



GBH Enterprises, Ltd.



Process Engineering Guide:

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Selection of Reboilers for Distillation Columns

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Refinery Process Stream Purification Refinery Process Catalysts Troubleshooting Refinery Process Catalyst Start-Up / Shutdown Activation Reduction In-situ Ex-situ Sulfiding Specializing in Refinery Process Catalyst Performance Evaluation Heat & Mass Balance Analysis Catalyst Remaining Life Determination Catalyst Deactivation Assessment Catalyst Performance Characterization Refining & Gas Processing & Petrochemical Industries Catalysts / Process Technology - Hydrogen Catalysts / Process Technology - Ammonia Catalyst Process Technology - Methanol Catalysts / process Technology - Petrochemicals Specializing in the Development & Commercialization of New Technology in the Refining & Petrochemical Industries

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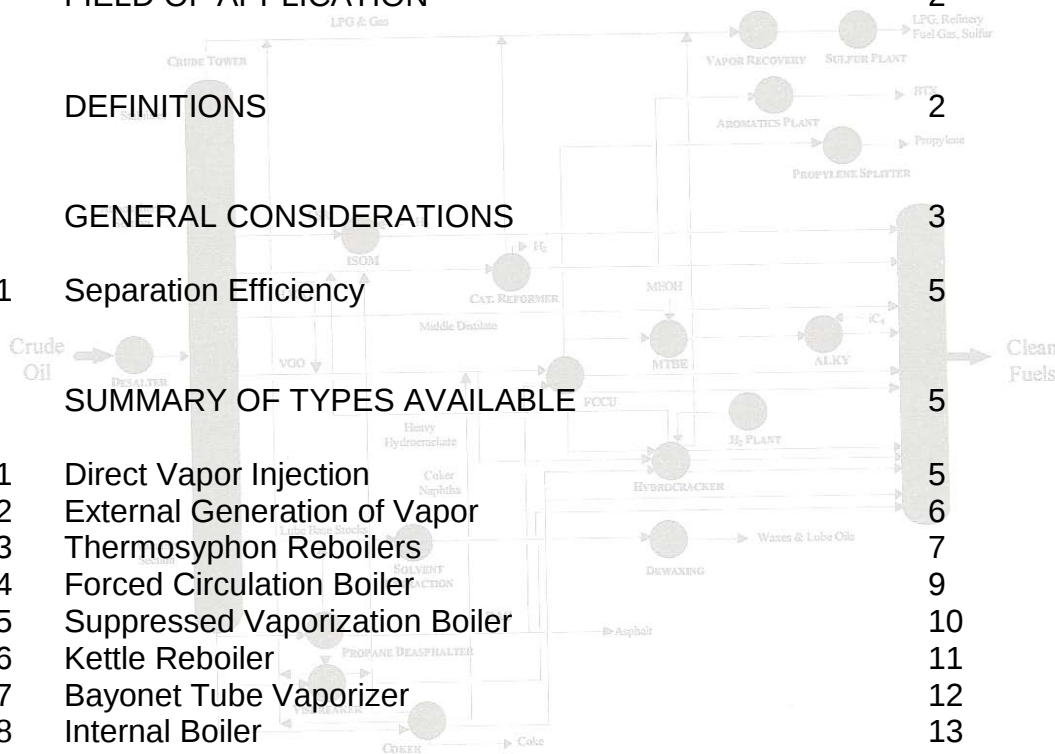
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0 INTRODUCTION/PURPOSE

This Process Engineering Guide (PEG) is one of a series on heat transfer prepared for **GBH Enterprises**.

There are several different forms of reboiler which may be used with a distillation column, each of which has both merits and drawbacks. Guidance is required in selecting the most appropriate form for a given duty.

1 SCOPE

This Process Engineering Guide is designed as an aid to the selection of reboilers for distillation columns. It describes the various options and details their merits and drawbacks.

2 FIELD OF APPLICATION

This Guide is intended for process engineers and plant operating personnel in **GBH Enterprises** worldwide, who may be involved in the specification or design of reboilers.

3 DEFINITIONS

For the purposes of this Guide, the following definitions apply:

HTFS Heat Transfer and Fluid Flow Service. A co-operative research organization, in the UK, involved in research into the fundamentals of heat transfer and two phase flow and the production of design guides and computer programs for the design of industrial heat exchange equipment.

HTRI Heat Transfer Research Incorporated. A co-operative research organization, based in the USA, involved in research into heat transfer in industrial sized equipment, and the production of design guides and computer programs for the design of such equipment.

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FRI Fractionation Research Incorporated. A co-operative research organization, based in the USA, involved in research into distillation in industrial sized equipment, and the production of design guides and computer programs for the design of such equipment.

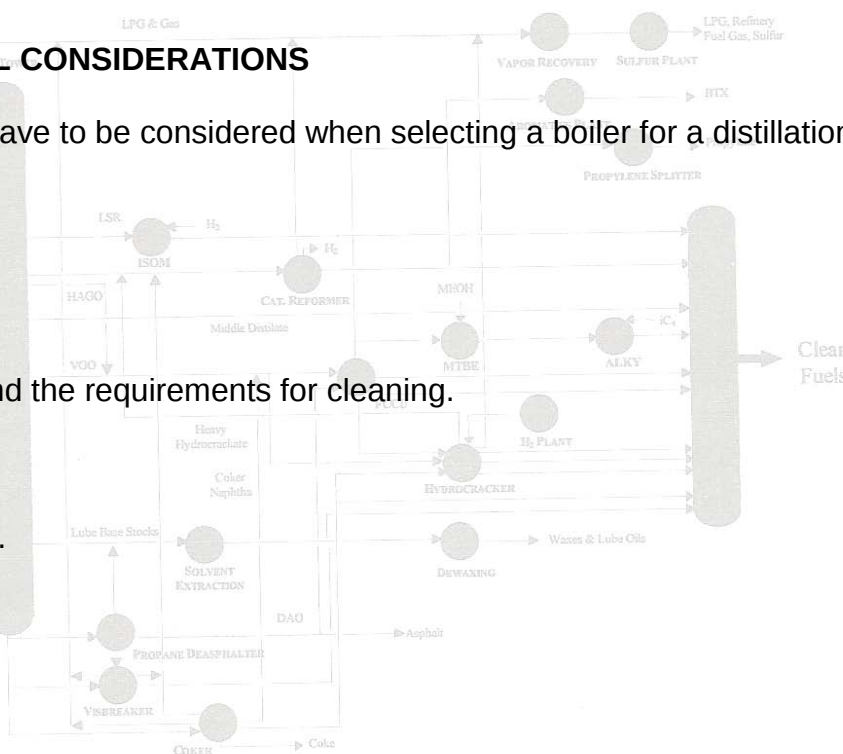
TEMA The Tubular Exchanger Manufacturers' Association. An organization of US manufacturers of shell and tube exchangers. Their publication 'Standards of the Tubular Exchanger Manufacturers Association' is widely accepted as the basis for the specification of heat exchangers.

4 GENERAL CONSIDERATIONS

Several factors have to be considered when selecting a boiler for a distillation column.

These include:

- (a) Layout.
- (b) Fouling and the requirements for cleaning.
- (c) Stability.
- (d) Turndown.
- (e) Inventory.
- (f) Cost.



4.1 Separation Efficiency

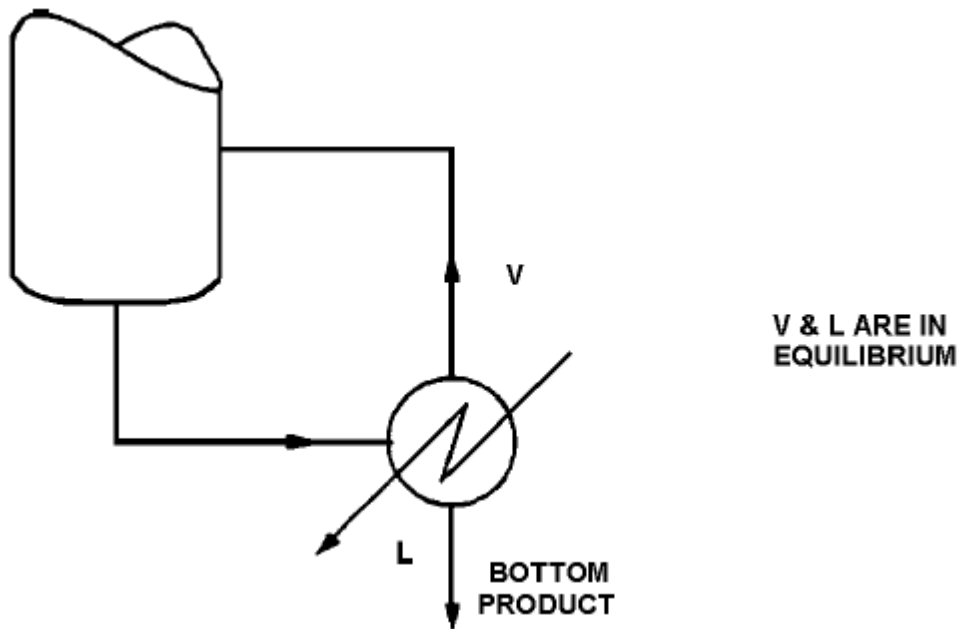
The boiler forms part of the distillation system, and as well as providing the vapor for the separation within the column, contributes some measure of separation itself. Different boiler types have different separation efficiencies. This has to be allowed for when designing the column.

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Commercially available programs, which are widely used for assessing column performance, assumes that the vapor entering the base of the column and the bottom liquid product are in equilibrium. This is the same as assuming that the boiler is equivalent to one theoretical stage. For a squat kettle boiler, with the bottom product taken off from the boiler, this is a reasonable assumption (Figure 1(a)).

FIGURE 1 (a) EQUILIBRIUM RELATIONSHIPS IN SQUAT KETTLE REBOILER

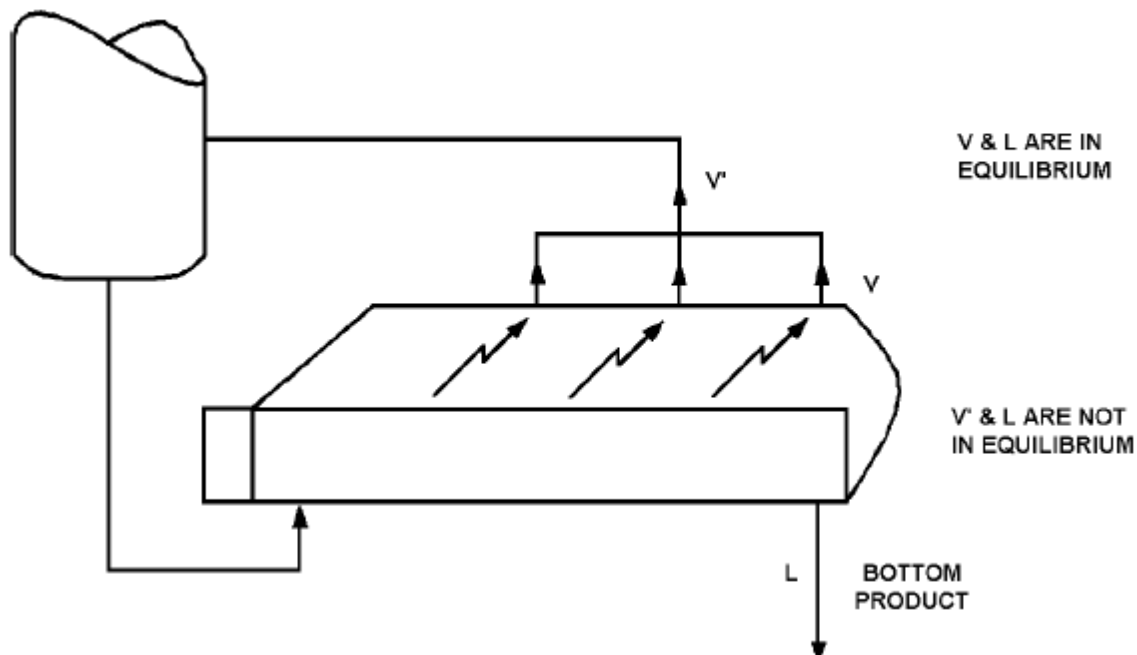


For a long narrow kettle with poor longitudinal mixing, in which the liquid flows along the boiler from one end and vapor is removed from contact with the liquid at several places along the boiler, (Figure 1(b)), the bottom liquid product will be in equilibrium with the vapor at the far end of the boiler. However, the vapor removed from the earlier parts of the boiler will be richer in the more volatile component; the mixed vapor returned to the column will be richer in more volatile components than that in equilibrium with the liquid from the boiler, so the boiler separation efficiency will be greater than unity.



FIGURE 1 (b)

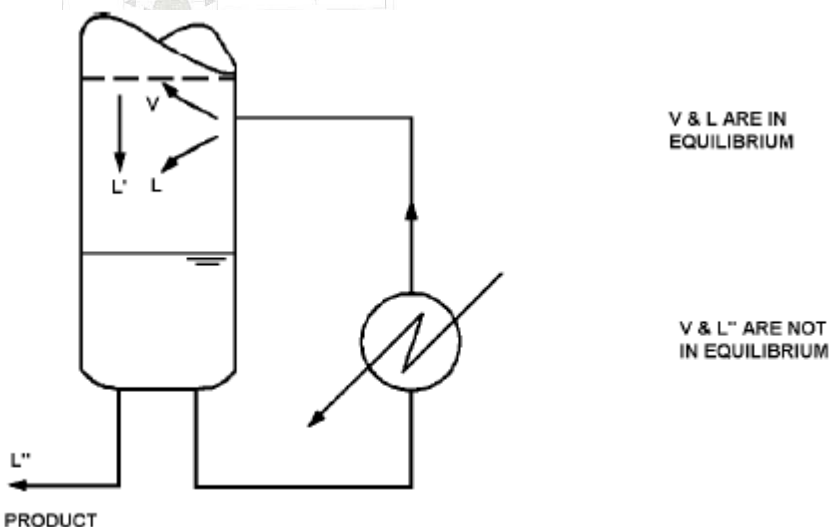
EQUILIBRIUM RELATIONSHIPS IN LONG NARROW KETTLE REBOILER



In most recirculating boilers, operating in either a thermosyphon or forced circulation fashion, the bottom liquid product is taken from the column separately from the feed to the boiler (Figure 1(c)).

FIGURE 1 (c)

EQUILIBRIUM RELATIONSHIPS IN THERMOSYPHON AND FORCED CIRCULATION REBOILER



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Within the boiler, the liquid and vapor are generally kept in intimate contact, so the vapor and liquid returning to the column are in equilibrium. However, inside the column the returned liquid is mixed with the liquid overflow from the bottom plate, which will have a higher concentration of more volatile components than the returned liquid. This mixture, which forms the bottom product, will be richer in more volatile components than liquid in equilibrium with the returned vapor, and the efficiency of the reboiler is thus less than unity. If all the liquid entering the boiler is evaporated, the stage efficiency is zero; it approaches unity as the fraction vaporized per pass approaches zero. Some idea of the extent of the separation can be given if we calculate the Murphree efficiency of the boiler as a function of relative volatility and percentage vaporization (Table 1).

TABLE 1 MURPHREE EFFICIENCY OF A REBOILER

Relative Volatility % Vaporisation	1.2	2	5	10
15	85	75	55	40
50	45	35	20	10
75	20	15	10	5

With 15% vaporization, the reboiler will contribute about the same amount of separation as an actual tray, to a first approximation. At 50% this falls to about half a tray. These figures are typical for thermosyphon and pumped circulation respectively.

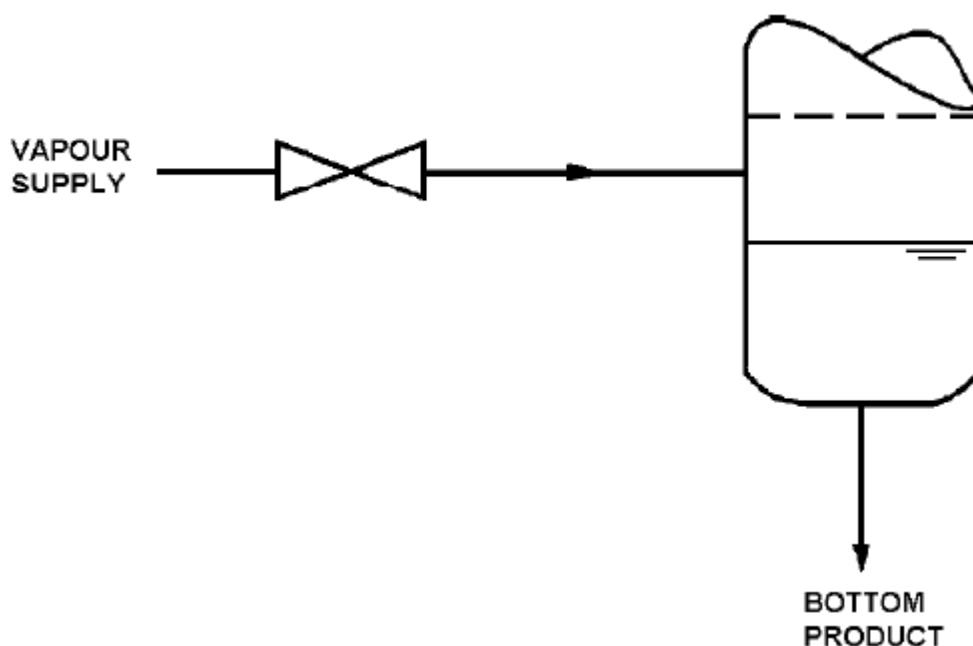
5 SUMMARY OF TYPES AVAILABLE

5.1 Direct Vapor Injection

If there is available on the plant a supply of suitable vapor at appropriate temperature and pressure, the column reboiler may be dispensed with, and direct vapor injection used (Figure 2). The most likely case for this to apply is where the bottom product is essentially aqueous; here steam from the plant mains would be a suitable vapor.



FIGURE 2 DIRECT VAPOUR INJECTION



5.1.1 Advantages

- (a) There is no need to provide a heat exchanger.
- (b) Fouling of the heat transfer surface will be avoided.
- (c) As the column does not need to be above the boiler, a shorter skirt may be possible.

5.1.2 Disadvantages

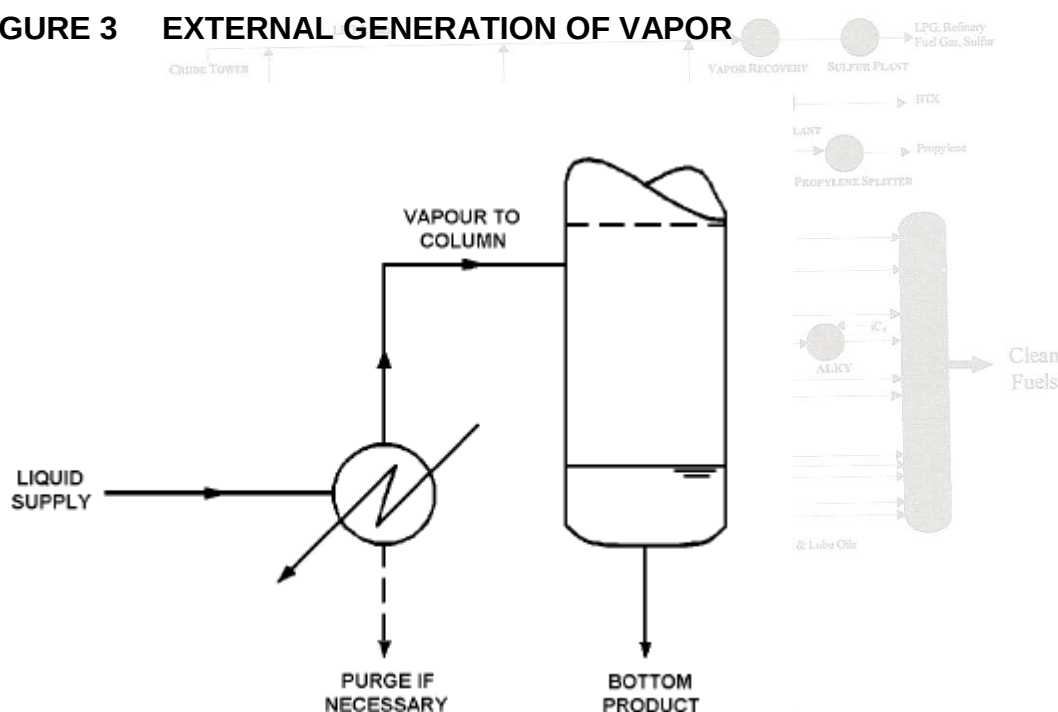
The bottom product will be diluted by the condensed vapor. This may not matter if the bottom product is water and direct steam injection is used.



5.2 External Generation Of Vapor

Where a supply of suitable vapor for direct injection is not available, but a liquid of suitable composition is, it may be advantageous to consider vaporizing this liquid and using the vapor for direct injection rather than providing a reboiler (Figure 3). This system is particularly appropriate when the bottom product contains a material which is prone to cause fouling of heat transfer surfaces. For example, the bottom product could contain small quantities of a temperature sensitive material which degrades to tars on contact with a heated surface. If the available liquid does not contain this impurity, fouling of the external vaporizer should not be a problem.

FIGURE 3 EXTERNAL GENERATION OF VAPOR



The external heat exchanger can be one of several forms, including the types — which are described below as column reboilers. Typical choices might be: kettle or coil in tank; vertical bayonet tube; thermosyphon or forced circulation operating round a separate vessel.



5.2.1 Advantages

- (a) Fouling of the heat transfer surface will be reduced. The required heat transfer surface should thus be less than for a conventional reboiler and there will be a reduced requirement for cleaning.
- (b) As the column does not need to be above the boiler, a shorter skirt may be possible.
- (c) In some circumstances it may be possible for one boiler to serve several columns.

5.2.2 Disadvantages

- (a) The bottom product will be diluted by the vapor provided.
- (b) If the thermosyphon or forced circulation boiler operating round a separate vessel is chosen, the vessel represents an extra item of equipment.
- (c) If the liquid supply contains any low volatile impurities, a purge will probably be necessary, which will require suitable handling.

5.3 Thermosyphon Reboilers

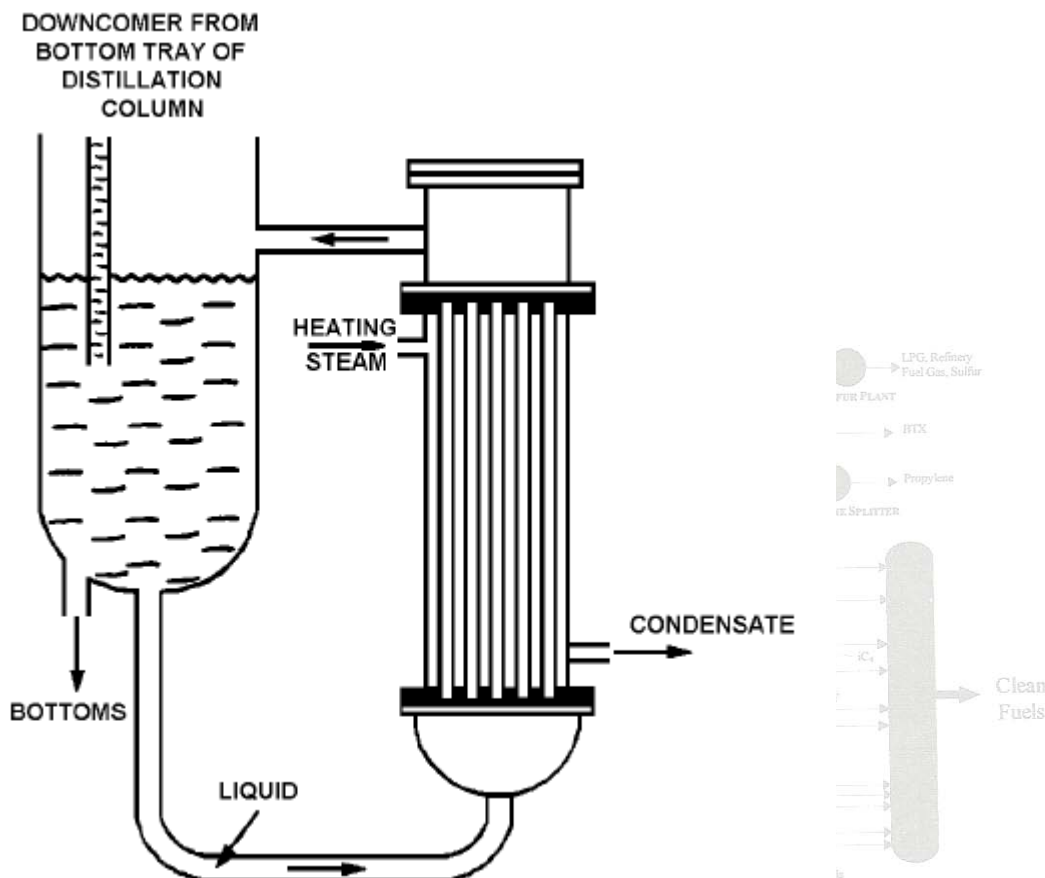
Thermosyphon reboilers exploit the difference in density between the liquid feed and the two-phase product to induce a circulation of the boiling fluid through the exchanger, without the need for a pump. They are probably the commonest form of reboiler. Some industries favor vertical thermosyphon boilers, while others prefer horizontal units.

5.3.1 Vertical Thermosyphon Reboiler

The vertical thermosyphon reboiler is a vertically mounted single pass shell and tube heat exchanger, with the boiling fluid on the tube-side (Figure 4). The design and layout of vertical thermosyphon reboilers is discussed in PEG.HEA.205.



FIGURE 4 VERTICAL THERMOSYPHON REBOILER



5.3.1.1

Advantages

- The exchanger is cheap.
- Low plot area requirements.
- High circulation can be achieved, leading to high heat transfer coefficients and reduced fouling.
- The single pass tube-side arrangement facilitates cleaning. Mechanical cleaning can often be performed without removing the exchanger.
- The inventory of boiling fluid is relatively low.

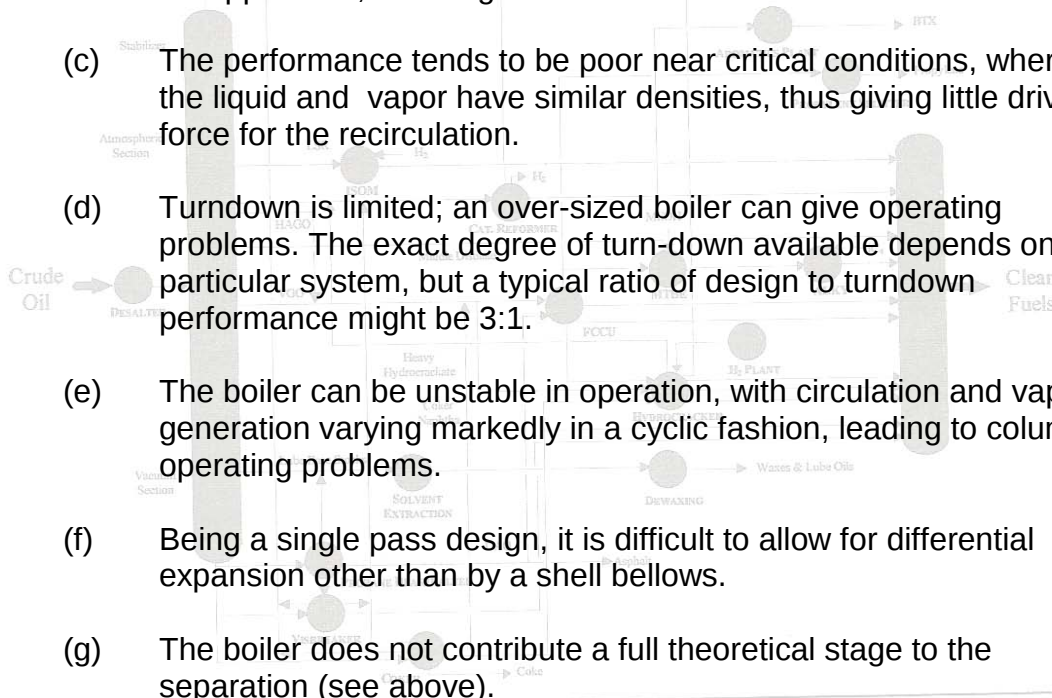
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- (f) The process fluid is on the tube-side, which is an advantage for corrosive duties.

5.3.1.2 Disadvantages

- (a) The column has to be raised to be above the boiler, requiring an increased skirt or additional steelwork.
- (b) The performance tends to be poor under deep vacuum conditions. This is because the extra static head between the column sump and the base of the reboiler results in a relatively large boiling point elevation. As a result, there may be a long inlet zone where boiling is suppressed, resulting in a low heat transfer coefficient.
- (c) The performance tends to be poor near critical conditions, where the liquid and vapor have similar densities, thus giving little driving force for the recirculation.
- (d) Turndown is limited; an over-sized boiler can give operating problems. The exact degree of turn-down available depends on the particular system, but a typical ratio of design to turndown performance might be 3:1.
- (e) The boiler can be unstable in operation, with circulation and vapor generation varying markedly in a cyclic fashion, leading to column operating problems.
- (f) Being a single pass design, it is difficult to allow for differential expansion other than by a shell bellows.
- (g) The boiler does not contribute a full theoretical stage to the separation (see above).
- (h) Severe fouling can reduce the rate of circulation, leading to increased percentage vaporization, increased rate of fouling and poorer separation efficiency.

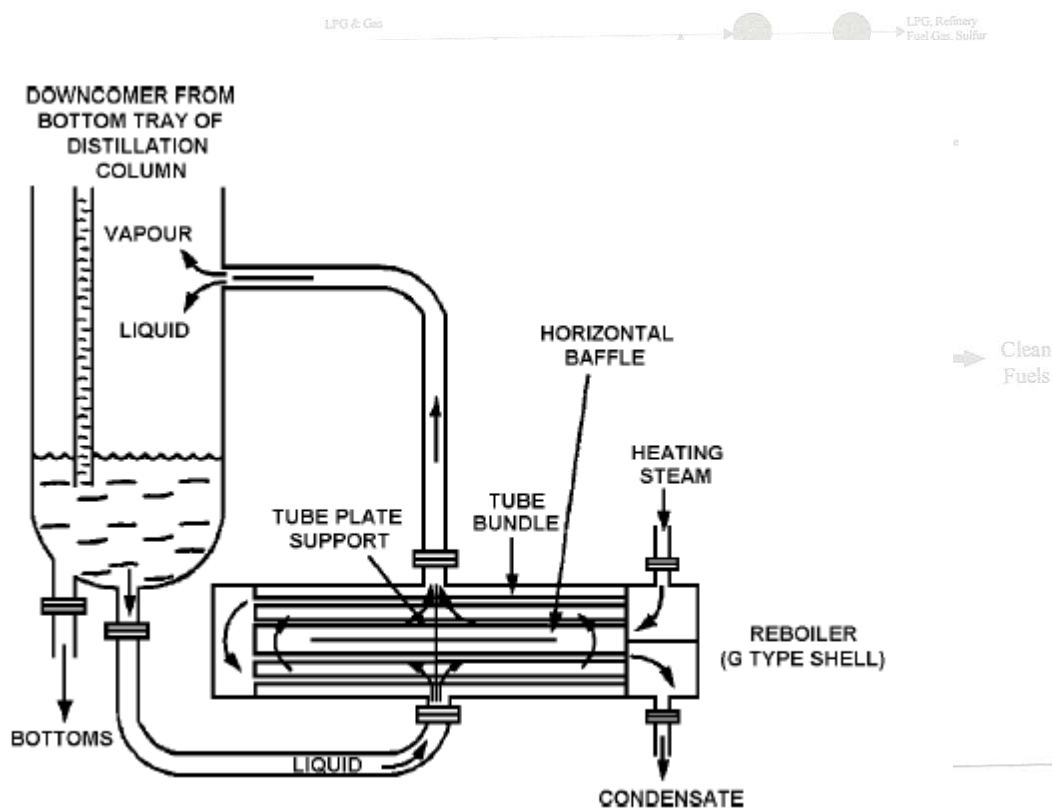




5.3.2 Horizontal Thermosyphon Reboiler

The horizontal thermosyphon reboiler is a horizontally mounted shell and tube exchanger, with the boiling fluid on the shellside (Figure 5). Traditionally, TEMA 'X' 'G' or 'H' shells have been used for this purpose, but work by HTRI has shown that equally good thermal performance can also be obtained from an 'E' shell. (For the definition of TEMA types see **GBHE-PEG-HEA-506**). HTRI data suggest that for a given temperature difference, horizontal reboilers give the best performance of horizontal and vertical thermosyphons and kettles.

FIGURE 5 HORIZONTAL THERMOSYPHON REBOILER



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5.3.2.1 Advantages

- (a) The exchanger is relatively cheap.
- (b) Multi-pass arrangements for the heating fluid can be used. Differential expansion can be accommodated.
- (c) Removable bundles are possible.
- (d) High circulation can be achieved, leading to high heat transfer coefficients and reduced fouling.
- (e) The elevation of the column to be above the boiler is less than for a vertical unit.

5.3.2.2 Disadvantages

- (a) The design methods are less developed.
- (b) Larger plot area is required than for a vertical unit, especially if the bundle is to be removed.
- (c) The process fluid is on the shellside, creating potential problems with fouling or corrosive fluids.
- (d) Mechanical cleaning of the process side can only be done by removing the bundle, and then generally only if square pitch tube layout is used.
- (e) The boiler does not contribute a full theoretical stage to the separation (see above).

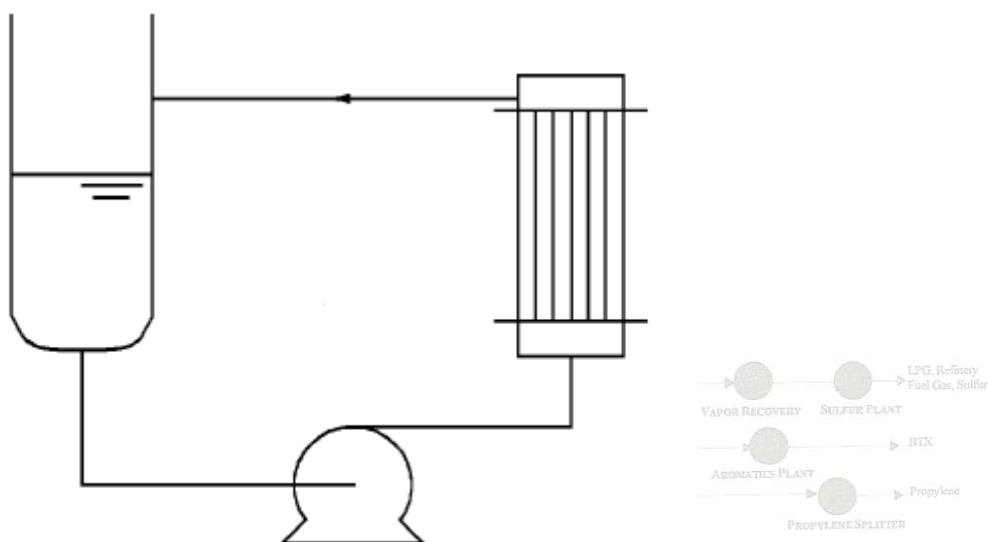
5.4 Forced Circulation Boiler

A forced circulation boiler is used for cases where a thermosyphon boiler poses problems in design or operation. A pump is used to provide the circulation (Figure 6). The exchanger can be of any type capable of handling two phase boiling flows.

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FIGURE 6 FORCED CIRCULATION BOILER



5.4.1 Advantages

- (a) A good circulation, resulting in good heat transfer and reduced fouling, can be guaranteed. However, the circulation is usually less than would be chosen for a thermosyphon, especially on large duties.
- (b) Because the circulation rate is known, the design is more certain.
- (c) There is less likelihood of instabilities.
- (d) Smaller diameter pipework can be used than for a thermosyphon boiler.
- (e) The exchanger does not need to be located close to the column. There is no need for the column to be above the boiler.
- (f) There are fewer constraints on the type of exchanger which can be used.

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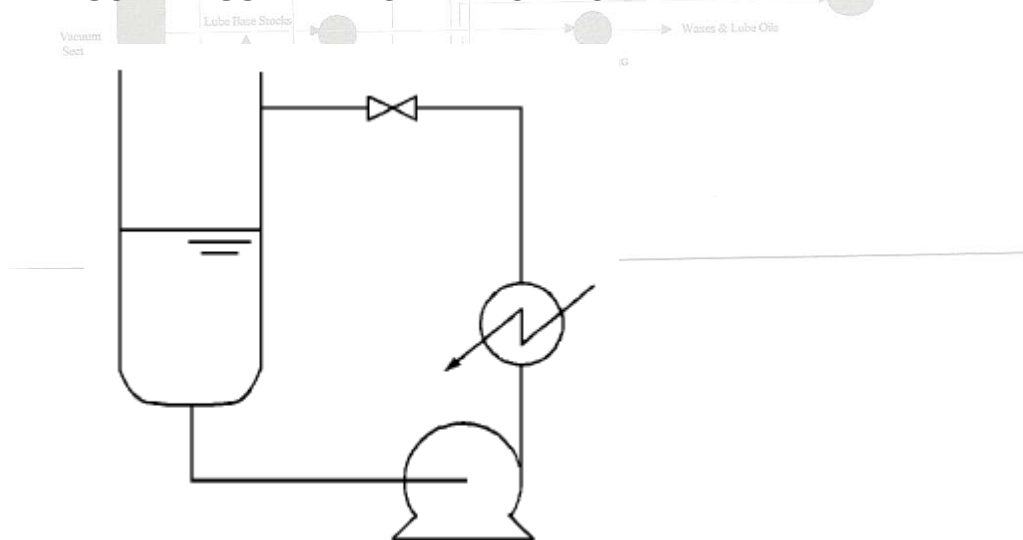
5.4.2 Disadvantages

- (a) A pump is required.
- (b) The boiler does not contribute a full theoretical stage to the separation (see above).
- (c) With horizontal in-tube boilers, especially in vacuum duties, and even with pumped circulation, the extent of vaporization is likely to be highest in the tubes at the top of the bundle. These therefore suffer more fouling, total flow falls and percentage vaporization rises, thus promoting further fouling. Blockage of the upper tubes may eventually occur.

5.5 Suppressed Vaporization Boiler

This is usually a modified case of the forced circulation boiler. In deep vacuum operation, the two phase pressure drop from the boiler to the column can often be comparable to the operating pressure, so that much of the flashing takes place in the return pipework. It can sometimes be advantageous to ensure that no evaporation takes place in the exchanger, as this may ease the design of the unit. The fluid is then heated without boiling in the exchanger, and flashes across a valve or orifice at the column entry (Figure 7).

FIGURE 7 SUPPRESSED VAPORIZATION BOILER





5.5.1 Advantages

As for the forced circulation boiler plus:

- (a) The return pipework can be designed for single phase liquid flow.
- (b) Any convenient form of heat exchanger can be used to provide the heat input, including types which are not suitable for two phase flow.

5.5.2 Disadvantages

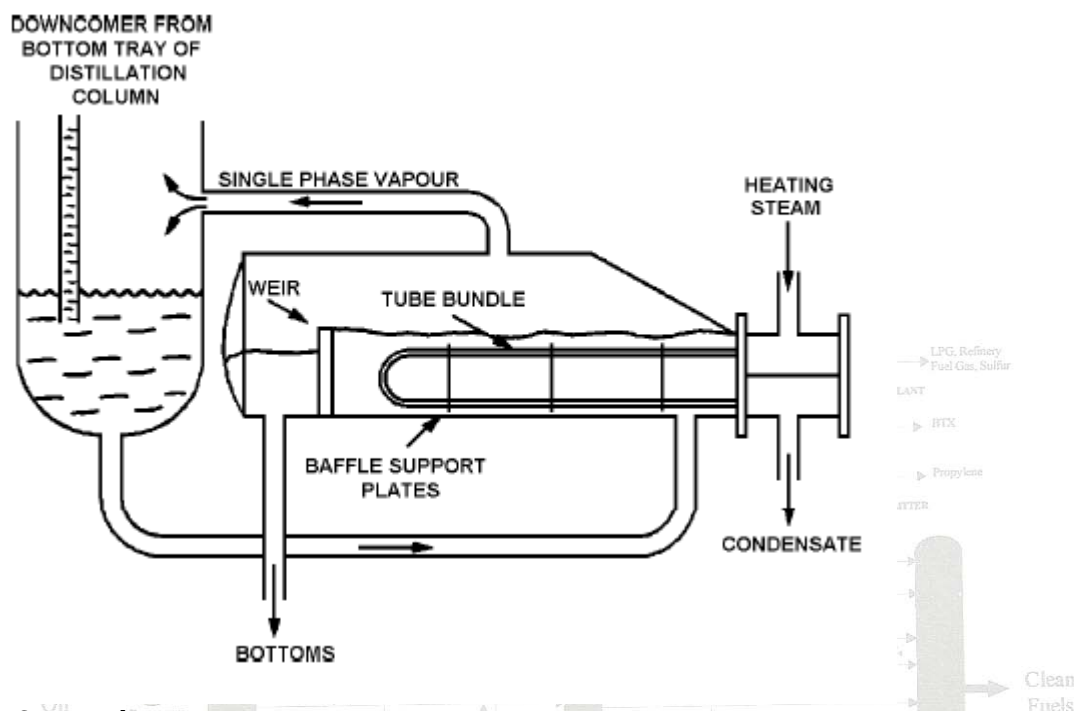
- (a) As all the heat input is sensible heat, the process fluid must be heated to a higher temperature than for a normal boiler.
- (b) A pump is required.
- (c) A very high circulation is likely to be needed, especially with heat sensitive materials.
- (d) The boiler does not contribute a full theoretical stage to the separation (see above). However, with the high circulations required, the percentage vaporization after letdown is likely to be low, so the separation efficiency may approach or even exceed that of an actual tray.
- (e) The let-down valve back into the column may suffer erosion.

5.6 Kettle Reboiler

A kettle boiler consists of a horizontal tube bundle mounted in an over-sized shell. The liquid level is normally maintained just above the bundle, either by automatic level control, or by allowing excess liquid to overflow a weir at the end of the shell (Figure 8). Although often considered as a pool boiling device, in fact there is a good circulation of fluid within the bundle induced by the density difference between the boiling fluid in the bundle and the single phase liquid around the edge of bundle. The kettle boiler is thus a form of thermosyphon.



FIGURE 8 KETTLE REBOILER



5.6.1 Advantages

- (a) Very stable in operation.
- (b) No limit to turn-down; an over-sized boiler presents few operational problems.
- (c) Differential expansion can be readily accommodated.
- (d) The required elevation for the base of the column is less than for a vertical thermosyphon.
- (e) The separation efficiency of the boiler approaches one theoretical stage.

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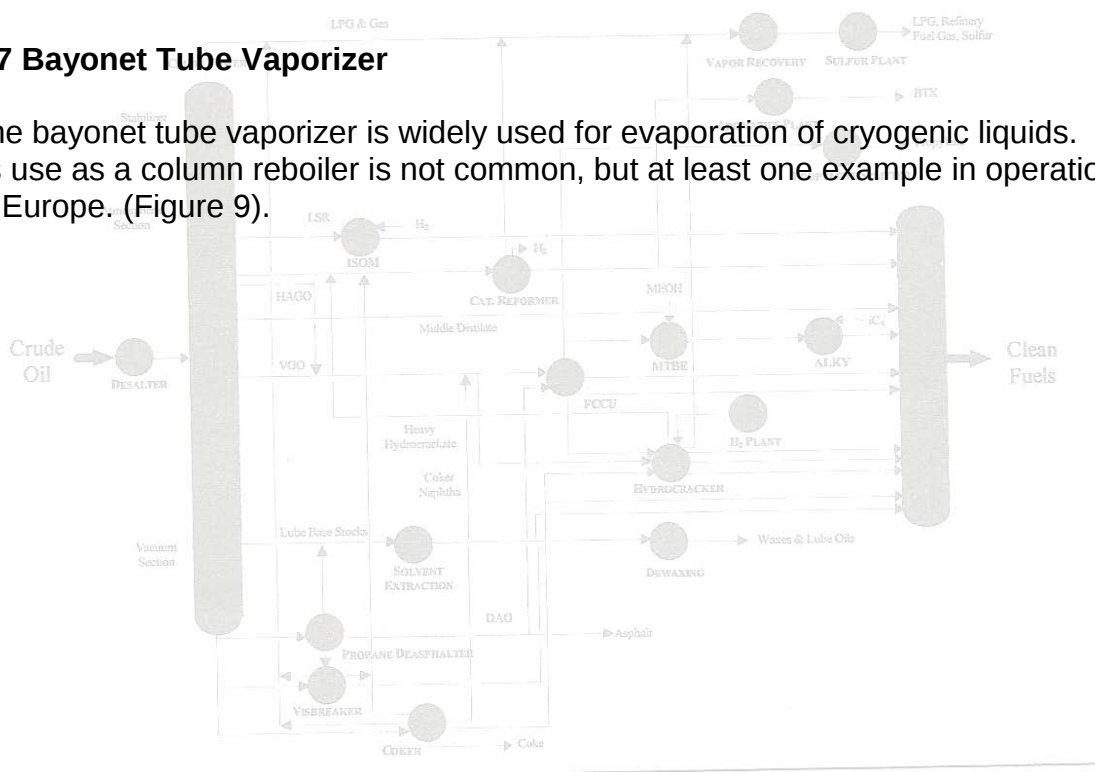


5.6.2 Disadvantages

- (a) Large inventory of boiling liquid.
- (b) Large plot area.
- (c) Expensive shell.
- (d) Mechanical cleaning of the process side can only be done by removing the bundle, and then generally only if square pitch tube layout is used.

5.7 Bayonet Tube Vaporizer

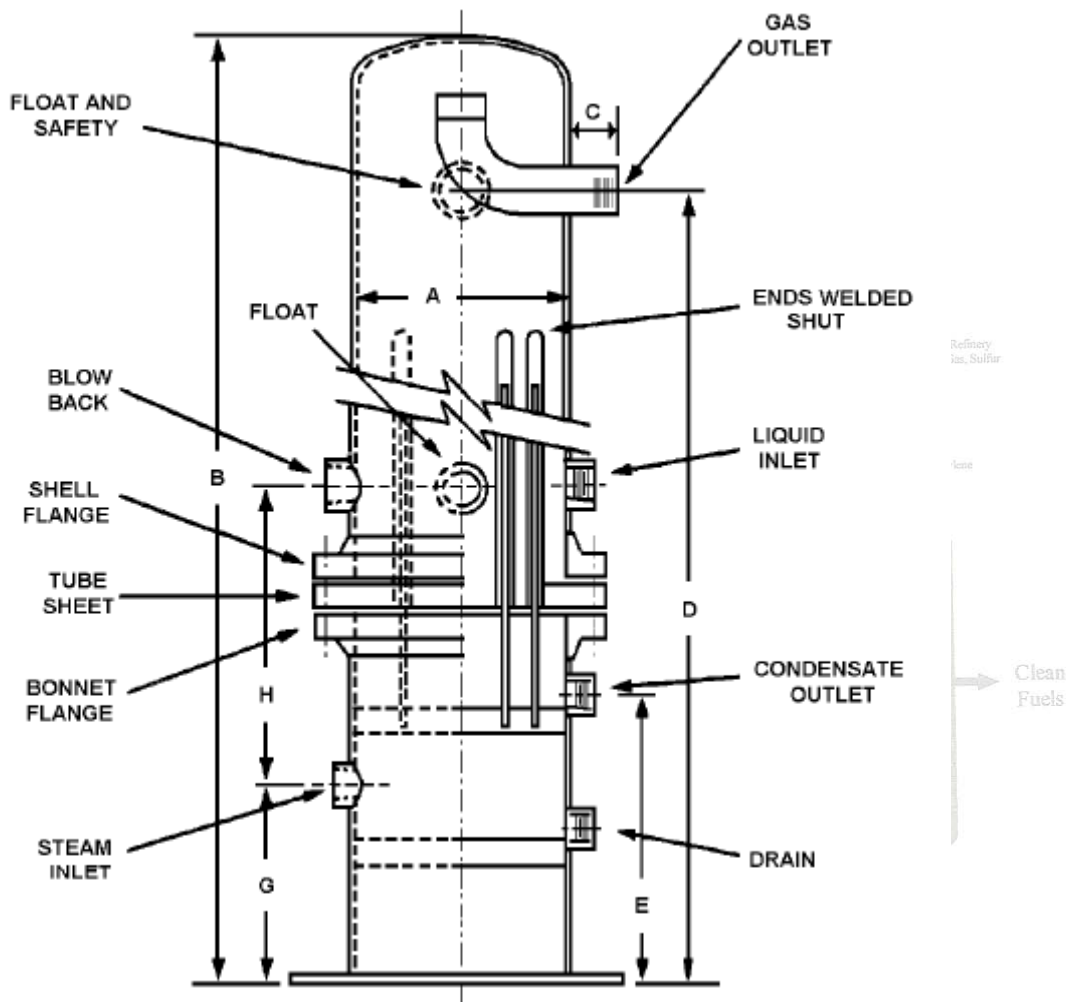
The bayonet tube vaporizer is widely used for evaporation of cryogenic liquids. Its use as a column reboiler is not common, but at least one example in operation in Europe. (Figure 9).



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FIGURE 9 BAYONET TUBE VAPORIZER



5.7.1 Advantages

- (a) Low plot area requirements.
- (b) The boiler can be run to evaporate all the liquid fed to it up to its maximum capacity with stable operation at turndown. No level control is needed on the boiler itself.
- (c) The inventory of boiling liquid is relatively low.

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5.7.2 Disadvantages

- (a) The design methods are uncertain.
- (b) Mechanical cleaning of the process side can only be done by removing the bundle.

5.8 Internal Boiler

If the base of the column is of sufficient size, it is possible to incorporate the heat exchanger into the column. The most common forms of this are the use of a glass coil in the base of a glass column, and a horizontal 'stab-in' boiler in a conventional column (Figure 10). The latter is effectively a kettle boiler located within the column. It would be feasible to mount a bayonet tube bundle or 'U-tube' bundle vertically into the base of a column, but no example of this is known to the author.

If a horizontal 'stab-in' boiler is used, it is important to ensure that there is sufficient headroom above the liquid surface to allow for good liquid disengagement. Failure to do so may result in damage to the bottom plate of the column due to liquid impact. The flow patterns in a kettle boiler or a 'stab-in' bundle are not those of pool boiling; instead the boiling process sets up a rapid recirculation through the bundle resulting in a two-phase plume above the bundle which may rise considerably above the nominal liquid surface. This phenomenon may be more marked for square pitch tube layouts than for triangular layouts. An estimate of the likely height of the plume may be made from momentum considerations. Information on the circulation rate and void fraction, needed to calculate the velocity at the top of the bundle, is given in the slice-by-slice output which may be obtained by running commercially available programs with an extended output option.

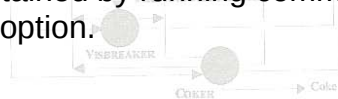
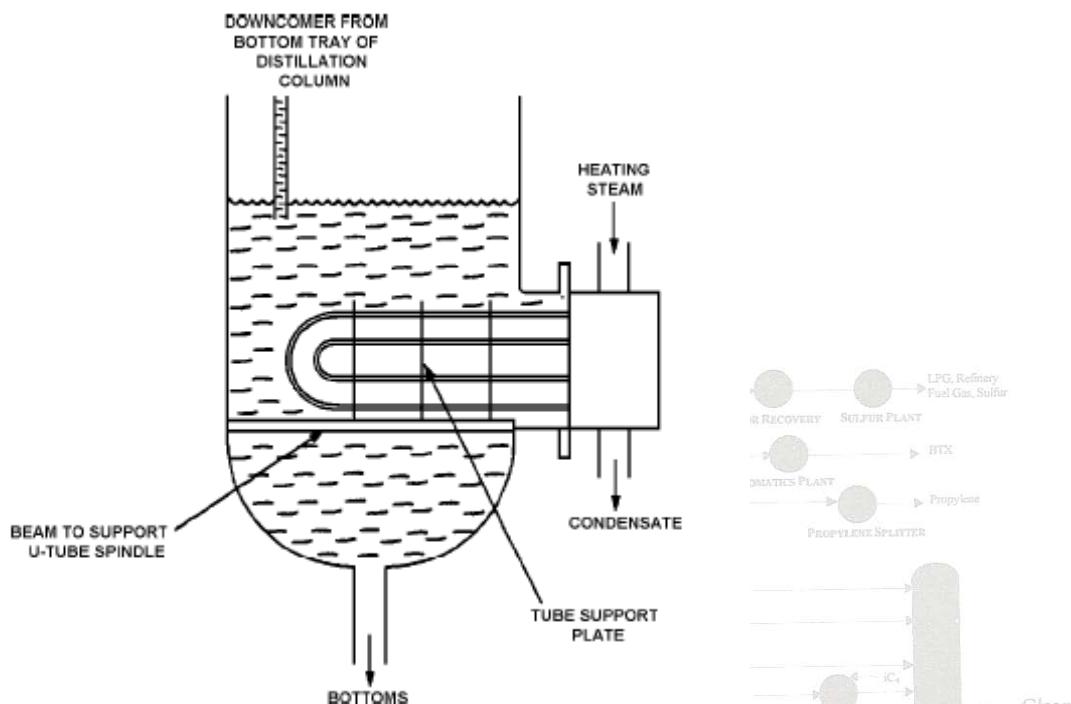




FIGURE 10 INTERNAL REBOILER



5.8.1 Advantages

- The expense of the shell on a conventional kettle is saved.
- Differential expansion can be readily accommodated.
- The required elevation for the base of the column is less than for a vertical thermosyphon.
- The separation efficiency of the boiler approaches one theoretical stage.

5.8.2 Disadvantages

- There is a limit to the heat transfer surface that can be fitted into the column. It is usually only applicable to large diameter columns.
- There may be a relatively large inventory of boiling liquid.

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- (c) Mechanical cleaning of the process side can only be done by removing the bundle, and then generally only if square pitch tube layout is used.
- (d) The experiences of FRI members of internal reboilers, particularly of the stab-in type, indicate that there can be unstable operation associated with base level control problems. Their recommendation was to put the boiler in a separate sump, with overflow to the column base. This then becomes to all intents a kettle boiler.

DOCUMENTS REFERRED TO IN THIS PROCESS ENGINEERING GUIDE

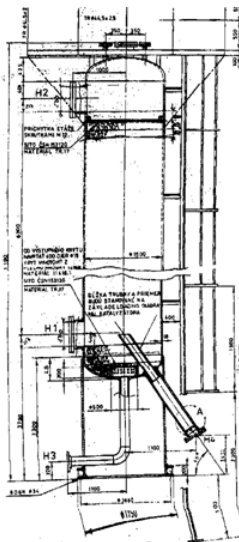
This Process Engineering Guide makes reference to the following documents:

PROCESS ENGINEERING GUIDES

GBHE-PEG-HEA-506 Selection of Heat Exchanger Type
(referred to in 5.3.2)

GBHE-PEG-HEA-515 The Design and Layout of Vertical Thermosyphon
Reboilers (referred to in 5.3.1).

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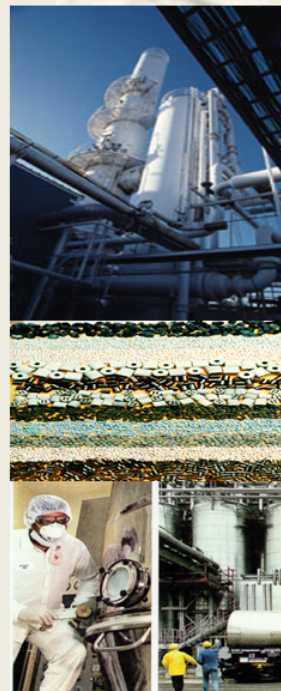
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