"Design of A Vertical Thermosyphon Reboiler"

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Introduction

Thermpsyphon reboilers play a wide role in chemical industry, which provides a simple, low maintenance design for distillation tower reboiler system. The thermosyphon reboiler contains the two endearing qualities of the evaporator, namely mechanical simplicity and operation in the nucleate boiling regime with its attractive high fluxes [Mckee Hugh R. , 1970]. These reboilers require rational design procedure as several flow patterns manifests during the heat transfer to a flowing two phase boiling mixture, which in-turn depends upon the flow rates, physical properties of the components, pipe diameter and orientation. The circulation rate, heat-transfer rate and pressure drop all are interrelated, and hence iterative design procedures must be used [Johnson D.L. and Yukawa Y., 1979]

The advantages and disadvantages of thermosyphon reboiler [Frank O. and Pricket R.D…, 1973] are listed in table 1.

Table 1: Advantages and Disadvantages of thermosyphon reboiler

Advantages:

- Cheapest reboiler installation in terms of capital and operating cost
- Permits simple, compact piping arrangement
- Provides excellent thermal performance

Disadvantages:

- Not suitable for viscous or solid bearing fluids
- More heat transfer area required for vacuum operation
- Not specified for pressure below 0.3 bar
- Column base must be elevated to provide the hydrostatic head required for the thermosyphon effect. This increases the cost of the column supporting structure.

Features of Construction

In thermosyphon reboilers, performance is determined by the interrelated thermal and hydraulic characteristics, of the reboiler and the interconnecting piping. Circulation is established through the reboiler by the difference between the hydraulic head of the liquid in the column and of the two phase mixture in the reboiler. Raising the liquid level in the column, relative to the reboiler increases this difference in hydrostatic head and thus increases the rate at which the fluid to be vaporized flows through the reboiler. Hence the hydraulic characteristics as well as heat transfer must be taken into the consideration while designing the reboiler.
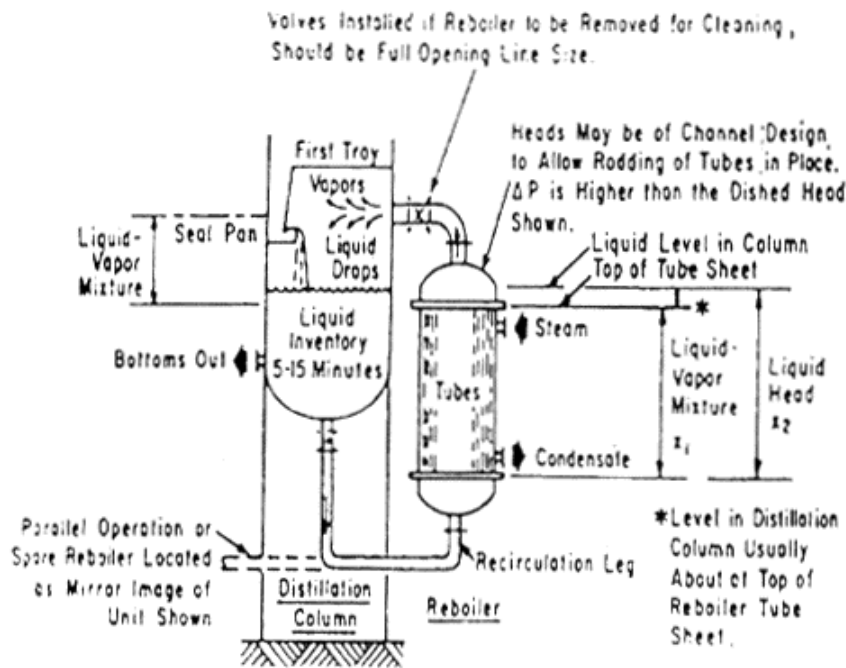[Frank O. and Prickett R.D…, 1973]
[Martin R. and Sloley A.W., 1995]

Fig. 1 Vertical Thermosyphon Reboiler

Classification of thermosyphon reboiler

(a) According to orientation :
- o Vertical thermosyphon reboiler
- o Horizontal thermosyphon reboiler

(b) According to the flow pattern
- o Once-through circulation
- o Natural circulation

Design Procedure

Process Design Aspects

Fair's method for vertical thermosyphon is based on semi-empirical correlation of experimental data, and is stated to predict that heat transfer coefficients $\pm$ 30 %, which is about the same range of accuracy for the most boiling coefficient data. Fair's method recognizes two-phase flow in the reboiler, and points out that slug type flow is most predominate, and that mist flow should be avoided [Ludwig].

Assumptions in the design procedure:

- Perfect mixing of vapor in the tower sump vapor space.
- Perfect vapor-liquid separation of return material from the thermosyphon, in the column space.
- Steady state fluid flow regimes
- Full disengagement of vapor generated inside the liquid in the tower sump
- No leakage from tower internals and across the sump baffles
- Constant heat flux condition exists throughout the length of the reboiler tube.
- The top tube sheet of the reboiler is in the line with the liquid level in the fractionator
- At any point in the two-phase region along the tube, thermodynamic equilibrium exist between saturated liquid and vapor corresponding to the pressure at that point

Refer Flowchart 1.

Parameters affecting:

The performance of thermosyphon reboiler is mainly affected by the nature of fluid (mainly on viscosity) and the liquid head in the reboiler [Orrell W.H., 1973].

At low liquid levels, the liquid feed entering the reboiler is nearly completely vaporized. In this situation, the liquid heating zone is small and nucleate boiling occurs almost immediately. In the reboiler above the nucleate boiling zone, mist flow develops and heat transfer will superheat the gas. In this mist flow zone, the temperature rise can be significant, because of the gas superheating, which results in a low overall temperature difference and low overall heat transfer coefficient. This explains the poor performance of the reboiler [Johnson D. L. and Yukawa Y. . 1979]

An increase in the liquid driving head results in a higher boiling point at the bottom of the reboiler. Since the inlet liquid must be preheated to a higher temperature to initiate heating zone. Due to the low heat transfer coefficient in the liquid heating zone, less area is available for nucleate boiling heat transfer; finally resulting a decrease in the overall heat transfer coefficient for the reboiler [Johnson D.L. and Yukawa Y., 1979]
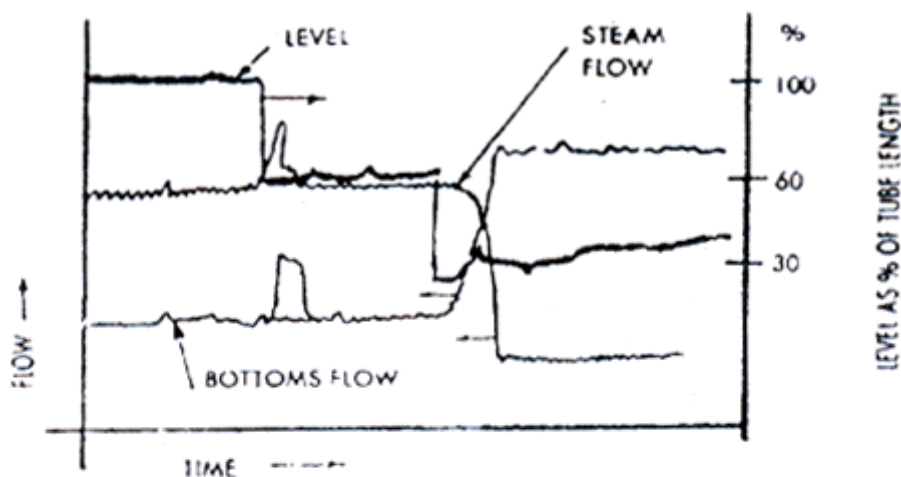
AS THE LEVEL IS LOWERED TO 60% OF TUBE LENGTH, ESSENTIALLY NO CHANGE IS OBSERVED IN THE STEAM OR BOTTOMS FLOW. BECAUSE OF LOWER LIQUID HEAD AVAILABLE. HOWEVER. LIQUID CIRCULATION WILL BE LOWER.

WITH FURTHER REDUCTION IN THE LEVEL TO 20%-25% OF THE TUBE LENGTH, STEAM FLOW DROPS TO A LOW VALUE (STEAM VALVE WIDE OPEN) INDICATING LOSS OF HEAT TRANSFER. BECAUSE OF LOWER BOIL-Ur (MIST FLOW REGIME) THERE IS A CONSEQUENT - INCREASE IN THE BOTTOMS FLOW.

The optimum practical liquid driving head for vertical reboilers operating at atmospheric pressure or higher is top tube sheet level. For the vacuum reboiler it is about 50 % of the tube length. Figure 2 shows the effect of liquid level on a vertical thermosyphon reboiler. Moreover, to prevent surging to the reboiler, avoid subjecting heavy components (viscous in nature) to repeated thermal contacts [Shah G.C., 1979].

Maximum heat flux:

As the vapor-liquid mixture flows through the reboiler tube, the flow is not continuous and smooth but is rather pulsating. The amplitude of pulsation is controlled by the rate of heat flux and at sufficiently high values of heat flux, the amplitude of pulsation is large enough so that the down-flow pulse sucks

the vapor into the compartment below the tubes resulting in "vapor locking". This corresponds to the maximum permissible heat flux and critical temperature difference to be used in any reboiler design [Furzer Ian A., 1990]

This maximum heat flux is found to be dependent on the roughness of the surface and the number of nucleation sites. The value of the heat flux in pool boiling provide the global maximum of the CHF when the reduced pressure is from 0.25 to 0.30.

The principle characteristics of a vertical thermosyphon reboiler near the maximum heat flux are as follows:

(a) The temperature of the in and out of the reboiler is equal.
(b) There is a temperature pinch condition near the tube entry
(c) The fraction of the tube length in the single-phase is small
(d) The mass flux in the tubes decreases with increasing heat flux

Flow chart 1: Design of Vertical Thermosyphon Reboiler
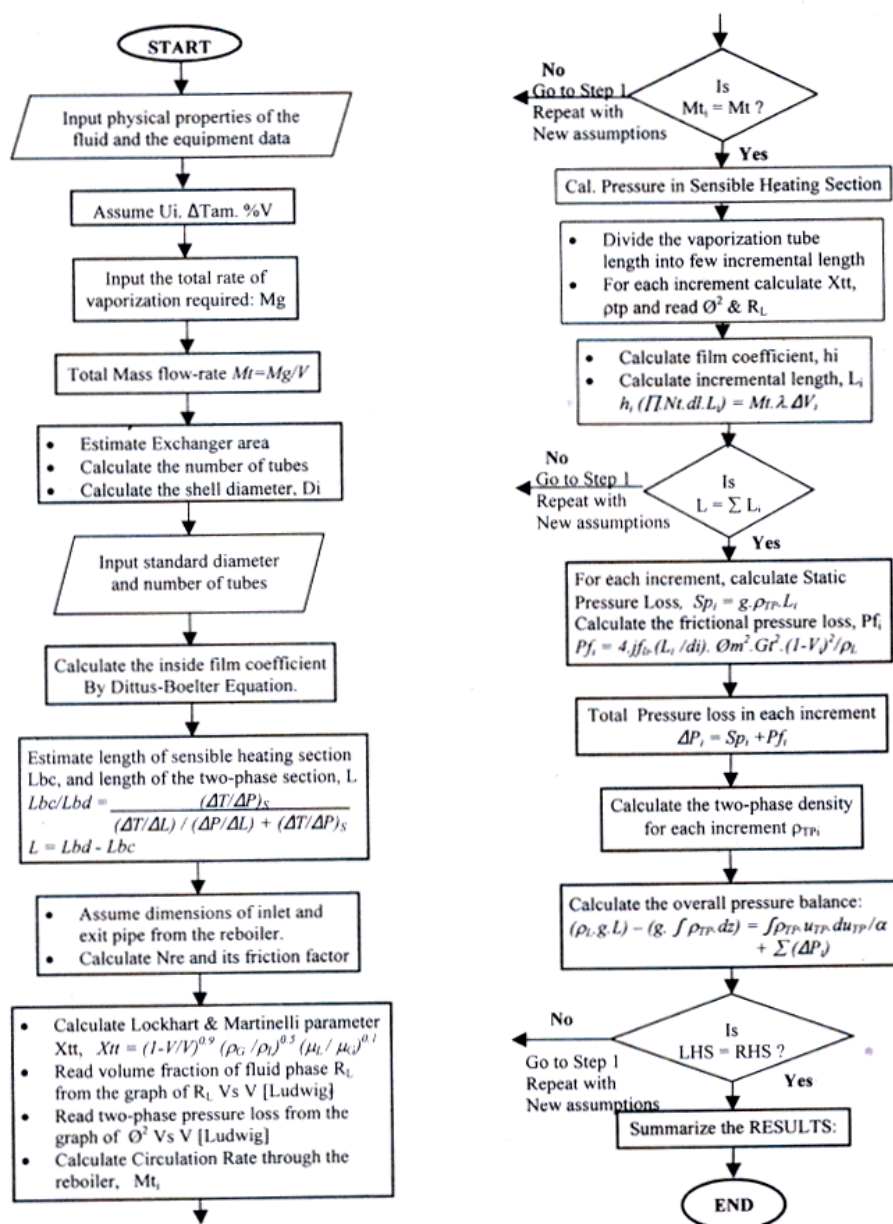
Example

Tube side: Pure liquid cyclopean

Shell Side: Steam

Properties of the fluid:

λ_L	=	152.6 Btu/lb	σ	=	0.0388 pdl/ft.
μ_L	=	1.258 lb/ft.hr	μ_G	=	0.02036 lb/ft.hr
ρ_L	=	46.12 lb/ft^3	ρ_G	=	0.1855 lb/ft^3
Cp_L	=	0.5498 Btu/lb°F	k_l	=	0.09521 Btu/ft.hr °F
k_w	=	218 Btu/ft.hr.F°			

Equipment Data:

d_0	=	0.0625 ft	di	=	0.05183 ft
DI	=	0.5054 ft	DE	=	0.835 ft
LI	=	100 ft	LE	=	50 ft
L_{BD}	=	5 ft	p	=	0.08333 ft

Calculation Results:

hfi	=	1000 Btu/ft^2.hr.F°	hfs	=	2411.73 Btu/ft^2.hr.F°
hs	=	2411.73 Btu/ft^2.hr.F°	$\triangle$Tam	=	42 °F
Nt	=	192			
%vaporization	=	15 %	Ui	=	289.5 Btu/ft^2.hr.F°
Pressure head	=	1.6014 psig			
Pressure loss	=	1.463 psig			

Comparison of results by Kern's method:

Nt	=	150	Ui	=	300 Btu/ft^2.hr.F°
Pressure head	=	1.6014 psig			
Pressure loss	=	1.3516 psig			

Result and Discussion

Fair's method considered both nucleate and convective contribution owing to presence of two-phase. Whereas Kern's method has no such consideration for the two=phase flow of the fluid. Fair's method thus has an upper hand.

It is seen that to design a thermosyphon reboiler using hand calculations would be tedious and time consuming. The iterative nature of the procedure lends itself to solution by computers.

Hence, the computer program not only saves from the tedious hand calculations but also helps in obtaining the optimum design for the thermosyphon reboilers.

Nomenclature

Cp_L	=	Specific heat of liquid
d_o	=	outside diameter of the tube.
Di	=	inside diameter of the tube
DI	=	shell inner diameter
DE	=	diameter of the outlet pipe to the reboiler
Gt	=	mass flow rate
Hi	=	heat transfer coefficient
hfi	=	frictional heat transfer coefficient on tube side
hfs	=	frictional heat transfer coefficient on the shell side
jfli	=	friction factors for reboiler tubes
kL	=	thermal conductivity of the liquid
kL	=	thermal conductivity of the wall
L	=	two-hase heating section

Li	=	incremental length
Lbc	=	single phase heating section
Lbd	=	total tube length
Ll	=	length of the inlet pipe to the reboiler
LE	=	length of the out pipe to the reboiler
Mg	=	flow rate of vapor
Mt	=	total flow rate
Mti	=	calculated total flow rate
Nt	=	Number of tubes
p	=	tube pitch, ft
$\triangle$Pfi	=	pressure loss due to friction in each increment
R_L	=	liquid volume fraction
Sp_i	=	static pressure loss
$\triangle$Tam	=	mean temperature difference
Ui	=	overall heat transfer coefficient
%V	=	% vaporization
Xtt	=	Lockhart and Martinelli parameter

Greek letters:

ϕ^2	=	two phase pressure loss
ρ	=	density (Suffix "$_L$" for liquid and "$_G$" for vapor)
μ	=	viscosity (Suffix "$_L$" for liquid and "$_G$" for vapor)
σ	=	surface tension

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