressures. Saturated 100 psig steam was supplied from the refinery header on flow control, with the rate

Steam tables – saturated conditions	
Pressure (PSIG)	Temperature (°F)
30	270
50	298
70	316
100	338
150	366

Table 1

manipulated to meet the desired exchanger duty. In theory, the level controller attached to the channel head controlled the condensate flow from the exchanger to the header. However, during initial testing, the condensate level was above 100%, so the level was in the exchanger tubes above the controller range.

When an exchanger is designed, the engineer often assumes that all the exchanger surface area is available for condensing. However, when condensate floods the exchanger, the surface area becomes a variable. While this is not the designer's intention, when an exchanger is clean, duty is low and the steam condensing pressure approaches the condensate header pressure. Condensate then floods the exchanger.

When the steam reboiler surface area is not flooded, the temperature required to provide sufficient exchanger LMTD determines the condensing pressure of the steam. As the steam rate is increased, the pressure downstream of the flow control valve rises to satisfy Equation 1. As long as the exchanger is not flooded, pressure downstream of the steam control valve sets the condensing temperature. When the exchanger is clean, the LMTD and steam condensing pressure are low. As the exchanger fouls, a higher LMTD is needed and the condensing temperature must increase. Thus, steam pressure downstream of the flow control valve rises to adjust the exchanger LMTD to meet the required duty. Table 1 shows the saturation temperature of steam at various pressures.

### Steam and condensate systems

CITGO's design provides for direct control of the steam flow to the reboiler. The control valve changes the steam flow to the reboiler, which consequently changes the condensing pressure in the reboiler as needed. Varying the condensing pressure alters the condensing temperature, which controls the exchanger duty. The level controller spans a portion of the tubes to compensate for the clean exchanger over-surface. A minimum level should be kept in the condensate pot to prevent steam "blow-by" into the condensate system.

Steam and condensate hydraulics are linked. The condensate return and steam supply header pressures are fixed. The steam condensing pressure must be high enough to meet the condensing temperature inside the exchanger, and the condensing pressure must be sufficient to allow condensate to flow into the return header through the condensate control valve without flooding the exchanger. In this case, the

exchanger is located at grade about 16ft below the condensate return header.

### Case study

During normal FCC operation, a test was conducted to determine whether the supplemental reboiler would meet its design duty. However, after commissioning, there were problems flowing condensate from the accumulator pot into the condensate system. The condensate level was above 100% and the condensate control valve was wide open. Also, the steam flow rate was only 8000 lb/hr, about half its design rate.

The flow-control valve controls the steam flow rate. Pressure downstream of the valve provided the exchanger with the LMTD needed to meet the desired exchanger duty. Condensate forms as the steam condenses and it accumulates in a pot attached to the exchanger head. Level control sets flow into the condensate return header. In this case, the low-pressure condensate header operated at approximately 23–25 psig. Pressure inside the channel head must be high enough for condensate to flow to the condensate header.

A pressure survey is critical when evaluating operations, because measurements are reality, not the results of a computer model. Figure 3 shows measured pressure throughout the system. Condensing pressure was only 30 psig inside the exchanger, because the exchanger was clean and duty was low. Pressures upstream and downstream of the condensate flow control valve were 33 psig, thus the valve consumed very little pressure drop. The condensate return header was operating at 23 psig. Since the condensate control valve is located at grade 23ft below the condensate header, the operating pressure downstream of the condensate control valve was 33 psig due to the static head of the condensate.

When the condensing pressure inside an exchanger is high enough for condensate to flow on level control and the exchanger has no condensate in it, condensing pressure is solely dependent on equation 1. However, when the exchanger duty and LMTD are below that needed to flow condensate to the header, the exchanger floods. Once the exchanger tubes are flooded, both the exchanger surface area and the LMTD become variables and the condensing pressure is determined by the condensate system hydraulics.

Another test was conducted to determine whether the exchanger would meet its design duty. The steam flow rate was slowly increased to 15 600 lb/hr, which provided enough steam to meet the design duty. Figure 4 shows the pressure survey data. The condensing

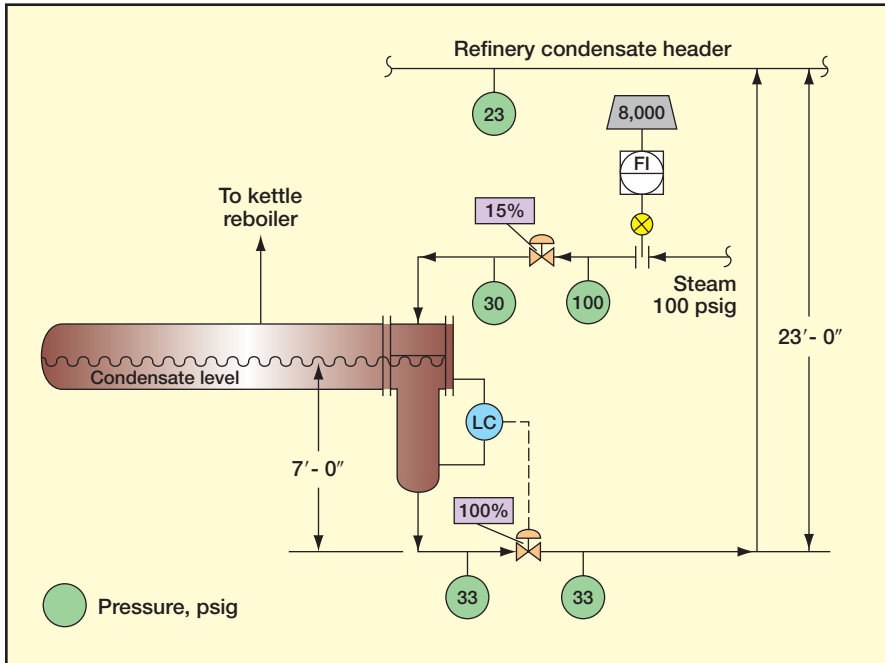


Figure 3 Pressure survey – low duty

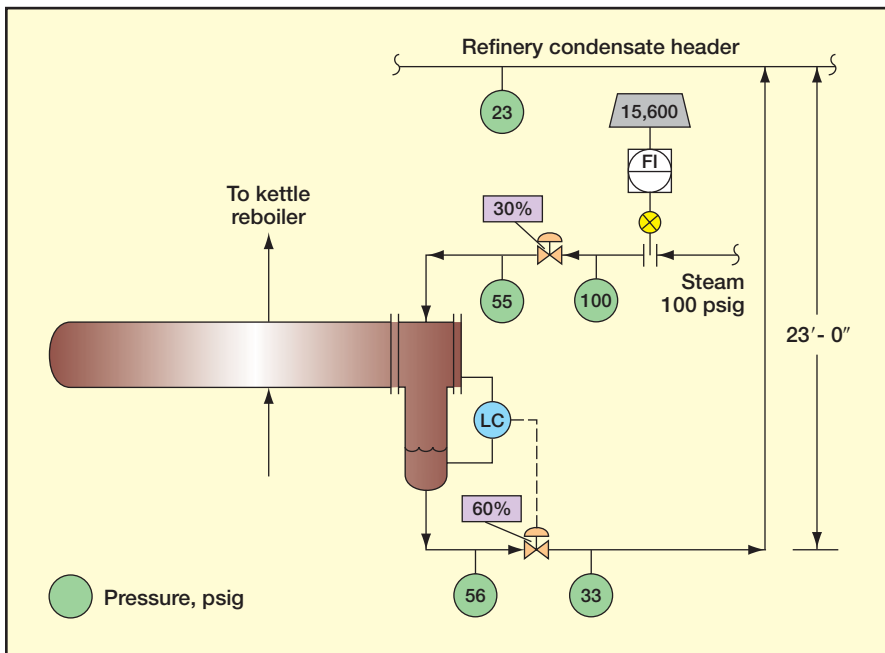


Figure 4 Pressure survey – higher duty

pressure in the exchanger increased to 55 psig and the condensate level dropped into the level control range.

Often, fundamental principles are needed to understand equipment operation. In this example, the exchanger has a minimum duty for operation in a non-flooded condition or in this case even partially flooded due to the condensate header pressure. Once the pressure for the required condensing temperature drops below the pressure needed for the level control system to maintain condensate level in the control range, the exchanger floods even more. At this point, condensate system hydraulics set the condensing

pressure and it is self-regulating. After working through basic principles, the observed performance made sense even though there appeared to be a problem.

**Ken Weston** is a process engineer at CITGO Petroleum Corporation's refinery in Corpus Christi, Texas.

**Steve White** is a chemical engineer for Process Consulting Services Inc, Houston, Texas, providing revamp front-end process engineering to the refinery industry. He has more than 25 years of process design experience, previously working for Jacobs Engineering, UOP and ARCO. Email: [swhite@revamps.com](mailto:swhite@revamps.com)