How Much Spare Capacity is in Your Reboiler?

Steam Heated Reboilers

Reboilers can limit your next debottleneck opportunity. Here is a way to quickly estimate the spare capacity in your reboiler system.

Figure 1 represents the parts in a reboiler system, including the steam header, steam supply control valve, the shell and tube reboiler, and process streams in and out. The reboiler may be of the thermosiphon or forced circulation variety.

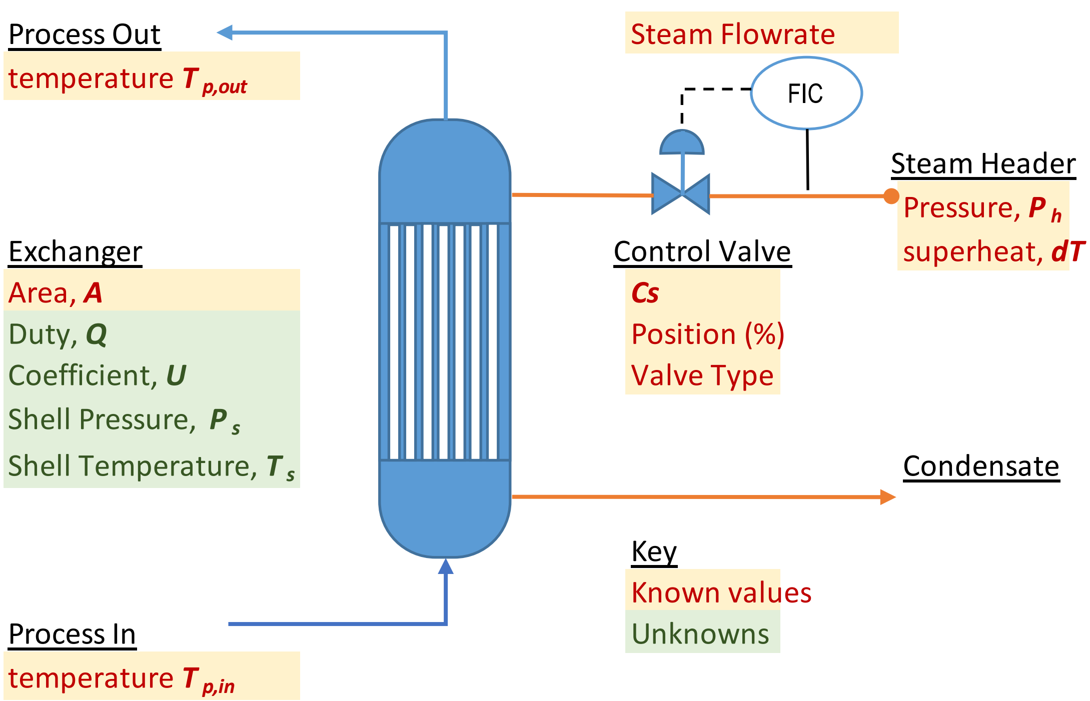


Figure 1 Steam Reboiler System

We expect to know physical characteristics of the equipment, such as heat exchanger area, steam control valve size and type (equal percent or linear). We also know some process conditions from operational experience. Some conditions may need to be calculated, such as process outlet temperature, and pressure (and thus temperature) on the steam side of the reboiler.

Governing Equations

The Reboiler

The heat duty, Q, must balance on the process side, shell side, and across the reboiler.

Equation 1

$$Q_{process} = Q_{reboiler} = Q_{steam}$$

Equation 2

$$Q_{reboiler} = U\ A\ dT_{lm} = U\ A\ \frac{T_{p,out} - T_{p,in}}{ln\left(\frac{T_s - T_{p,out}}{T_s - T_{p,in}}\right)}$$

Equation 3

$$Q_{steam} = \dot{m}_{steam}(H_{header} - H_{condensate})$$

Where H is the enthalpy from steam tables at the header and condensate conditions.

For thermosiphon reboilers, the process temperature may change little from inlet to outlet – perhaps a degree or two, unless small amounts of lighter components are contained in the column bottoms. If necessary, use process modeling software to plot a vaporization curve of T vs Q for vapor fractions between zero and about 0.4, a maximum for most thermosiphon systems.

For forced circulation reboilers, the process stays as a liquid in the reboiler and absorbs a sensible heat gain which raises temperature. The temperature rise is roughly proportional to the heat gained.

In either case, if the process side temperature change is small compared to the temperature across the exchanger, $dT_{lm} \approx T_s - T_{p,in}$.

The Control Valve

Flow across the steam control valve is governed by

Equation 4 [1]

$$\dot{m}_{steam} = C_s\, P_h \sqrt{1 - 5.67\left(0.42 - \frac{P_h - P_s}{P_h}\right)^2}$$

Note that critical flow is assumed to occur when the downstream pressure is below 58% of the upstream absolute pressure. Shell side pressures lower than this will not increase steam flow, and the limiting critical flow is simply:

Equation 5

$$\dot{m}_{steam} = C_s\, P_h$$

Critical flow or not, for superheated steam supply, multiply the value of C_s by (1+.00065*dT), where dT is the amount of steam superheat in deg F. [2]

In operation, the steam valve is not fully open or the process would not be controllable. Valves characteristics must be known to translate the known position of the valve positioner into the valve constant $C_{s,\ operating}$ which will be used in the valve equations above. The more common valve types are linear and equal percent. For linear valves, the orifice size, and thus the value of $C_{s,\ operating}$ is directly proportional to the percent

[1] (Spirax Sarco eqn 3.21.2, 2016)
[2] (The Engineering Toolbox, 2016)

open on the valve positioner (equation 6). For equal percent valves, the valve constant given by equation 7.

Equation 6 Coefficients for Linear Valve

$$C_{s,operating} = xC_s$$

Equation 7 Coefficients for Equal Percent Valves [3]

$$C_{s,operating} = C_s \frac{e^{(\ln \tau)x}}{\tau}$$

$$\boldsymbol{\tau} = \text{valve rangeability (around 50)}$$

$$\boldsymbol{x} = \text{fraction valve open (postioner lift)}$$

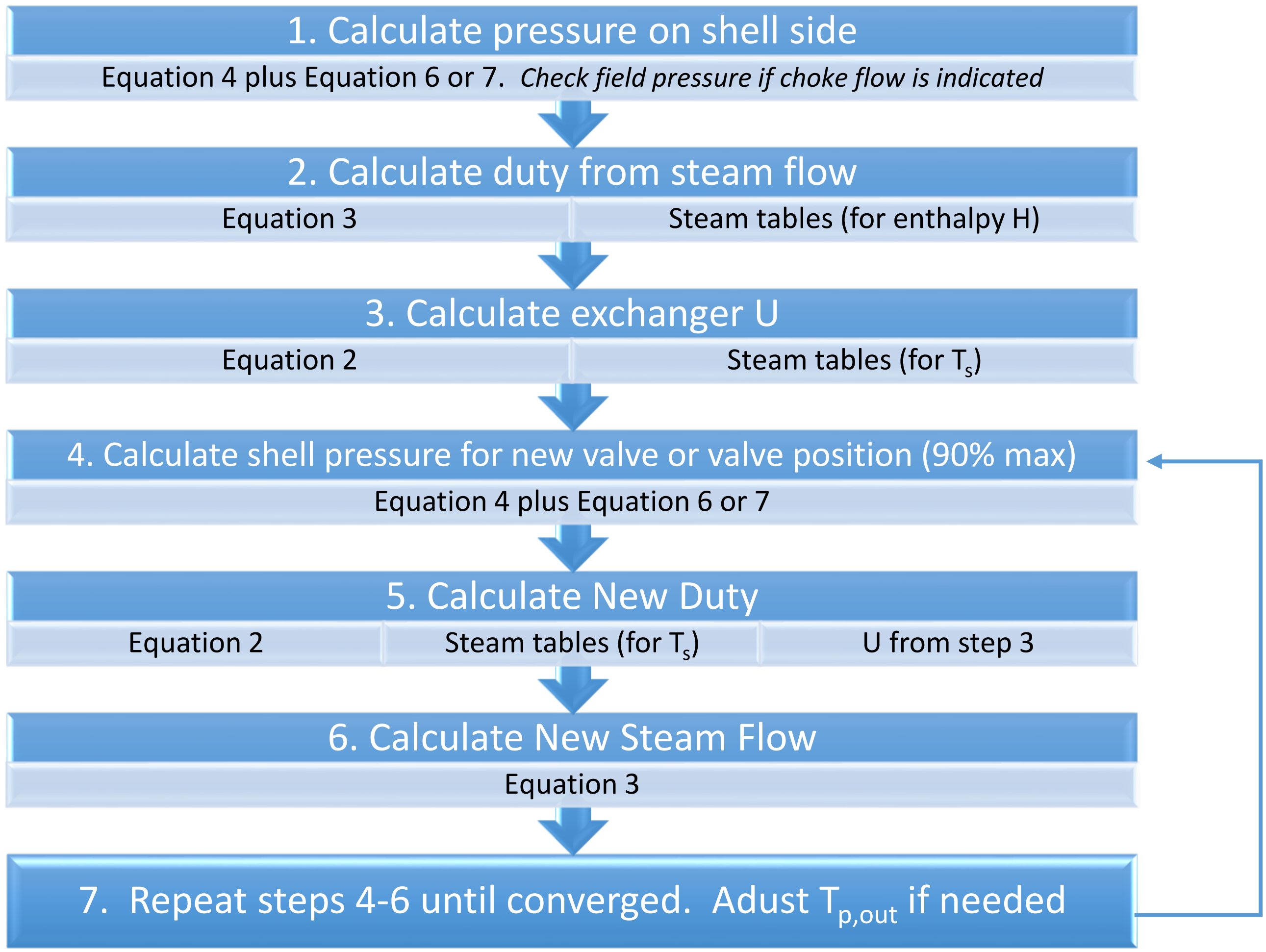
Calculation Procedure

The governing equations can be used to evaluate the extra heat duty available without any equipment modifications or changes to the process conditions. The table below outlines a procedure that is easily programmed into Excel. Steam tables such as those from NIST [4] can be used. It may be necessary to adjust $T_{p,out}$; see the discussion above on thermosiphon versus forced circulation reboilers.

Generally, local pressure gauges are installed on the steam side, either on the exchanger itself or on the condensate drum. However, this measurement is not usually recorded in the control room. A field check would confirm that the flow is sub-critical and that the valve sizing equation is reasonably accurate.

[3] (Spirax Sarco eqn 6.5.1, 2016)
[4] (NIST, Saturation Properties for Water — Pressure Increments, 2016)

Table 1 Calculation Procedure for Reboiler Capacity Evaluation



Example

Figure 2 shows an example with a 4000 ft^2 exchanger, using 50,000 lb/hr of 300 psig steam through an equal percent control valve (C_s = 1000) that is 60% open. The process fluid is 310 F entering, and estimated to be 312 F exiting based on vaporization curves for the reboiler fluid.

From this input, we can calculate steam flowrate, heat duty, shell pressure, exchanger heat transfer coefficient, and condensate temperature as shown in Figure 3. Note that the heat transfer coefficient inferred from the data, 110 BTU/hr/ft2/F, falls within typical parameters for process reboilers.

Figure 4 shows the process and heat balance for a steam valve that is now 90% open. Note that the reboiler duty went from about 43 to 48 MMBTU/hr, a 12% increase.

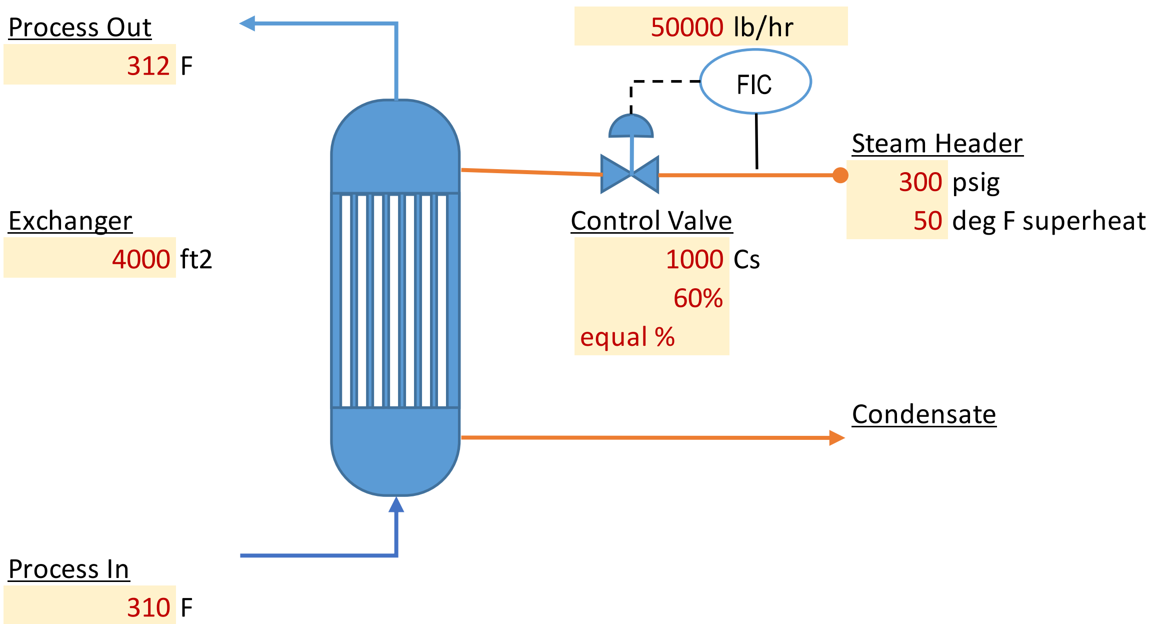


Figure 2 Measurements of Current Reboiler Operation

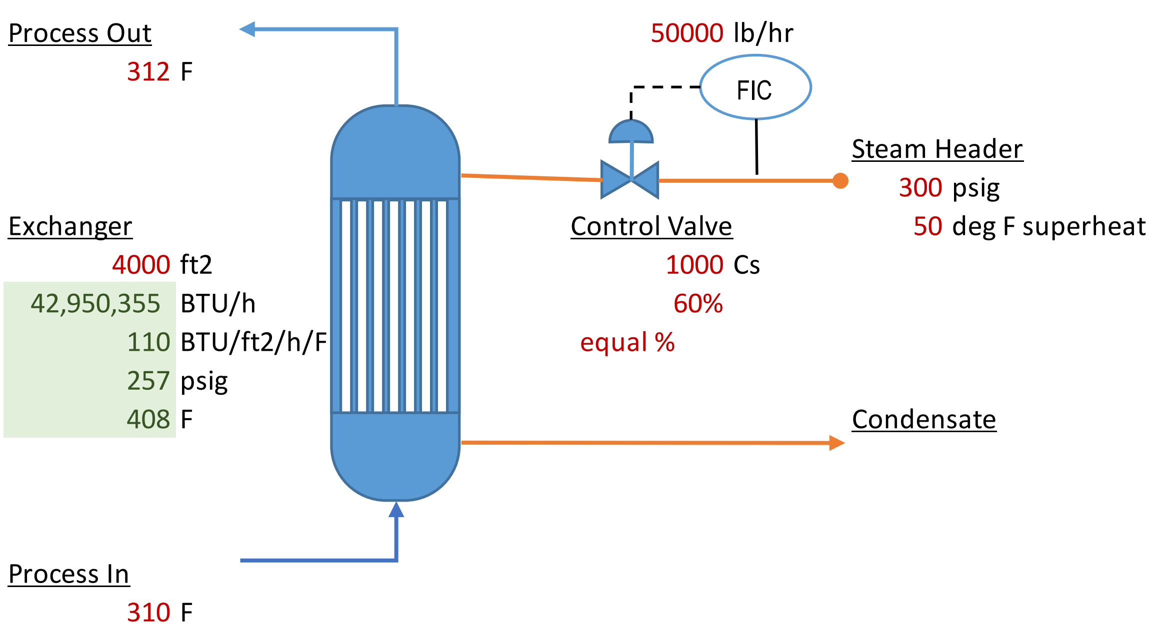


Figure 3 Calculated Operating Conditions and Reboiler Duty

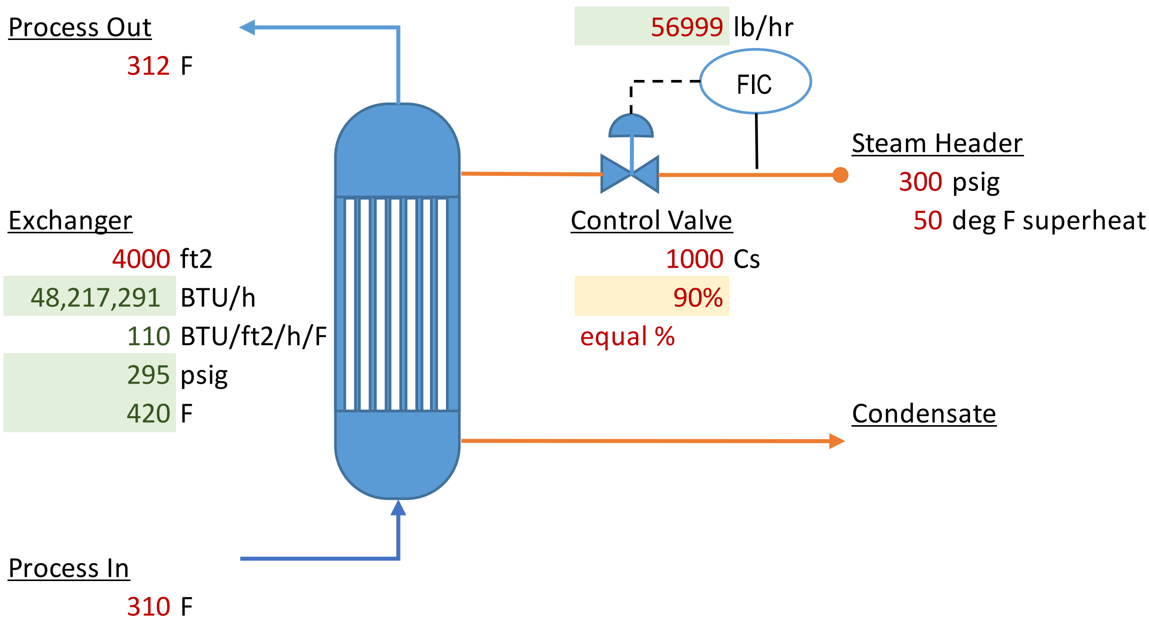


Figure 4 Converged Solution if Steam Valve is at 90%

Closing Thoughts

Superheated steam does little to enhance capacity. The sensible heat of superheat is small compared to the heat of condensation, and most of the exchanger has a temperature driving force dictated by the temperature of the saturated liquid.

Capacity could also be increased by other means, such as:

- Replacing the steam valve with a larger one
- Lowering process pressure, and thus temperature, which increases driving force for heat transfer
- Increase heat transfer coefficient by
  - Reducing fouling with additives
  - Use enhanced coefficient tubes or tube inserts

The calculation tools shown here are easily written in a spreadsheet. This approach is especially suitable for use as a survey of all the reboilers in the plant being debottlenecked. Of course, a detailed thermal analysis would be in order for any exchanger considered for replacement or further study.

About the Author

Gary Sawyer's 32 year career as process and project engineer included working for Lyondell Chemical Company and Union Carbide prior to that. Most of his career was in process design and economic evaluations for developing projects in R&D. He is now a private consultant. He received his B.S. and M.S. from Rensselaer Polytechnic Institute.

www.process-evaluations.com

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