Optimize reboiler design

Use these guidelines for best performance

E. Chen, Foster Wheeler USA, Houston, Texas

Reboiler design consists of four steps: process specification, piping arrangement, thermal design and hydraulic balance. A good reboiler design shall meet the process requirement and provide stable and flexible tower operation.

Optimizing reboiler design is a team effort of related disciplines such as process, fluid system, piping and heat transfer. The process engineer specifies heat duty, return temperature, heat medium (and provides vaporization curves) and process fluid properties (physical, thermodynamic and transportation) from the process simulation output. The process engineer also sets tower elevation, liquid levels, preliminary circulation rate and percent initial vaporization, which will be subject to final reboiler design by heat transfer engineers.

The fluid system engineer and piping designer (sometimes vessel engineer) shall be consulted to determine tower elevation and piping arrangement. After all the design basic data are provided, the heat transfer engineer will select reboiler type, proceed with reboiler thermal design and calculate reboiler circuit hydraulic balance. The heat transfer engineer will advise the process engineer of the circulation flowrate, percent vaporization and the change in liquid level, if necessary. When reboiler design is finalized, the fluid system engineer will independently recheck reboiler circuit hydraulics to ensure the design is correct.

For revamp projects, the process engineer and the piping designer have to take the lead to determine piping modifications. Frequently, a line size change is required.

Reboiler types. Reboiler types can be classified by circulation and reboiler position. The reboiler can be either natural circulation with available liquid head or forced circulation with a pump. Reboilers can be installed either horizontally or vertically.

Fig. 1 shows different reboiler types used in the petroleum and chemical industries.

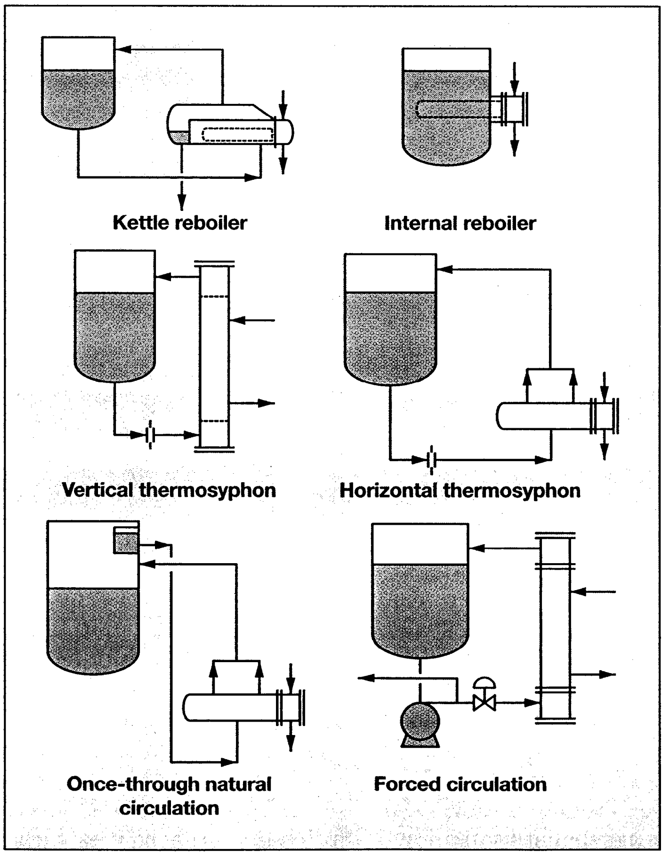

Fig. 1. Reboiler types.

Natural circulation reboilers. Natural circulation reboilers can be divided into two categories: pool boiling and thermosyphon.

Pool boiling reboilers. Characteristics of pool boiling-type reboilers are isothermal boiling and high vaporization fraction up to 100%. All pool boiling reboilers are horizontal. Kettle-type reboilers are a good choice in the refining and chemical industries for their reliability and flexibility of operation. An internal stab-in bundle inserted into the tower bottom section is not often seen in refinery services.

TEMA-type AKT kettle reboilers are used for high-fouling heat medium such as heavy oil or slurry process streams. A floating head construction gives easy access for tube-side cleaning. Type BKU is adopted when steam is used as the heat medium for low equipment cost and minimum steam leakage. Fixed-tubesheet designs such as type BKM or NKN are selected for clean boiling service on the shell side.

Thermosyphon reboilers. These can be horizontal or vertical depending on process design and available plot area. They can be once-through or recirculation by the process engineer's choice.

TEMA-types AEL, NEN or BEM single-pass fixed-tubesheet designs with or without a shell expansion joint are the most commonly used for vertical thermosyphon reboilers. Normally, boiling liquid is inside of 1-in.-OD or larger tube. MP or LP steam is used as heat media in the shell. A shell-side, high

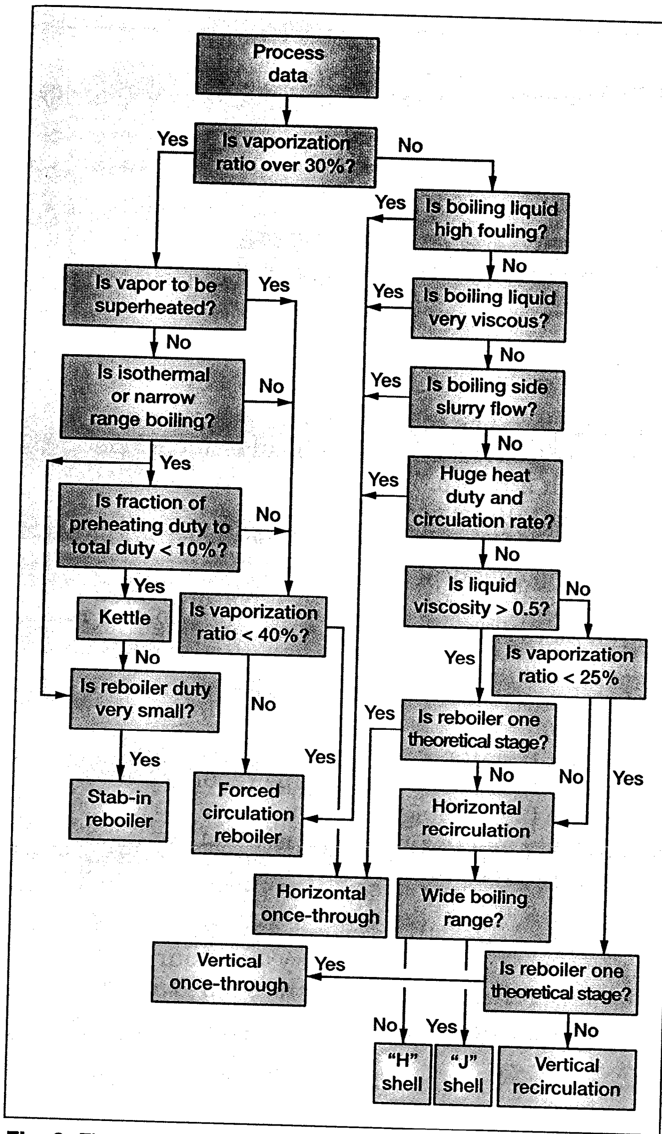

Fig. 2. Flow chart for selecting reboilers.

point vent and low point drain through the tubesheet shall be designed. To minimize return vapor line pressure drop and make piping design simple, a direct-couple nozzle connection between the reboiler top channel and tower is preferred. In case of high fouling boiling, NEN with a removable channel cover shall be provided.

TEMA "J," "G" or "H" shells are common for horizontal thermosyphon reboilers. When the service has a long boiling range or liquid preheat duty exceeds 20% of total duty, the "J" shell is selected. "G" or "H" shells are not preferred for boiling ranges over 40°F. The "J" shell design requires more pressure drop (1–2 psi) than "G" and "H" shells, which require only 0.5–1 psi. For extremely low allowed pressure drop and small boiling ranges, sometimes an "X" shell (pure cross flow) will be used. When liquid head is too great because of elevation difference between the tower and horizontal reboiler, a flow restriction (control valve or restriction orifice) shall be installed in the liquid line to reduce the head.

In general for new equipment, percent vaporization shall not be designed to exceed 30% for vertical and 40% for horizontal thermosyphon reboilers. Existing vertical reboilers can allow up to 40% vaporization if the hydraulics work well. Horizontal reboilers can allow up to 60% vaporization. If more than 60% vapor is required, a forced circulation reboiler shall be designed if boiling liquid has to return to the tower.

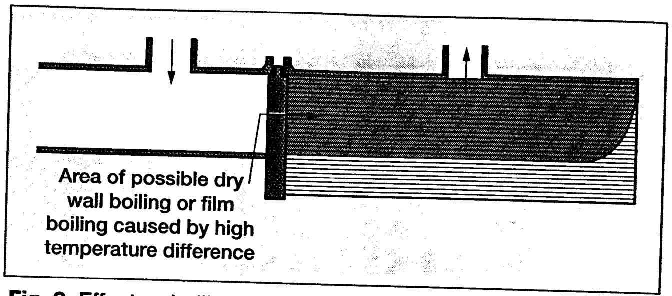

Fig. 3. Effect on boiling by superheated steam or hot heat medium.

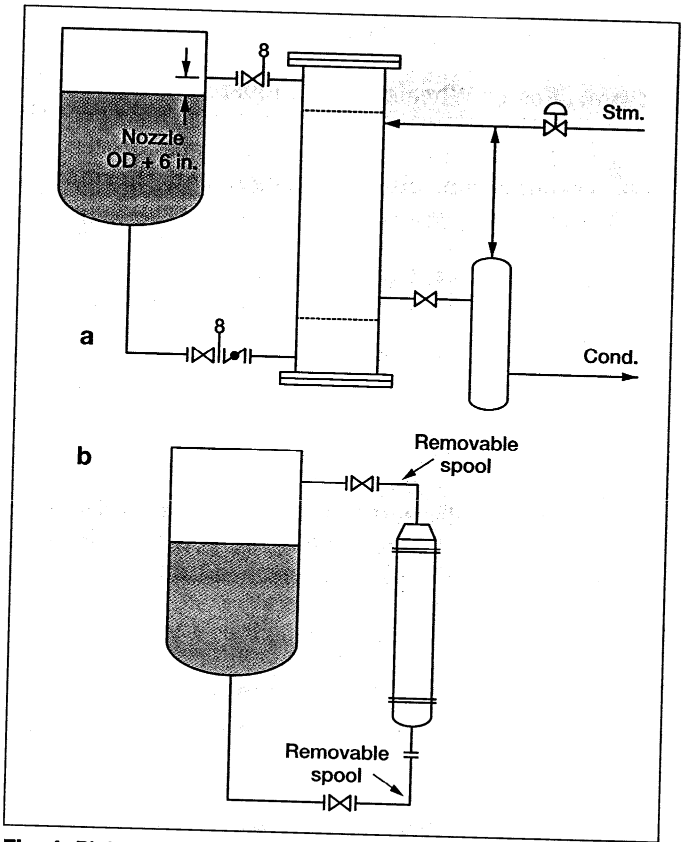

Fig. 4. Piping arrangement for vertical reboilers.

The once-through type thermosyphon reboiler withdraws liquid from the trapout pan, and two-phase flow returns to the space below the trapout tray. Liquid head is constant during normal operation. Thus, circulation rate is maintained constant. Percent vapor returned to the tower stays constant if the heat input is kept unchanged. The once-through reboiler is considered as one equilibrium stage for a fractionation tower.

In contrast to the once-through, the recirculation reboiler withdraws the liquid from the bottom of the tower, partially vaporizes the stream and returns it to the space between the bottom tray and liquid level. This type reboiler is not counted as an additional equilibrium stage. Circulation rate and percent vaporization will vary with liquid level. Hydraulic balance shall be checked for all three levels (NLL, HLL and LLL) after the reboiler is sized.

Forced circulation reboiler. The forced circulation reboiler has the boiling liquid driven by a pump. It normally allows a 3- to 5-psi pressure drop or higher and is designed with a TEMA "E" shell with segment baffles. If boiling fluid is extremely fouling, very vis-

Table 1. Advantages and disadvantages of various type reboilers

Type	Advantages	Disadvantages	Remarks
Kettle reboiler	1. Most reliable in terms of operation. 2. High vaporization percentage and good vapor quality. 3. Equivalent to one theoretical stage. 4. Easy cleaning and maintenance. 5. Low circulation rate.	1. Expensive installation cost (larger shell, connection piping and level control). 2. Long residence time. 3. Not good for high-pressure boiling. 4. Lower heat flux and heat transfer rate. 5. Accumulation of heavy and polymerized substances.	1. Multiple outlets can be designed to reduce shell size. 2. Continuous blowdown can be provided to avoid accumulation of heavy and polymerized materials and, hence, reduce fouling.
Internal reboilers	1. Low installation cost. 2. No space available in vicinity of the tower. 3. For very small reboiler duty.	1. Lower heat transfer rate. 2. Process side cannot be isolated. 3. Difficult for cleaning and maintenance. 4. Tube length limited by tower diameter. 5. Cannot be counted as one theoretical stage.	Normally not recommended.
Vertical thermosyphon reboiler	1. High heat transfer rate. 2. Occupy less space. 3. Simple piping. 4. Low residence time. 5. Not easily fouled. 6. Good controllability. 7. Low installation cost for fixed tubesheet design.	1. Maximum vaporization fraction shall not exceed 30% per HTRI. 2. Limited tube length, normally not over 16 ft. 3. Not easily accessible for maintenance and repair. 4. Some designs require expansion joint on shell.	1. For critical towers, dual reboilers are normally designed with 70% capacity and can be readily isolated for repair. 2. Overall heat transfer coefficient, U_0, is in the range of 90–160 Btu/hr ft^2 °F in most HC reboilers.
Horizontal thermosyphon reboiler	1. Moderate heat transfer rate. 2. Can be designed for very large heat duty. 3. Low residence time. 4. Not easily fouled. 5. Good controllability. 6. Easy for cleaning and maintenance.	1. Extra piping required. 2. Low vaporization fraction, normally not over 35%. 3. Phase separation may occur if shellside velocity is too low. 4. Uneven flow distribution if multishell and multiinlet are designed.	1. Overall heat transfer rate, U_o, is in range of 70–100 for heavy HC and up to 150 for light HC. 2. Careful baffle design to meet ΔP requirement and to eliminate tube vibration.
Once-through natural circulation reboiler	1. As thermosyphon reboiler, has the flexibility to be either vertical or horizontal depending on tower elevation. 2. Moderate to high heat transfer rate. 3. Equivalent to one theoretical stage. 4. Low residence time. 5. Not easily fouled.	1. No control over circulation rate. 2. Danger of back-up in column. 3. Danger of excessive per-pass vaporization ratio (for vertical position).	1. Vaporization can be up to 40% of total inlet flow.
Forced circulation reboiler	1. Suitable for viscous high-fouling and solid-bearing boiling liquid. 2. Circulation rate is well controlled. 3. For very large circulation rate. 4. For very large surface area requirement. 5. Furnace reboiler. 6. To avoid phase separation. 7. Enable erosion—corrosion balance. 8. Superheating is possible.	1. Highest cost due to pump, piping and control instruments. 2. Potential leaking from pump seal. 3. Additional area for pump installation. 4. High operation cost.	Forced circulation reboiler will be considered only when kettle-type or horizontal thermosyphon reboiler cannot work.

cous or solid bearing (i.e., slurry), this type is recommended. When vaporization exceeds 40% and boiling liquid has to return to the tower, the forced circulation reboiler shall be specified. It is also a good selection for service that requires a large circulation rate and heat transfer area.

Table 1 summarizes advantages and disadvantages of various reboiler types.

Fig. 2 shows the logic flow diagram of selecting a reboiler.

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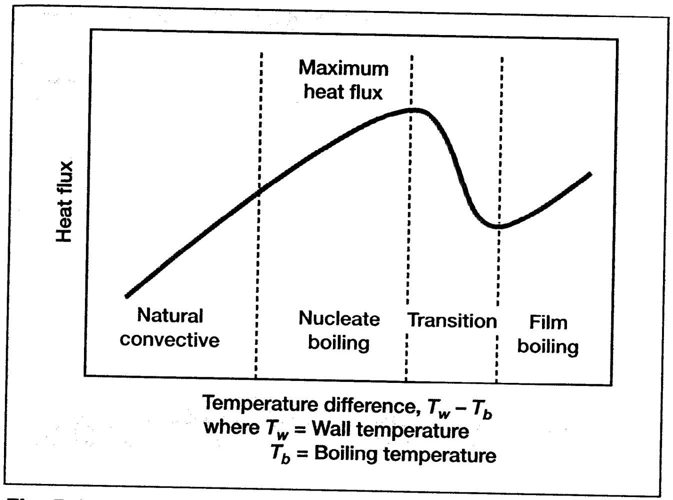

Fig. 5. Boiling curves and boiling flow regimes.

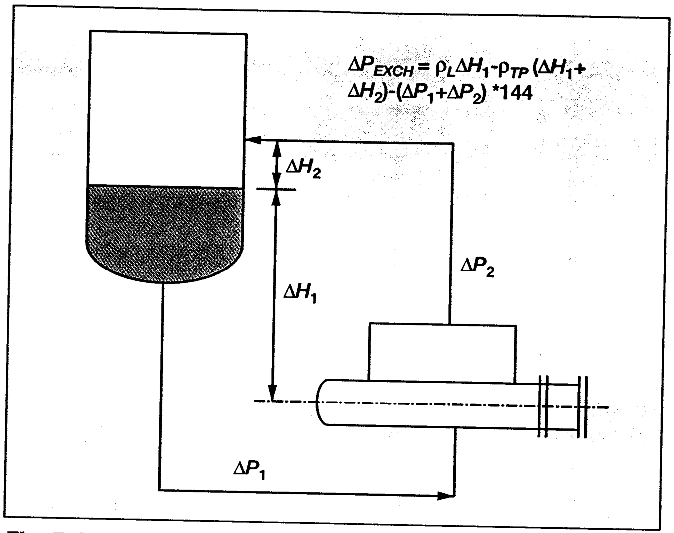

Fig. 7. Hydraulic balance for horizontal reboiler.

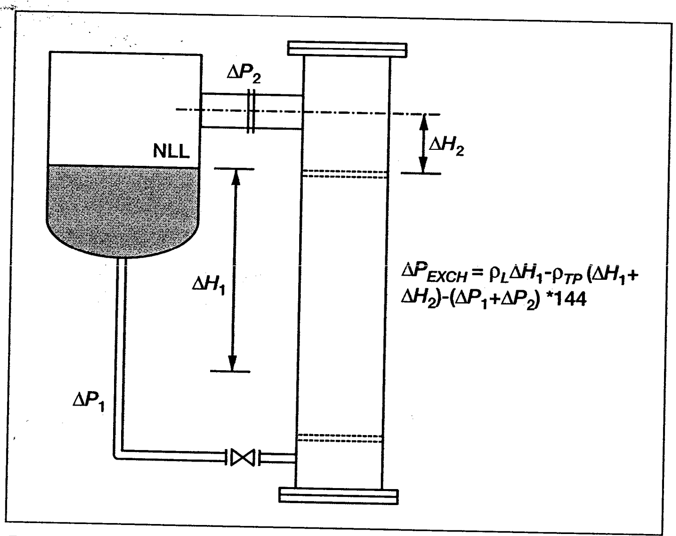

Fig. 6. Hydraulic balance for vertical reboiler.

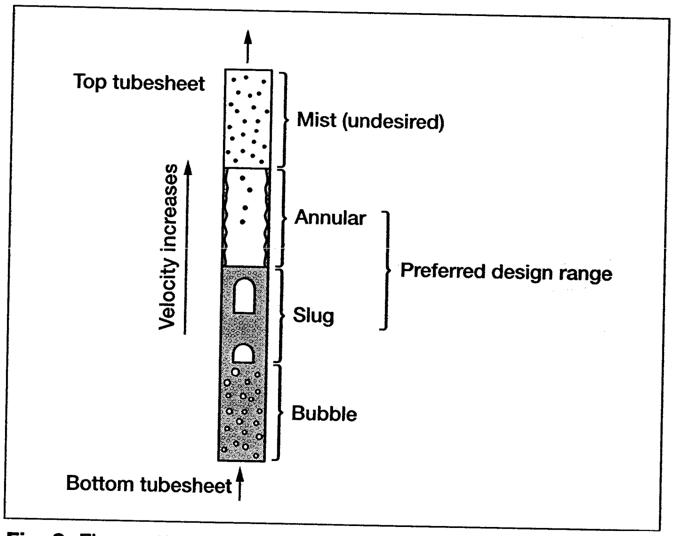

Fig. 8. Flow patterns for two-phase flow in vertical tubes.

Heat medium. Heat media can be steam, process stream or hot oil (heat transfer fluids). In refineries, steam and process streams are the most common heat media.

Steam. In most cases, MP or LP saturated steam is introduced to the reboiler rather than superheated steam. Superheated steam will create a dry wall boiling zone close to the tubesheet. (Fig. 3). The dry wall area will be quickly fouled and create a high tube wall temperature that may cause tube failure. Thermal design of the desuperheating zone is normally oversized due to variation of steam superheating. A desuperheater may be installed if the superheat temperature is too high. A steam flow control cascaded with tower bottom temperature or heat input is necessary. A condensate pot or steam trap could be installed downstream of the reboiler to improve energy efficiency (Fig. 10).

Process streams. In many reboiler services, the process stream is used as a heat medium to improve energy efficiency. Unfortunately, many of these applications have a film boiling problem due to the high temperature difference between the heat medium and boiling liquid. This results in increasing reboiler size and the tendency for fouling. To avoid film boiling, heat medium temperature should not exceed 80°F over boiling liquid bulk temperature. A proper process simulation could resolve this problem. The hot process stream can be cooled in another heat exchanger before entering the reboiler. Temperature bypass control is normally used to control boiler heat duty.

Hot oils (heat transfer fluids). Most hot oil reboilers in chemical or gas plants do not have steam available or the steam temperature is too low. The hot oil system may have equivalent capital investment and operating cost like a steam system, but does not require boiler water treatment and blowdown disposal.

Boiling flow regimes. Basically, there are four boiling flow regimes as indicated in typical HTRI boiling curves (Fig. 5): natural convection (subcooled), nucleate, transition and film. Try to design the reboiler in the nucleate flow regime left of the peak heat flux at the end of the nucleate zone. If it is impossible to design the reboiler in the nucleate regime due to heat medium temperature, design it in the stable film boiling regime with extra heat transfer area. Never design a reboiler in the transition boiling regime.

Heat flux limit. As a rule of thumb, maximum heat flux recommended for nucleate boiling design are:

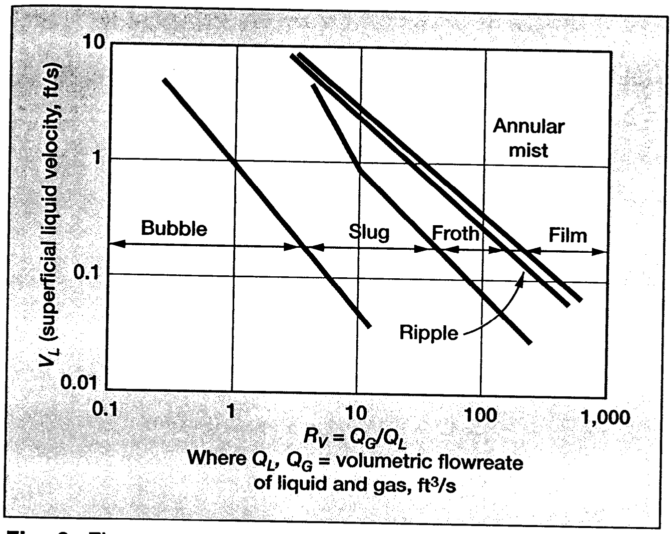

Fig. 9. Flow pattern prediction chart for two-phase flow (from Anderson, R. J. and T. W. F. Russel, "Designing for Two-Phase Flow, *Chemical Engineering,* Dec. 6 1965).

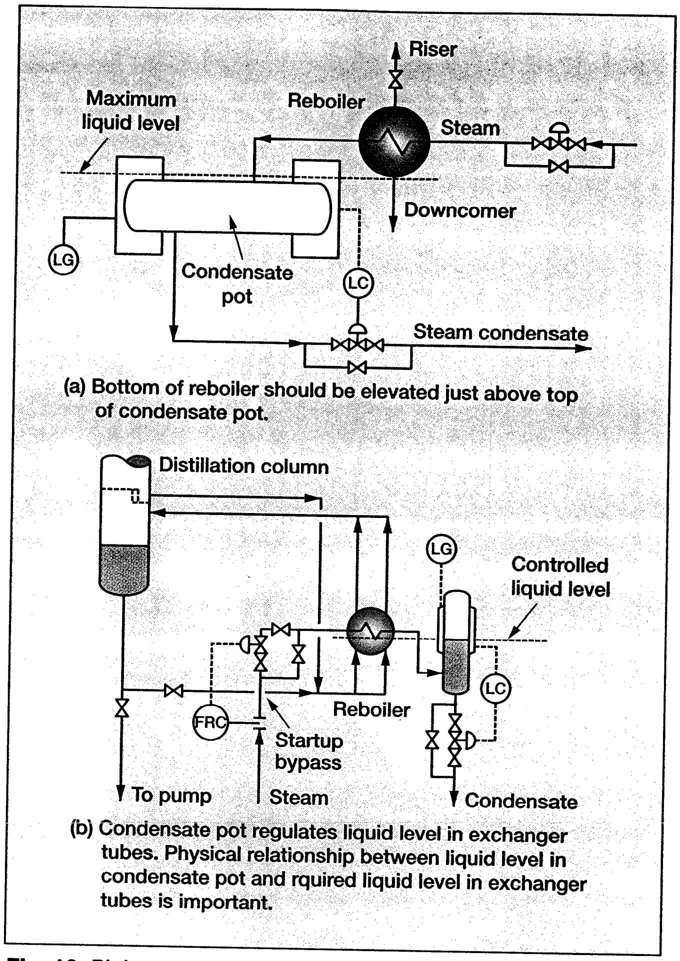

Fig. 10. Piping arrangement for horizontal thermosyphon reboilers (from Kern, R., "How to Design for Reboiler Systems," *Chemical Engineering,* August 1975).

Kettle reboiler:	9,000 Btu/ft^2-hr
Thermosyphon reboiler:	15,000 Btu/ft^2-hr
Stripper reboiler:	25,000 Btu/ft^2-hr

Calculating local heat flux if the transition boiling regime is suspected may be used to check individual cases.

Enhanced heat transfer surface. Enhanced heat transfer surface shall be considered when pinch point is less than 10°F. Low fin tubes are good for clean boiling service applications with a 6–10°F temperature difference. Otherwise, high flux tubes shall be used. Consider plate fin exchangers in cryogenic boiling. If enhanced heat transfer surfaces are used, a removable bundle shall be designed for easy access for inspection and cleaning.

Design considerations.

Kettle reboiler.

1. To avoid inlet impingement, a liquid inlet nozzle can be located on the side of the kettle with deflector.
2. When tube length exceeds 16 ft and vapor volumetric flowrate is high, two vapor outlet nozzles shall be designed to reduce kettle size.
3. Keep a minimum 1 in. clearance between bottom tubes and shell for U-bundle and fixed tube sheet designs.
4. A weir plate to keep the bundle fully submerged shall be designed a minimum of 2 in. above the top of the tube bundle.
5. A liquid compartment behind the weir plate is usually designed for 3-min hold-up but limited to 6 ft long due to cost. Maximum liquid level shall be 6 in. below the top of the weir plate, and minimum liquid level shall be 4 in. above the bottom of the shell. Hold-up time calculated based on the surge volume between maximum and minimum levels shall be indicated in the equipment data sheet.
6. Provide a vortex breaker at the liquid withdrawal nozzle.
7. HTRI program RKH is used to design kettle reboilers.
8. Vapor disengage space height is 12 in. minimum.
9. One or more flash out connections at the bottom of the kettle shall be designed for dirty boiling service.

Vertical thermosyphon reboiler.

1. Place boiling liquid on tube side. Use 1-in. or larger tubes.
2. Normally, design tubes to be 8–12 ft. Very seldom is a tube length more than 16 ft.
3. Keep top tubesheet elevation the same height as tower normal liquid level for initial design of recirculation-type reboilers (Fig. 6).
4. Minimize complexity of the 2-phase flow return piping by using a direct-couple nozzle connection or 90° elbow if direct-couple nozzle cannot be achieved (Fig. 4).
5. When steam is used as a heat medium on the shell side, a vapor escape space at the tube sheet circumference shall be designed to avoid the dry tube near the tube-to-tube sheet joint. A multiple steam inlet nozzle design is preferred if a large amount of steam is being consumed. Horizontal segment baffles with 40% cuts at 24-in. spacing are normally designed.
6. Design the vertical thermosyphon reboiler by HTRI's CST program with 5–10% over-design factor. Then use HTRI's RTF program to check the hydraulic balance and percent vaporization at the tube side outlet. When the design is finalized, run the HTRI-CST program again to check the heat flux and boiling flow regime.
7. Try to design a single vertical reboiler if shell size and length do not exceed the limit.
8. For critical services, design the reboiler for 120%

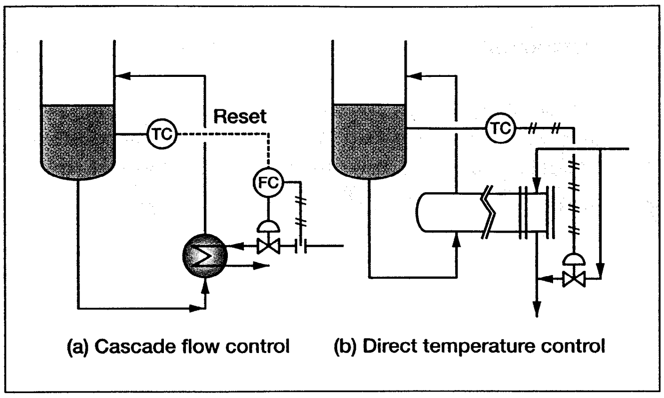

Fig. 11. Reboiler control.

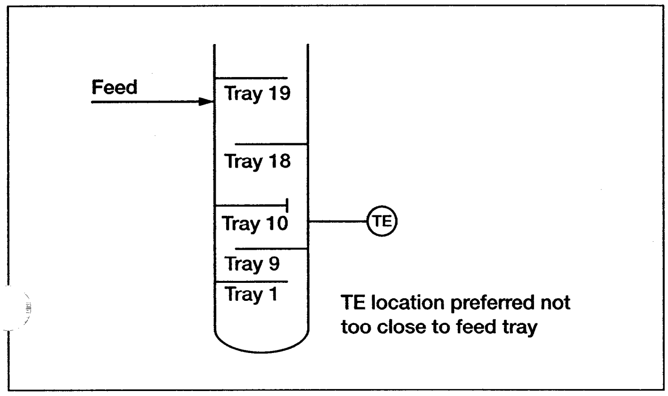

Fig. 12. Location of temperature element.

of required heat duty and flowrates.

9. Two isobaric heat curves with pressures about 5–10 psi apart shall be input to the HTRI-RTF program.

10. A condensate pot is installed next to the steam reboiler to recover uncondensed steam through a balance line to the steam supply piping.

11. Try to avoid two-phase slug flow returning to the tower (Figs. 8 and 9).

Horizontal thermosyphon reboilers.

1. Normally, the boiling fluid is placed on the shell side. Tube size selection depends on heat medium cleanness on the tube side.

2. A "J" shell with segment baffles or "H" shell is typically selected.

3. If a "J" shell is designed, watch out for the boiling fluid phase separation. The horizontal cut shall be used if there is a tendency of phase separation in the shell.

4. If an "H" shell is selected, length of the long baffle is about 4 ft or one-quarter of the tube length. The long baffle can be either solid or perforated. The perforated long baffle is not used very often in recent designs. No cross baffle shall be designed for the "H"-type reboiler.

5. Since horizontal reboiler elevation is much lower than tower liquid level, a manual control valve (globe valve for small pipe size and butterfly valve for large pipe size) is installed to adjust the liquid head. Sometimes the reboiler bundle is flooded by boiling liquid and thus loses effective surface area. Reboiler elevation has to be changed to make sure the boiling liquid entering the reboiler is at its bubble point.

6. A steam strap is installed at the steam reboiler condensate outlet piping.

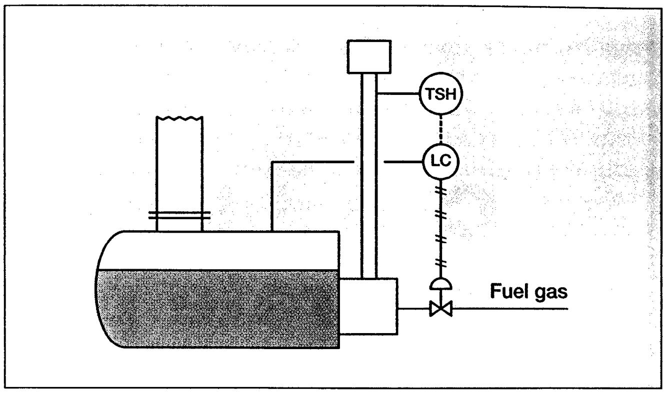

Fig. 13 Control of direct-fired reboilers.

7. Two isobaric heat curves with pressures about 5–10 psi apart shall be input to the HTRI-RKH program.

8. The HTRI-CST program shall be used to check maximum heat flux and tube-side pressure drop.

Reboiler circuit control.

1. Btu control is the most accurate but most expensive control. Thanks to instrument and DCS improvements, Btu control is becoming popular for the critical reboiler circuit.

2. Tower temperature control is sometimes in error because of the temperature transmitter location. When tower liquid level drops below the temperature transmitter, a lower temperature reading is sent to the controller. It is better to install the temperature transmitter in the liquid feed line to the reboiler.

3. Heat medium control:

a. Temperature bypass control is normally applied when the heat medium is process fluid or hot oil. Control heat medium outlet temperature by bypassing heat medium. A control valve shall be installed in the bypass line and sized for 30–40 % of total flow (Fig. 11b).

b. If the heat medium is steam, steam flow control shall be reset by the tower temperature controller (Fig. 11a).

BIBLIOGRAPHY

Kern, O. D., *Process Heat Transfer*, McGraw-Hill.
Bell, K., *Design of Vaporization Equipment.*
HTRI Design Manual.
Fair, J. R., "What You Need to Design Thermosyphon Reboiler," 1960.
Fair, J. R., and A. Klip, "Thermal Design of Horizontal Reboiler," *CEP*, March 1983.
Palen, J. W. and Small W. M., "A New Way to design Kettle and Internal Reboilers," *Hydrocarbon Processing*, November 1964.
Hughmark, G.A., "Designing Thermosyphon Reboilers," *CEP*, July 1961 and July 1964.
Collins, C. K., "Horizontal Thermosyphon Reboiler Design," *Chemical Engineering*, July 1976.
Frank, O., and R. D. Prickett, "Design Vertical Thermosyphon Reboilers," *Chemical Engineering*, September 1973.
Johnson, D. L., and Y. Yukawa, "Vertical Thermosyphon Reboilers in Vacuum Service," *CEP*, July 1979.
Guidelines Given for Designing Vacuum Reboilers, Dec. 1979.
Kern, R., "How to design Piping for Reboiler Systems," *Chemical Engineering*, August 1975.
Mason, G. S., "Good Design Simplifies Reboiler Maintenance," *Hydrocarbon Processing*, January 1983.
Shah, G. C., "Troubleshooting Reboiler Systems," *CEP*, July 1979.

***Edward Chen** is a principal heat transfer engineer with Foster Wheeler USA. He holds a BS degree from Taiwan University and an MS degree from Tulsa University, both in chemical engineering. Mr. Chen started his career in heat transfer with Western Supply Co. Before rejoining Foster Wheeler USA, he worked for ARCO, Stone & Webster and Bechtel.*