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Practical Engineering Guidelines for Processing Plant Solutions

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Kolmetz Handbook Of Process Equipment Design

DISTILLATION COLUMN REBOILER SELECTION, SIZING AND TROUBLESHOOTING

(ENGINEERING DESIGN GUIDELINES)

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SCOPE

This document covers the basic elements in the design of reboilers. It includes sufficient detail to allow an engineer to design a reboiler with the suitable size of diameter, velocity, and type. A reboiler is a heat exchanger that is used to generate the vapor supplied to the bottom tray of a distillation column. Thermal and hydraulic analyses of reboilers are generally more complex than for single-phase exchangers. Reboilers are classified according to their orientation and the type of circulation employed.

The choice of the best type of reboiler or vaporizer for a given duty will depend on the following factors:

1. The nature of the process fluid, particularly its viscosity and propensity to fouling;
2. The operating pressure: vacuum or pressure;
3. The equipment layout, particularly the headroom available.

INTRODUCTION

The transfer of heat to and from process fluids is an essential part of most chemical processes. A reboiler is a heat exchanger that is used to generate the vapor supplied to the bottom tray of a distillation column. The liquid from the bottom of the column is partially vaporized in the exchanger, which is usually of the shell-and-tube type. The heating medium is most often condensing steam, but commercial heat-transfer fluids and other process streams are also used. Boiling takes place either in the tubes or in the shell, depending on the type of reboiler

The following should be considered when the selection of a reboiler type is made.

1. Fouling -Tube-side is easier to clean than shell-side.
2. Corrosion - corrosion or process cleanliness may dictate the use of expensive alloys; therefore, these fluids are placed inside tubes in order to save the cost of an alloy shell.
3. Pressure - high pressure fluids are placed on tube side to avoid the expense of thick walled shells. For very low pressures (vacuum) other factors involved in the selection of reboiler type determines the tube-side fluid.
4. Temperatures - very hot fluids are placed inside tube to reduce shell costs. The lower stress limits at high temperatures affect shell design the same as high pressures.
5. Heating medium requirements may be more important than the boiling liquid requirements.
6. Boiling fluid characteristics: Temperature sensitive liquids require low holdup design. Boiling range and mixture concentration together with available ΔT affect circulation requirements to avoid stagnation. Foaming can be better handled inside tubes.
7. Temperature difference and type of boiling (film or nucleate) affects the selection.
8. Space constraints; e.g., if head room is limited then vertical units would be inappropriate or the limitation of space for internal reboilers.
9. Enhanced surfaces are suitable only for some types.

Types of Reboilers

Reboilers are classified according to their orientation and the type of circulation employed. The most commonly used types are described below.

A. Kettle Reboiler

Kettle reboilers are commonly applied when a wide range of process operations (high turndown capability), large heat exchange surface, or high vapor quality is required. Kettle reboiler is also called a “submerged bundle reboiler”. Installations include column bottom reboilers, side reboilers, or vaporizers. Kettles are generally more costly than other reboiler types due to shell size, surge volume size, and uncertainty in the TMTD. They are often used as vaporizers, as a separate vapor-liquid disengagement vessel is not needed. They are suitable for vacuum operation and for high rates of vaporization up to 80% of the feed.

B. Horizontal Thermosyphon

This is a very common type of reboiler. Horizontal thermosiphon reboilers are the preferred reboiler type in refining applications. The process side is on the shell side, and the heating medium is on the tube side. The boiling occurs inside shell in horizontal thermosyphon. There is recirculation around the base of the column. A mixture of vapor and liquid leaves the reboiler and enters the base of the column where it separates.

Compared to the vertical thermosiphon reboiler, the horizontal thermosiphon reboiler generally requires less headroom but have more complex pipework and plot space making it more expensive to install and has a higher fouling tendency which leads to a slightly lower availability (because of outages for cleaning). Horizontal exchangers are more easily maintained than vertical, as tube bundles can be more easily withdrawn. They are generally better suited than vertical thermosyphons for services with very large duties.

C. Vertical Thermosyphon

This is a very common type of reboiler in the chemical and petrochemical industries. Vertical thermosiphon reboilers are used almost exclusively in chemical applications, while the petrochemical industry is about 70% vertical and 30% horizontal. In vertical thermosyphon reboiler, the liquid circulation occurs due to density difference between vapor-liquid mixture (two phase) in the exchanger from the reboiler and the liquid through the downcomer to the reboiler.

E. Forced-Circulation Reboilers

Forced circulation reboilers are similar to vertical thermosiphon reboilers, except the pump is used for the circulation of the liquid and the hot liquid flows inside column. Usually arranged in a Unbaffled Recirculating Circuit unless there is a critical temperature level beyond which the process material undergoes decomposition or polymerization. If this is the case then a preferential type column draw-off design would be recommended over the Unbaffled Recirculation design.

For sensitive materials, precautions should be taken in the design of fired reboilers, such that the pressure drop is reasonably low and the heat rate in the heater is such that the film temperatures in the furnace tubes does not approach a temperature where excess fouling, product decomposition, or polymerization can initiate. The main use of forced flow reboilers is in services with severe fouling problems and/or highly viscous (greater than 25 cp) liquids for which kettle and thermosyphon reboilers are not well suited. Pumping costs render forced flow units uneconomical for routine services.

F. Internal Reboilers

Also known as stab-in reboilers or stab-in bundles, internal reboilers are another special application of the horizontal reboiler design. The internal reboiler is usually used where the process can be on the shell side and the reboiler surface area is small enough to fit into the distillation column bottom sump. The process side is on the shell side and the heating medium is on the tube side.

Boiling takes place in the pool of liquid at the bottom of the tower, the heating fluid being inside the bundle of tubes. Since the boiling liquid forms froth, which may vary in density, controlling bottom level can be difficult. This fact can makes this type of reboiler less attractive, particularly in foaming and vacuum services. Applications where internal reboilers are sometimes used include:

- Batch distillation: where the tube bundle can easily be fitted into the batch drum, and periodic cleaning can be easily accommodated.
- Very low heat duty clean services: where column diameter is large due to other considerations, and where the reboiler tube bundle is small.

DEFINITIONS

Batch distillation - Distillation where the entire batch of liquid feed is placed into the still at the beginning of the operation, in contrast to continuous distillation, where liquid is fed continuously into the still.

Boiling point - the temperature at which the liquid and vapor (gas) phases of a substance can exist in equilibrium. When heat is applied to a liquid, the temperature of the liquid rises until the vapor pressure of the liquid equals the pressure of the surrounding gases. At this point there is no further rise in temperature, and the additional heat energy supplied is absorbed as latent heat of vaporization to transform the liquid into gas.

Critical pressure - The vapor pressure of a substance at its critical temperature.

Critical temperature - For a pure component, the maximum temperature at which the component can exist as a liquid.

Downcomer - a vertical channel that connects a tray with the next tray below which carries froth and creates residence time which helps the vapor disengage from the froth.

Fouling - Deposition on the surface of a heat-transfer device of sediment in the form of scale derived from burned particles of the heated substance.

Heat duties - the amount of heat needed to transfer from a hot side to the cold side over a unit of time.

Heat exchanger - A device used to transfer heat from a fluid on one side of a barrier to a fluid on the other side without bringing the fluids into direct contact.

Heat flux - the rate of heat transmission through the tubes into the process fluid.

Heating medium - Any solid or fluid (such as water, steam, air, or flue gas) which is used to convey heat from a heat source (such as a boiler furnace), either directly or through a suitable heating device, to a substance or space being heated.

Heat-transfer - any or all of several kinds of phenomena, considered as mechanisms, that convey energy and entropy from one location to another. The specific mechanisms are usually referred to as convection, thermal radiation , and conduction

Kettle reboiler - Tube-and-shell heat exchange device in which liquid is vaporized on the shell side from heat transferred from hot liquid flowing through the tubes; dome space allows liquid-vapor separation above the tube bundle.

Liedenfrost point - The heat flux reaches a minimum, where the entire solid surface is covered by a vapor blanket

Nozzle – the pipe sections use to connect to the heat exchanger headers to the piping.
nucleate boiling - the phoneme where heat is transferred primarily from the solid surface directly to the liquid flowing across the surface

Pool boiling - where hot fluid inside a tube causes vapor generation on the outside surface of the tube from a pool of liquid

Reboiler - are heat exchangers typically used to provide heat to the bottom of industrial distillation columns. They boil the liquid from the bottom of a distillation column to generate vapors which are returned to the column to drive the distillation separation

The driving force - the density difference between the fluid in the reboiler feed line and the froth-filled reboiler return line.

Thermosiphon reboilers - A liquid reheater (as for distillation-column bottoms) in which natural circulation of the boiling liquid is obtained by maintaining a sufficient liquid head.

Tube bundles - In a shell-and-tube heat exchanger, an assembly of parallel tubes that is tied together with tie rods.

Vaporizers - a device for reducing medicated liquids to a vapor useful for inhalation or application to accessible mucous membranes.

NOMENCLATURE

A	heat transfer area, m^2
A_{1t}	Area of one tube, (m^2)
A_t	Total cross sectional area of bundle, m^2
D_B	the bundle diameter, m
D_i	Inside diameter, m
D_o	Outside diameter, m
f	the friction factor
g	gravity acceleration
G	Mass flux, kg/m^2 s
G_t	Mass flow rate, kg/s
G_V	Vapor mass rate, kg/s
h_{NB}	the boiling film coefficient, W/m^2K
h_{nb}	the pool boiling coefficient, W/m^2C
h_{TF}	Film Coefficient for condensing tube, W/m^2 K
H_{vap}	Heat of vaporization, j/kg / kj/mol
k	Thermal conductivity, W/m K
L_t	Length tube, m
M_L	Liquid molar rate, kmol/s
Mr	Molecular mass, kg/kmol
M_V	Vapor molar rate, kmol/s
Nt	number of tubes required,
P	pressure operation at botom column, bar
p_C	pitch configuration factor
P_C	Critical pressure, bar
q	heat flux, W/m^2
Q	specific heat duty, W / KW
q_C	critical heat flux, W/m^2K
Re	reynold number at tube exit,
T	Temperature of vaporize, ^oC
t	tube thickness, m
T_C	Critical temperature, K
T_R	Reduce temperature

T_S	Steam condensing temperature, °C
U	Overall heat transfer coefficient, W/m^2K / W/m^2 C
v_l	Outlet specific volumes, m^3/kg
V_L	liquid flow rate leaving the reboiler, m^3
v_o	Inlet specific volumes, m^3/kg
v_{ten}	Tube entry velocity, m/s
v_{tex}	velocity at tube exit, m/s
V_V	the vapor flow rate leaving the reboiler, m^3

Greek letters

ΔP_{df}	the available head (Driving Force), N/m^2
ΔP_{en}	tube entry pressure drop per unit length, N/m^2 per m tube length
ΔP_{ex}	tube exit pressure drop per unit length, N/m^2 per m tube length
ΔP_S	the static head in the tubes, N/m^2
ΔP_t	pressure drop over tube, N/m^2
ΔP_{tot}	the total pressure drop over tubes, N/m^2
ΔT	Mean temperature difference
μ	liquid viscosity, Nm/s^2
ρ_{ex}	Exit density, kg/m^3
ρ_L	Liquid density, kg/m^3
ρ_V	Vapor density, kg/m^3

Superscript

TEMA	Tubular Exchanger Manufactures Association Inc (www.tema.org)
HTRI	Heat Transfer Research Inc (www.htri.net)
ONB	Onset of nucleat boiling