054410 Plant Design

LECTURE 8:
REBOILER CIRCUIT DESIGN

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Ref: Kern, R. "Thermosyphon Reboiler Piping Simplified," Hydrocarbon Processing, Dec 1968, 47, No. 12, pp. 118-122

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Lecture Objectives

After this lecture, you should:

❶ Understand the physics behind a thermosyphon.

❷ Be familiar with the four main types of reboiler arrangements in use, and their advantages and disadvantages.

❸ Be able to perform sizing calculations for a thermosyphon.

❹ Be able to select and design the appropriate reboiler circuit for a given application.

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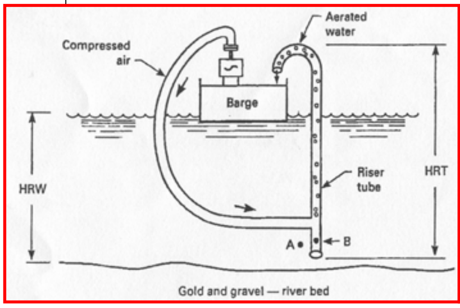
How reboilers work

"Almost as many towers flood because of reboiler problems as because of tray problems."

Theory of thermosyphon, or natural circulation, can be illustrated by the airlift pump.



$$\Delta P = \frac{(HRW)(DRW)-(HRT)(DRT)}{2.31}$$

HRW = hgt of water above base (ft)

DRW = S.G. of fluid in riser (in this case 1.0)

HRT = hgt of aerated water in riser tube (ft)

DRT = S.G. of aerated water in riser tube

ΔP = diff. pressure between A and B (psi)

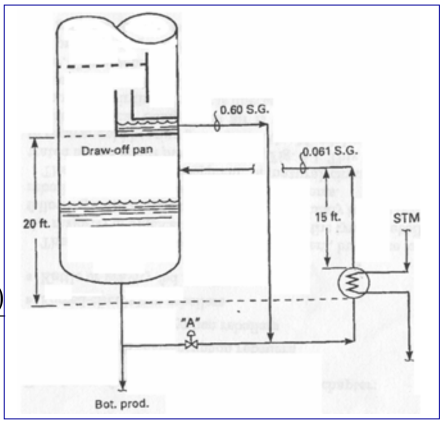
How reboilers work

The driving force to promote flow through this reboiler is the density difference between the fluid in the reboiler feed line and the froth-filled reboiler return line.

For the example on the right:

$$\Delta P = \frac{(20\text{ ft})(0.6)-(15\text{ ft})(0.061)}{2.31}$$

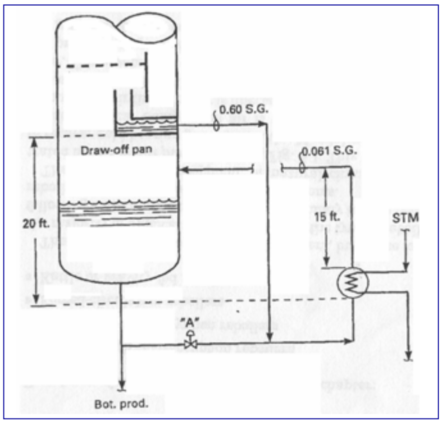
$$= 4.71\text{ psig}$$



How reboilers work

The developed ΔP of 4.7 psig is consumed in overcoming frictional losses, due to flow in the inlet line, reboiler, outlet line and nozzles.

- If these frictional losses are less than 4.7 psig, the inlet line does not run liquid full.
- If they are more than the 4.7 psig, the reboiler draw-off pan overflows, and the flow to the reboiler is reduced until the friction losses drop to the available thermosyphon force.



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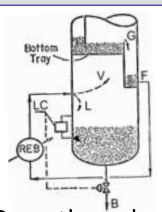
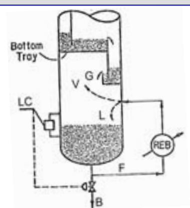
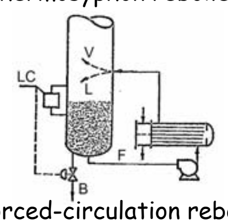
Four Types Considered



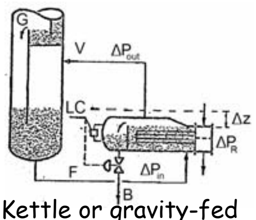
❶ Once-through thermosyphon reboilers



❷ Circulating thermosyphon reboilers



❸ Forced-circulation reboilers



❹ Kettle or gravity-fed reboilers

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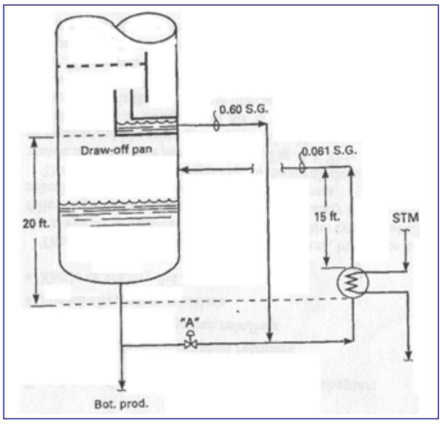
Once-through Thermosyphon Reboiler

The following statements characterize the operation of a once-through thermosyphon reboiler:

❶ All the liquid from the bottom tray flows to the reboiler.
❷ None of the liquid from the bottom of the tower flows to the reboiler.
❸ All the bottoms product comes from the liquid portion of the reboiler effluent.
❹ None of the liquid from the bottom tray flows to the bottom of the tower.
❺ The reboiler outlet temp. is the same as the tower bottoms temp.



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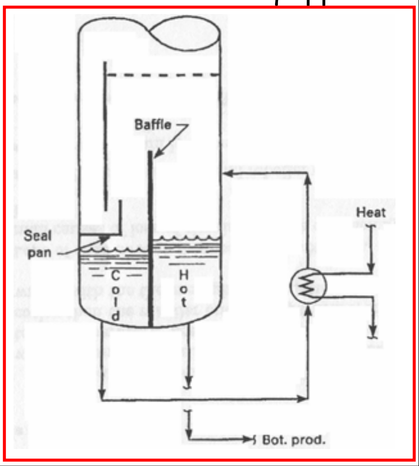
Once-through Thermosyphon Reboiler

A once-through thermosyphon reboiler can be equipped with a vertical baffle.

The reboiler return liquid goes only to the hot side of the tower bottoms.

Putting the reboiler return liquid to the colder side is poor engineering practice.



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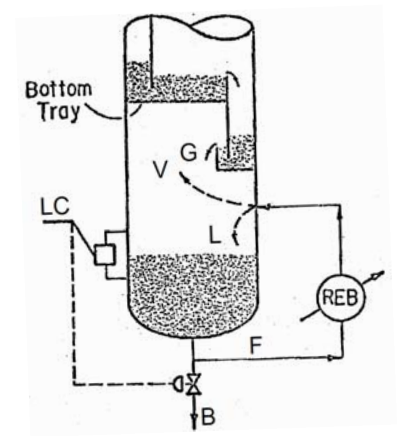
Circulating Thermosyphon Reboiler

In this type of thermosyphon reboiler circuit:

1. The reboiler outlet temp. is always higher than tower bottoms temperature.
2. Some of the liquid from the reboiler outlet will always circulate back into the reboiler feed.
3. Some of the liquid from the bottoms tray ends up as bottoms product.
4. Tower bottoms product temperature and composition is the same as the temperature and composition of the feed to the reboiler.



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Forced-circulation Reboiler

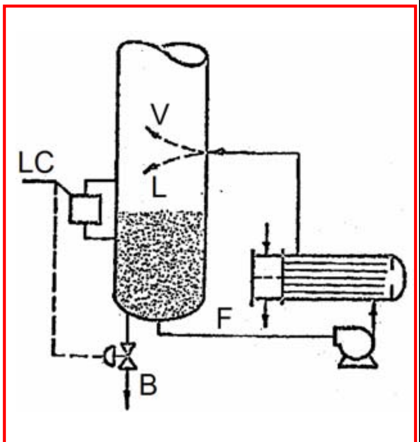
Similar to a "once-through" design, but equipped with a pump to impose circulation.

Advantages:

1. Careful calculation of circuit ΔP is not critical.
2. Can overcome large ΔPs in the reboiler circuit.

Disadvantages: Wastes energy.

Main usages: (a) If the reboiler is a furnace, where loss of flow will lead to tube damage, and the higher ΔP needs to be overcome; (b) if a number of distinct heat sources supply the reboiler duty.



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Kettle Reboiler

In this type of thermosyphon reboiler circuit:

❶ Liquid flows from the column sump to the bottom of the kettle's shell.

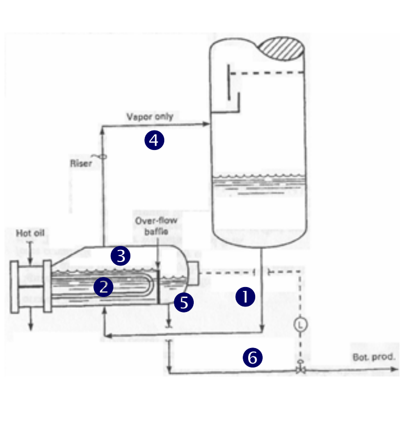
❷ It is partially vaporized.

❸ The domed top section of the reboiler separates the vapor and the liquid.

❹ The vapor flows back into the tower via the riser.

❺ The liquid overflows the baffle, which is set high enough to keep the tubes submerged.

❻ This liquid is the bottoms product.



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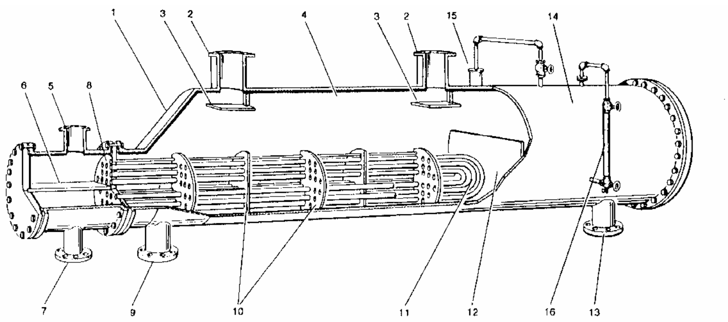
Kettle Reboiler



The components of a kettle reboiler. 1 Shell, 2 shell outlet nozzles (vapour), 3 Entrainment baffles, 4 vapour-disengaging space, 5 channel inlet nozzle, 6 channel partition, 7 channel outlet nozzle, 8 tube sheet, 9 shell inlet nozzle, 10 tube support plates, 11 U-tube returns, 12 weir, 13 shell outlet nozzle (liquid), 14 liquid hold-up (surge) section, 15 top of level—instrument housing (external displacer), 16 liquid level gauge

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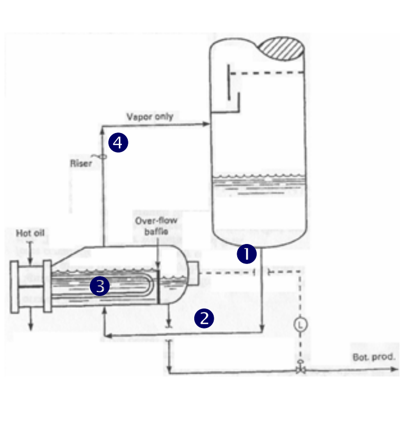
Kettle Reboiler

The level in the tower sump is the sum of the following:

1. Nozzle exit losses.
2. Liquid feed-line ΔP.
3. The shell-side exchanger pressure drop, including the effect of the baffle height.
4. The vapor-line ΔP, including the vapor outlet nozzle loss.

Note:

- Pressure in reboiler is always higher than tower pressure.
- Thus, increase in duty will lead to an increase in sump level.
- Sump level is not controlled!



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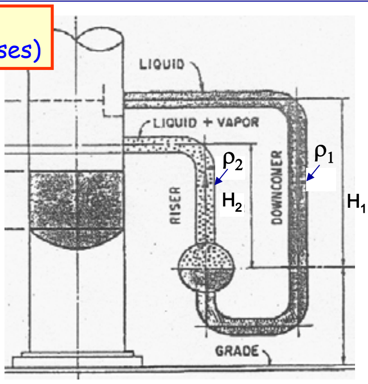
Once-through Reboiler Design

Natural circulation is maintained if
ΔP (driving force) $\leq \Delta p$ (frictional losses)



Driving force for circulation.

$$P_1 - P_2 = \Delta P = (1/144)(\rho_1 H_1 - \rho_2 H_2)$$

P_i – pressure [psi]

ρ_i – density [lb/ft^3]

H_1 – head [ft]

Introducing a safety factor of 2:

$$\Delta P = (1/288)(\rho_1 H_1 - \rho_2 H_2)$$

Friction Losses.

$$\Delta p = \Delta p_d + \Delta p_e + \Delta p_r$$

Δp_e – reboiler ΔP [psi] – usually 0.25-0.5 psi

Δp_d – downcomer ΔP [psi]

Δp_r – riser ΔP [psi]

$\Delta p_d + \Delta p_r$ = 0.1-1 psi/100 ft by design

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Once-through Reboiler Design

<u>Horizontal Reboilers:</u>

The minimum downcomer nozzle elevation above a horizontal reboiler centerline is:

$$H_1 \geq \frac{288\Delta p - (\Delta H)\rho_2}{\rho_1 - \rho_2}$$

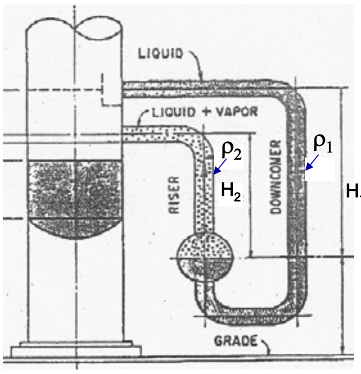
where $\Delta H = H_1 - H_2$. Kern (1968) recommends a head difference of 3 ft: $\Delta H = 3$. In which case:

$$H_1 \geq \frac{288\Delta p - 3\rho_2}{\rho_1 - \rho_2}$$

The density of fluid in riser is:

$$\rho_2 = \frac{W}{W_L/\rho_L + W_V/\rho_V}$$

W_i – mass flows [lb/hr]



Circulating Reboiler Design

Note that draw-off is from the bottom here!

<u>Horizontal Reboilers:</u>

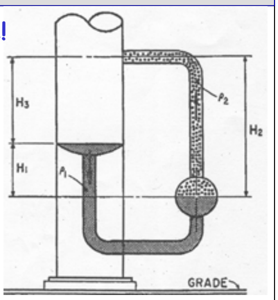
$$\Delta P = (1/288)(\rho_1 H_1 - \rho_2 H_2)$$

As before, the driving force must be at least equal to the frictional losses:

$$\Delta P \leq \Delta p = \Delta p_d + \Delta p_e + \Delta p_r$$

Here $H_2 = H_1 + H_3$. Thus, the minimum down-comer nozzle elevation is limited to:

$$H_1 \geq \frac{288\Delta p + \rho_2 H_3}{\rho_1 - \rho_2}$$



Circulating Reboiler Sizing

Vertical Reboilers (bottom draw-off):

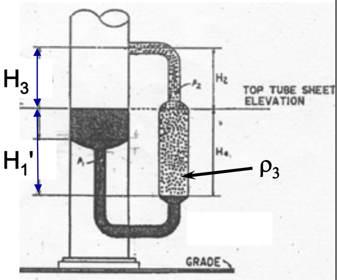
Conservative estimate of the exchanger fluid density: $\rho_3 = (\rho_1 + \rho_2)/2$

Thus, $\Delta P = (1/288)\left(\rho_1 H_1' - \rho_2 H_2 - \rho_3 H_4\right)$

$$\Delta P \le \Delta p = \Delta p_d + \Delta p_e + \Delta p_r$$

However, since $H_1' + H_3 = H_2 + H_4$:

$$H_1' \ge \frac{288\Delta p + \rho_2 (H_4 - H_3) + \rho_3 H_4}{\rho_1 - \rho_2}$$



The vertical reboiler should be flooded. The maximum elevation of the top tube-sheet should not be higher than the minimum liquid level in the tower, thus at minimum, $H_1' = H_4$ and $H_3 = H_2$ and:

$$\Delta P = (1/288)\left(H_1' (\rho_1 - \rho_3) - \rho_2 H_2\right) \text{ and } H_1' = \frac{288\Delta p + \rho_2 H_3}{\rho_1 - \rho_2}$$

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Once-through Reboiler Design

Vertical Reboilers (top draw-off):

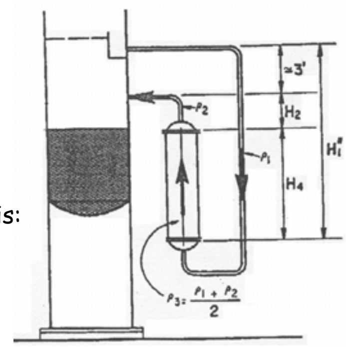
Here, $\Delta P = (1/288)\left(\rho_1 H_1'' - \rho_2 H_2 - \rho_3 H_4\right)$

Following Kern's recommendation:

$$H_1'' = 3 + H_2 + H_4$$

The minimum draw-off nozzle elevation is:

$$H_1'' \ge \frac{288\Delta p - \rho_2 (H_4 + 3) + \rho_3 H_4}{\rho_1 - \rho_2}$$



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Fraction of Fluid Evaporated

Source: Andrew Sloley, Distillation Group Inc.

The amount of incoming feed a thermosyphon reboiler can vaporize is typically between 30-40%. For any given exchanger the limit depends upon the construction details and the system involved. For some installations, it can be as low as 20-25%. Others have achieve levels as high as 45-50% in special circumstances.

There are two reason for this: (a) critical heat flux limitations; (b) vaporization blanketing. Both phenomena limit the amount of heat that can be transferred to a boiling fluid to an upper limit – which leads to the upper limitation in vaporization.

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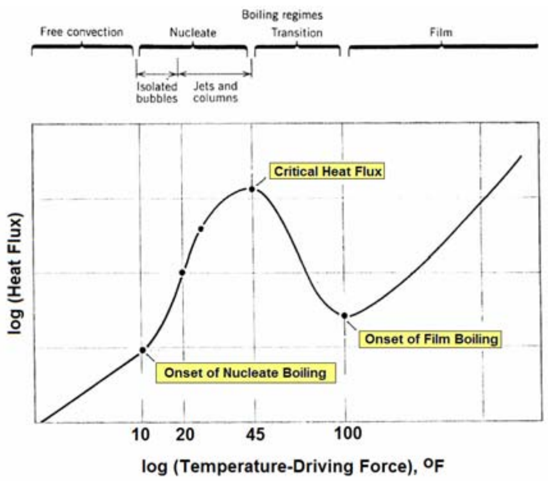
Critical Heat Flux in Boiling Duty



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Example Calculation

Downcomer:

Liquid: 186,850 lb/hr

ρ_1 = 36.7 lb/ft^3

Riser: (30% vapor)

Liquid: 130,750 lb/hr

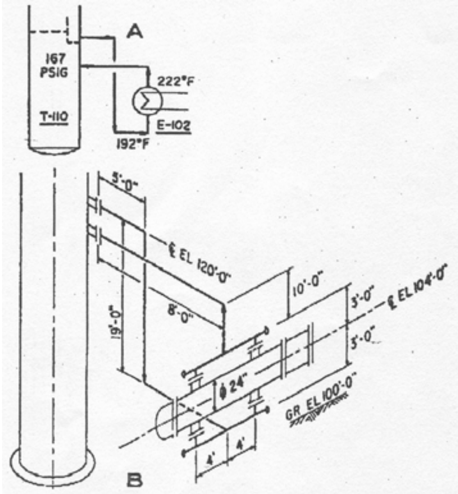
ρ_L = 36.7 lb/ft^3

vapor: 56,100 lb/hr

ρ_V = 1.32 lb/ft^3

$$\rho_2 = \frac{100}{70/30.7 + 30/1.32}$$

$$= 4.06 \text{ lb/ft}^3$$



Example Calculation

Available driving force:

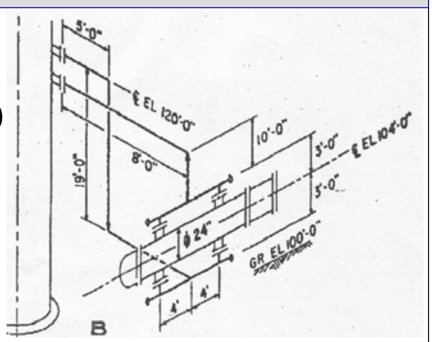
$$\Delta P = (1/288)(\rho_1 H_1 - \rho_2 H_2)$$

$$= (1/288)(36.7 \times 16 - 4.06 \times 13)$$

$$= 1.86 \text{ psi}$$

Frictions losses:

		Δp (psi)		Δp (psi)
Δp_d	8"	0.19	8"	0.19
nozzles		0.10		0.10
Δp_r	8"	1.13	10"	0.43
nozzles		0.95		0.39
Δp_e		0.35		0.35
Δp		2.71		1.46



Minimum draw-off nozzle elevation:

$$H_1 = \frac{288\Delta p - 3\rho_2}{\rho_1 - \rho_2} = \frac{288 \times 1.46 - 3 \times 4.06}{36.7 - 4.06}$$

$= 13$ ft --- 16 ft in actual design ☑

Selection of Reboiler Type

Source: Andrew Sloley, Distillation Group Inc.

Many factors influence reboiler type selection. In the end, all these factors reduce to economics. Every plant will weight the trade-off between these factors differently. No one-size fits all selection exists. Major factors include:

- Plot space available
- Total duty required
- Fraction of tower liquid traffic vaporized
- Fouling tendency
- Temperature approach available
- Temperature approach required

Summary

After reviewing this lecture, you should:

❶ Understand the physics behind a thermosyphon.

❷ Be familiar with the four main types of reboiler arrangements in use, and their advantages and disadvantages.

❸ Be able to perform sizing calculations for a thermosyphon.

❹ Be able to select and design the appropriate reboiler circuit for a given application.