A

MAJOR REPORT

ON

STUDY, DESIGN & SIMULATION OF KETTLE TYPE REBOILER

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STUDY,DESIGN & SIMULATION OF KETTLE TYPE REBOILER

A thesis submitted in partial fulfillment of the requirements for the Degree of
Bachelor of Technology
(Refining & Petrochemical Engineering)

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CERTIFICATE

This is to certify that the work contained in this thesis titled "**Study,design & simulation of kettle type reboiler** has been carried out by **Abhishek Kumar & Himanshu shekhar Jha** under my supervision and has not been submitted elsewhere for a degree.

Dr. N Choudhary
Date: 17/5/10

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1. Introduction

A heat exchanger is a heat-transfer devise that is used for transfer of internal thermal energy between two or more fluids available at different temperatures. In most heat exchangers, the fluids are separated by a heat-transfer surface, and ideally they do not mix. Heat exchangers are used in the process, power, petroleum, transportation, air conditioning, refrigeration, cryogenic, heat recovery, alternate fuels, and other industries. Common examples of heat exchangers familiar to us in day-to-day use are automobile radiators, condensers, evaporators, air preheaters, and oil coolers. Heat exchangers could be classified in many different ways. A heat exchanger consists of heat-exchanging elements such as a core or matrix containing the heat-transfer surface, and fluid distribution elements such as headers or tanks, inlet and outlet nozzles or pipes, etc. Usually, there are no moving parts in the heat exchanger; however, there are exceptions, such as a rotary regenerator in which the matrix is driven to rotate at some design speed. The heat-transfer surface is in direct contact with fluids through which heat is transferred by conduction. The portion of the surface that separates the fluids is referred to as the primary or direct contact surface. To increase heat-transfer area, secondary surfaces known as fins may be attached to the primary surface. There nearly as many different types of heat exchangers as there are applications for heat transfer. Usually, the best choice of exchanger is based on the lowest cost exchanger that can get the job done.

Reboilers are certain kind of heat exchangers which are used to provide heat to the bottom of distillation columns. Reboilers are used to generate vapors which are returned to the column to drive the distillation separation. These vapors are formed from the liquid which comes from the column bottom. Reboilers are usually of shell and tube type and liquid from the bottom of the column is partially vaporized in the exchanger. Most often condensing steam is used as heating medium. Boiling can take place either in the tube side or in the shell side, depending on the type of reboiler. Vaporizers are also similar in most respect to reboilers but they supply vapor for other unit operations.

The thermal & hydraulic analysis for reboilers are more complex then for single phase exchangers. The complicating factors are the following:

- Most often the distillation bottom liquids are mixtures having substantial boiling ranges. So, the physical properties of the liquid and vapour fractions can exhibit large variations throughout the reboiler. To determine the phase compositions and other properties within the reboiler thermodynamic calculations are required.
- A zone or incremental analysis is generally required for rigorous calculations.
- Two-phase flow occurs in the boiling section of the reboiler & in the case of thermosyphon units, in the return line to the distillation column.
- For recirculating thermosyphon reboilers, the circulation rate is determined by the hydraulics in both the reboiler and the piping connecting the distillation column and reboiler. Because of this, the reboiler and connecting piping must be considered as a unit. The hydraulic circuit adds another iterative loop to the design procedure.

Even with simplifying assumptions, the complete design of a reboiler system can be a formidable task without the aid of computer software. For rigorous calculations, commercial software is a practical necessity.

Selection criteria are many, but primary criteria are type of fluids to be handled, operating pressures and temperatures, heat duty, and cost. Fluids involved in heat transfer can be characterized by temperature, pressure, phase, physical properties, toxicity, corrosivity, and fouling tendency. Operating conditions for heat exchangers vary over a very wide range, and a broad spectrum of demands is imposed for their design and performance. All of these must be considered when assessing the type of unit to be used . When selecting a heat exchanger for a given duty, the following points must be considered:

1. Materials of construction
2. Operating pressure and temperature, temperature program, and temperature driving force
3. Flow rates
4. Flow arrangements

5. Performance parameters-thermal effectiveness and pressure drops
6. Fouling tendencies
7. Types and phases of fluids
8. Maintenance, inspection, cleaning, extension, and repair possibilities
9. Overall economy
10. Fabrication techniques

1.1. Materials of Construction

For reliable and continuous use, the construction materials for pressure vessels and heat exchangers should have a well-defined corrosion rate in the service environments. Furthermore, the material should exhibit strength to withstand the operating temperature and pressure. Shell and tube heat exchangers can be manufactured in virtually any materials that may be required for corrosion resistance, for example, from nonmetals like glass, Teflon, and graphite to exotic metals like titanium, zirconium, tantalum, etc. Compact heat exchangers with extended surfaces are mostly manufactured from any metal that has drawability, formability, and malleability. Heat exchanger types like plate heat exchangers normally require a material that can be pressed or welded.

1.2. Operating pressure and temperature, temperature program, & temperature driving force

1.2.1. ***Operating Pressure.*** The design pressure is important to determine the thickness of the pressure retaining components. The higher the pressure, the greater will be the required thickness of the pressure-retaining membranes and the more advantage there is to placing the high-pressure fluid on the tubeside.

- At low pressures, the vapor-phase volumetric flow rate is high and the low allowable pressure drops may require a design that maximizes the area available for flow, such as crossflow or split flow with multiple nozzles.

- At high pressures, the vapor-phase volumetric flow rates are lower and allowable pressure drops are greater. These lead to more compact units.
- In general, higher heat-transfer rates are obtained by placing the low-pressure gas on the outside of tubular surfaces.
- Operating pressures of the gasketed plate heat exchangers and spiral plate heat exchangers are limited because of the difficulty in pressing the required plate thickness, and by the gasket materials in the case of PHEs. The floating nature of floating-head shell and tube heat exchangers and lamella heat exchangers limits the operating pressure.

1.2.2. ***Operating Temperature.*** This parameter is important as it indicates whether a material at the design temperature can withstand the operating pressure and various loads imposed on the component. For low-temperature and cryogenic applications toughness is a prime requirement, and for high-temperature applications the material has to exhibit creep resistance.

1.2.3. ***Temperature Program.*** Temperature program in both a single pass and multipass shell and tube heat exchanger decides (1) the mean metal temperatures of various components like shell, tube bundle, and tubesheet, and (2) the possibility of temperature cross. The mean metal temperatures affect the integrity and capability of heat exchangers and thermal stresses induced in various components.

1.2.4. ***Temperature Driving Force.*** The effective temperature driving force is a measure of the actual potential for heat transfer that exists at the design conditions. With a counterflow arrangement, the effective temperature difference is defined by the log mean temperature difference (LMTD). For flow arrangements other than counterflow arrangement, the LMTD must be corrected by a correction factor, ***F.*** The ***F*** factor can be determined analytically for each flow arrangement but is usually presented graphically in terms of the thermal effectiveness P and the heat capacity ratio R for each flow arrangement.

Influence of Operating Pressure and Temperature on Selection of Some Types of Heat Exchangers.

The influence of operating pressure and temperature on selection of shell and tube heat exchanger, compact heat exchanger, gasketed plate heat exchanger, and spiral exchanger is discussed next.

Shell and tube heat exchanger units can be designed for almost any combination of pressure and temperature. In extreme cases, high pressure may impose limitations by fabrication problems associated with material thickness, and by the weight of the finished unit. Differential thermal expansion under steady conditions can induce severe thermal stresses either in the tube bundle or in the shell. Damage due to flow-induced vibration on the shellside is well known. In heat-exchanger applications where high heat transfer effectiveness (close approach temperature) is required, the standard shell and tube design may require a very large amount of heat transfer surface . Depending on the fluids and operating conditions, other types of heat-exchanger design should be investigated.

1.3. Flow Rate

Flow rate determines the flow area: the higher the flow rate, the higher will be the crossflow area. Higher flow area is required to limit the flow velocity through the conduits and flow passages, and the higher velocity is limited by pressure drop, impingement, erosion, and, in the case of shell and tube exchanger, by shell-side flow-induced vibration. Sometimes a minimum flow velocity is necessary to improve heat transfer, to eliminate stagnant areas, and to minimize fouling.

1.4. Flow Arrangement

As defined earlier, the choice of a particular flow arrangement is dependent upon the required exchanger effectiveness, exchanger construction type, upstream and downstream ducting, packaging envelope, and other design criteria. Performance Parameters-Thermal Effectiveness and Pressure Drops.

1.5. Performance parameters

1.5.1. ***Thermal Effectiveness.*** For high-performance service requiring high thermal effectiveness,use brazed plate-fin exchangers (e.g., cryogenic service) and regenerators (e.g., gas turbine applications), use tube-fin exchangers for slightly less thermal effectiveness in applications, and use shell and tube units for low thermal effectiveness service.

1.5.2. ***Pressure Drop.*** Pressure drop is an important parameter in heat exchanger design. Limitations may be imposed either by pumping cost or by process limitations or both. The heat exchanger should be designed in such a way that unproductive pressure drop is avoided to the maximum extent in areas like inlet and outlet bends, nozzles, and manifolds. At the same time, any pressure drop limitation that are imposed must be utilized as nearly as possible for an economic design.

1.6. Fouling Tendencies

Fouling is defined as the formation on heat exchanger surfaces of undesirable deposits that impede the heat transfer and increase the resistance to fluid flow, resulting in higher pressure drop. The growth of these deposits causes the thermohydraulic performance of heat exchanger to decline with time. Fouling affects the energy consumption of industrial processes, and it also decides the amount of extra material required to provide extra heat-transfer surface to compensate for the effects of fouling. Compact heat exchangers are generally preferred for nonfouling applications. In a shell and tube unit the fluid with more fouling tendencies should be put on the tube side for ease of cleaning. On the shellside with cross baffles, it is sometimes difficult to achieve a good flow distribution if the baffle cut is either too high or too low.Stagnation in any regions of low velocity behind the baffles is difficult to avoid if the baffles are cut more than about 20-25%. Plate heat exchangers and spiral plate exchangers are better chosen for fouling services. The flow pattern in plate heat exchanger induces turbulence even at comparable low velocities; in the spiral units, the scrubbing action of the fluids on the curved surfaces minimizes fouling.

1.7. Types and Phases of Fluids

The phase of the fluids within a unit is an important consideration in the selection of the heat exchanger type. Various combinations of fluid phases dealt in heat exchangers are liquid-liquid, liquid-gas, and gas-gas. Liquid phase fluids are generally the simplest to deal with. The high density and the favorable values of many transport properties allow high heat-transfer coefficients to be obtained at relatively low pressure drop.

1.8. Maintenance, Inspection, Cleaning Repair and Extension Aspects

Consider the suitability of various heat exchangers as regards maintenance, inspection, cleaning, repair, and extension. For example, the pharmaceutical, dairy, and food industries require quick access to internal components for frequent cleaning. Since some of the heat exchanger types offer great variations in design, this must be kept in mind when designing for a certain application. For instance, consider inspection and manual cleaning. Spiral plate exchangers can be made with both sides open at one edge, or with one side open and one closed. They can be made with channels between 5 mm and 25 mm wide, with or without studs. The shell and tube heat exchanger can be made with fixed tubesheets or with a removable tube bundle, with small- or large-diameter tubes, or small or wide pitch. A lamella heat exchanger bundle is removable and thus fairly easy to clean on the shellside. Inside the lamella, however, cannot be drilled to remove the hard fouling deposits. Gasketed plate heat exchangers (PHEs) are easy to open, especially when all nozzles are located on the stationary end-plate side. The plate arrangement can be changed for other duties within the frame and nozzle capacity. Repair of some of the shell and tube exchanger components is possible, but the repair of expansion joint is very difficult. Tubes can be renewed or plugged. Repair of compact heat exchangers of tube-fin type is very difficult except by plugging of the tube. Repair of the platefin exchanger is generally very difficult. For these two types of heat exchangers, extension of units for higher thermal duties is generally not possible. All these drawbacks are easily overcome in a PHE. It can be easily repaired, and plates and other parts can be easily replaced.

Due to modular construction, PHEs possess the flexibility of enhancing or reducing the heat transfer surface area, modifying the pass arrangement, and addition of more than one duty according to the heat-transfer requirements at a future date.

1.9. Overall Economy

There are two major costs to consider in designing a heat exchanger: the manufacturing cost and the operating costs, including maintenance costs. In general, the less the heat-transfer surface area and less the complexity of the design, the lower is the manufacturing cost. The operating cost is the pumping cost due to pumping devices such as fans, blowers, pumps, etc.The maintenance costs include costs of spares that require frequent renewal due to corrosion, and costs due to corrosioxdfouling prevention and control. Therefore, the heat exchanger design requires a proper balance between thermal sizing and pressure drop.

1.10. Fabrication Techniques

Fabrication techniques are likely to be the determining factor in the selection of a heat-transfer surface matrix or core. They are the major factors in the initial cost and to a large extent influence the integrity, service life, and ease of maintenance of the finished heat exchanger. For example, shell and tube units are mostly fabricated by welding, plate-fin heat exchangers and automobile aluminum radiators by brazing, copper-brass radiators by soldering, most of the circular tube-fin exchangers by mechanical assembling, etc.

2. Reboiling operation of a distillation column

Reboilers are certain kind of heat exchangers which are used to provide heat to the bottom of distillation columns. Reboilers are used to generate vapors which are returned to the column to drive the distillation separation. These vapors are formed from the liquid which comes from the column bottom. Reboilers are usually of shell and tube type and liquid from the bottom of the column is partially vaporized in the exchanger. Most often condensing steam is used as heating medium. Boiling can take place either in the tube side or in the shell side, depending on the type of reboiler. Vaporizers are also similar in most respect to reboilers but they supply vapor for other unit operations.

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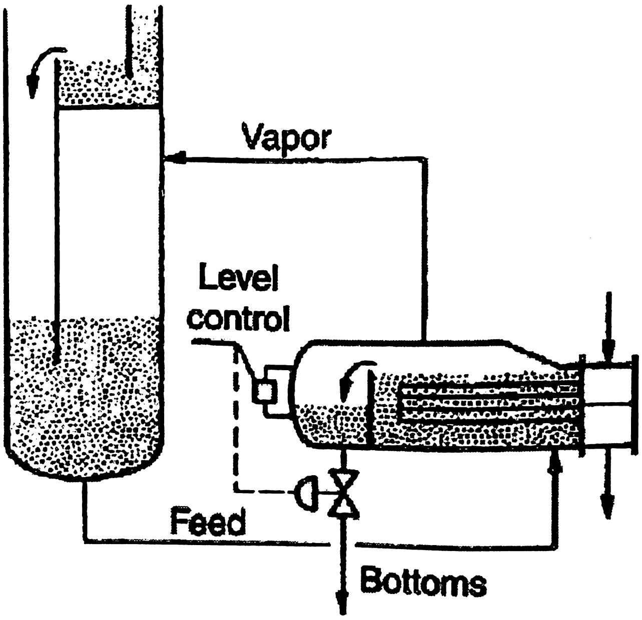
2.1. Classification of reboilers:-

2.1.1. Kettle reboilers

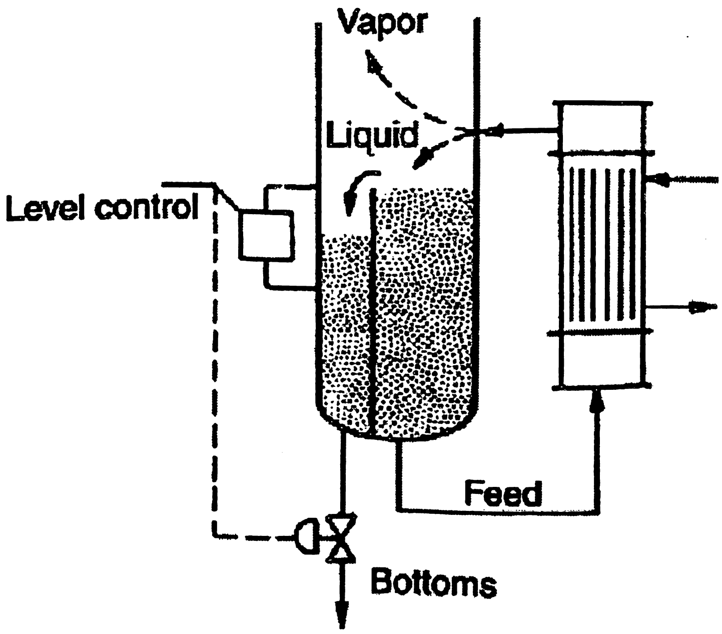
A kettle reboiler consists of a horizontally mounted TEMA K-shell and a tube bundle comprised of either U-tubes or straight tubes (regular or finned) with a pull-through (type T) floating head. Support plates are provided for tube support because tube bundle is unbaffled. Liquid is fed by gravity from the column sump and it enters at the bottom of the shell through one or more nozzles. The liquid flows upward across the tube bundle, where boiling takes place on the exterior surface of the tubes. Vapor and liquid are separated in the space above the bundle, and the vapor flows overhead to the column, while the liquid flows over a weir and is drawn off as the bottom product. Low circulation rates, horizontal configuration and all-vapor return flow make kettle reboilers relatively insensitive to system hydraulics. As a result, they tend to be reliable even at very low (vacuum) or high (near critical) pressures where thermosyphon reboilers are most prone to operational problems. Kettles can also operate efficiently with small temperature driving forces, as high heat fluxes can be obtained by increasing the tube pitch. On the negative side, low circulation rates make kettles very susceptible to fouling, and the over-sized K-shell is relatively expensive.



2.1.2. Vertical thermosyphon reboilers

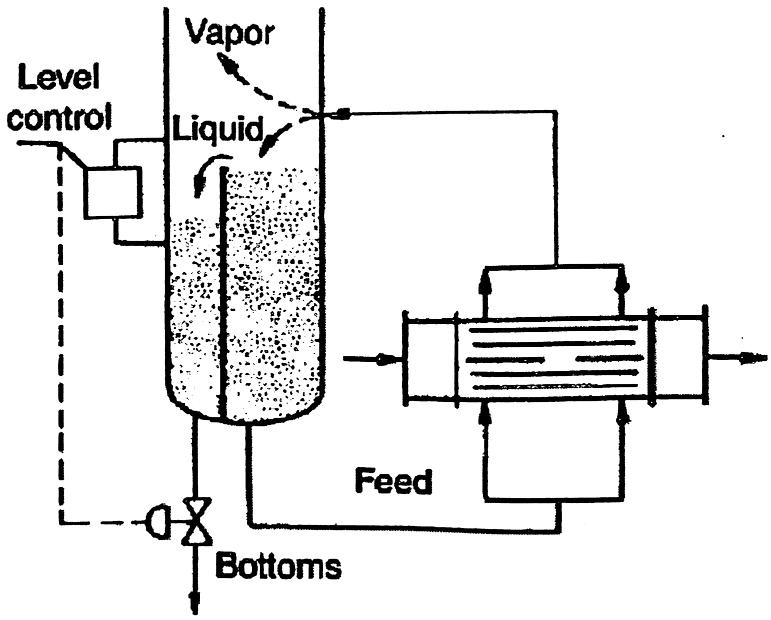
A vertical thermosyphon reboiler consists of a TEMA E-shell with a single-pass tube bundle. The boiling liquid usually flows through the tubes as shown, but shell-side boiling may be used in special situations, e.g., with a corrosive heating medium. A mixture of vapor and liquid is returned to the distillation column, where phase separation occurs. The driving force for the flow is the density difference between the liquid in the feed circuit and the two-phase mixture in the boiling region and return line. Except for vacuum services, the liquid in the column sump is usually maintained at a level close to that of the upper tubesheet in the reboiler to provide an adequate static

head. For vacuum operations, the liquid level is typically maintained at 50-70% of the tube height to reduce the boiling point elevation of the liquid fed to the reboiler. Vertical thermosyphon reboilers are usually attached directly to distillation columns, so the costs of support structures and piping are minimized, as is the required plot space. The TEMA E-shell is also relatively inexpensive. Another advantage is that the relatively high velocity attained in these units tends to minimize fouling. On the other hand, tube length is limited by the height of liquid in the column sump and the cost of raising the skirt height to increase the liquid level. This limitation tends to make these units relatively expensive for services with very large duties. The boiling point increase due to the large static head is another drawback for services with small temperature driving forces. Also, the vertical configuration makes maintenance more difficult, especially when the heating medium causes fouling on the outside of the tubes and/or the area near the unit is congested.



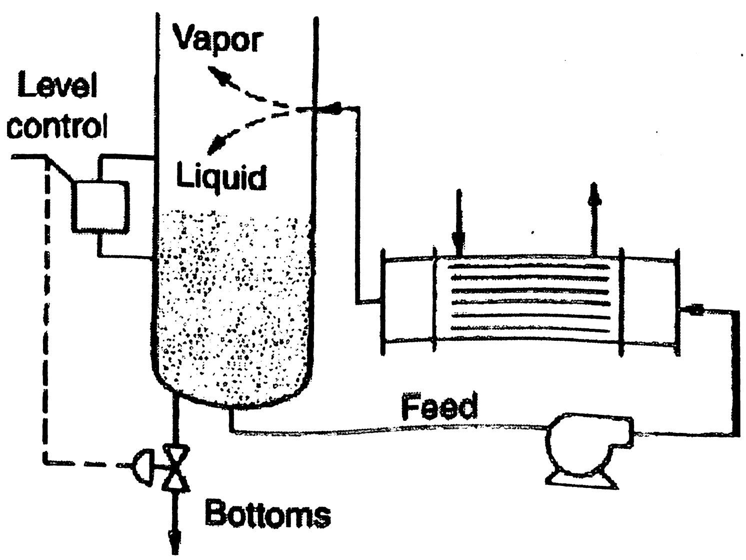
2.1.3. Horizontal thermosyphon reboilers

Horizontal thermosyphon reboilers usually employ aTEMA G-, H-, orX-shell, although E- and J-shells are sometimes used. The tube bundle may be configured for a single pass as shown, or for multiple passes. In the latter case, either U-tubes or straight tubes (plain or finned) may be used. Liquid from the column is fed to the bottom of the shell and flows upward across the tube bundle. Boiling takes place on the exterior tube surface, and a mixture ofvapor and liquid is returned to the column. As with vertical thermosyphons, the circulation is driven by the density difference between the liquid in the column sump and the two-phase mixture in the reboiler and return line. The flow pattern in horizontal thermosyphon reboilers is similar to that in kettle reboilers, but the higher circulation rates and lower vaporization fractions in horizontal thermosyphons make them less susceptible to fouling. Due to the horizontal configuration and separate support structures, these units are not subject to restrictions on weight or tube length. As a result, they are generally better suited than vertical thermosyphons for services with very large duties. The horizontal configuration is also advantageous for handling liquids of moderately high viscosity, because a relatively small static head is required to overcome fluid friction and drive the flow. Arule ofthumb is thata horizontal rather than a vertical thermosyphon should be considered if the feed viscosity exceeds 0.5 cp.



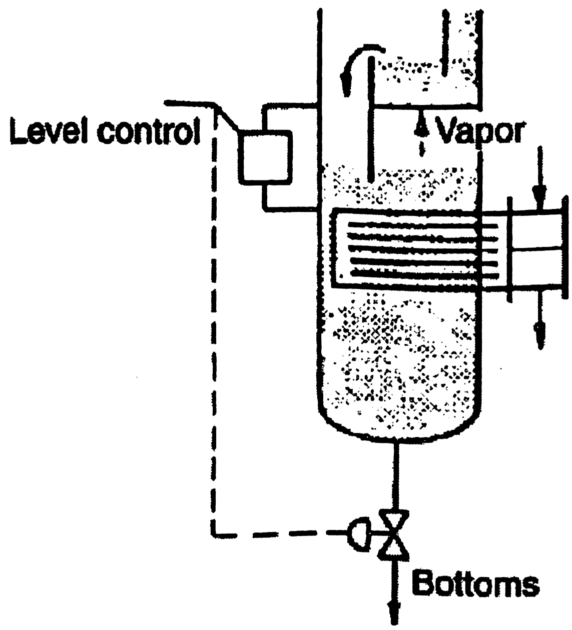
2.1.4. Forced flow reboilers

In a forced flow reboiler system circulation is driven by a pump rather than by gravity. The boiling liquid usually flows in the tubes, and the reboiler may be oriented either horizontally or vertically. A TEMA E-shell is usually used with a tube bundle configured for a single pass. These units are characterized by high tube-side velocities and very low vaporization fractions (usually less than 1% [1]) in order to mitigate fouling. 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.



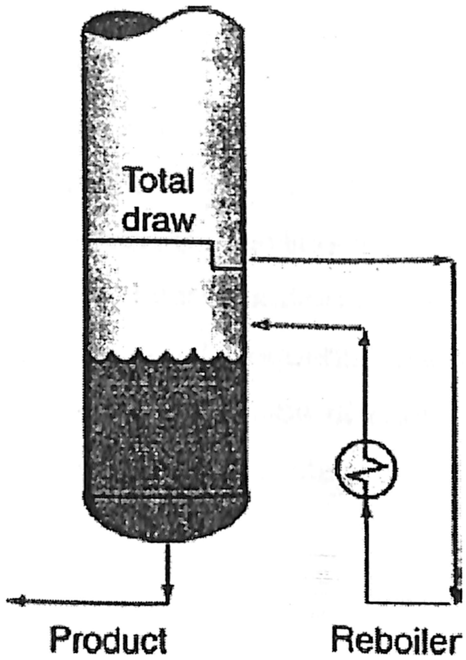
2.1.5. Internal reboilers

An internal reboiler consists of a tube bundle (usually U-tubes) that is inserted directly into the sump of the distillation column. Since no shell or connecting piping is required, it is the least expensive type of reboiler. However, the amount of heat-transfer area that can be accommodated is severely limited. Also, formation of froth and foam in the column sump can cause operational problems. As a result, this type of reboiler is infrequently used.



2.2. Recirculating versus once-through operation

Thermosyphon reboiler systems can be of either the recirculating type,or the once-through type. In the latter case, the liquid from the bottom tray is collected in a trap-out, from which it flows to the reboiler. The liquid fraction of the return flow collects in the column sump, from which it is drawn as the bottom product. Thus, the liquid passes through the reboiler only once, as with a kettle reboiler. Once-through operation requires smaller feed lines and generally provides a larger temperature driving force in the reboiler. For mixtures, the boiling point of the liquid fed to a recirculating reboiler is elevated due to the addition of the liquid returned from the reboiler, which is enriched in the higher boiling components. As a result, the mean temperature difference in the boiling zone of the exchanger is reduced. Recirculation can also result in increased fouling in some systems, e.g., when exposure to high temperatures results in chemical decomposition or polymerization. For reliable design and operation, the vapor weight fraction in thermosyphon reboilers should be limited to about 25-30% for organic compounds and about 10% for water and aqueous solutions [1,2]. If these limits cannot be attained with once-through operation, then a recirculating system should be used.



2.3. Reboiler selection

In some applications the choice of reboiler type is clear-cut. For example, severely fouling or very viscous liquids dictate a forced flow reboiler. Similarly, a dirty or corrosive heating medium together with a moderately fouling process stream favors a horizontal thermosyphon reboiler. In most applications, however, more than one type of reboiler will be suitable. In these situations the selection is usually based on considerations of economics, reliability, controllability, and experience with similar services. The guidelines presented by Palen [1] and reproduced in Table 10.1 provide useful information in this regard. Kister [3] also gives a good concise comparison of reboiler types and

the applications in which each is preferred. Sloley [2] surveyed the use ofvertical versus horizontal thermosyphon reboilers in the petroleum refining, petrochemical and chemical industries. Of the thermosyphons used in petroleum refining, 95% are horizontal units; in the petrochemical industry, 70% are vertical units; and in the chemical industry, nearly 100% are vertical units. He attributes this distribution to two factors, size and fouling tendency. For the relatively small, clean services typical of the chemical industry, vertical thermosyphons are favored, whereas the large and relatively dirty services common in petroleum refining dictate horizontal thermosyphons. Services in the petrochemical industry also tend to be relatively large, but to a lesser extent than in petroleum refining, and they are generally cleaner as well. Hence, the use of horizontal thermosyphons in petrochemical applications is less extensive

compared with petroleum refining, but greater than in the chemical industry. The above analysis is somewhat contradictory with Table 10.1 because size permitting, a vertical thermosyphon is indicated for moderate to heavy fouling on the boiling side. The reason is that in a vertical unit the boiling fluid is on the tube side, which is relatively easy to clean, the vertical configuration notwithstanding. Overall, however, the vertical thermosyphon is the most frequently used type of reboiler [3]. Size permitting, it will generally be the reboiler type of choice unless the service is such that one of the other types offers distinct advantages, as discussed above.

3. Comparative study of different reboilers

For horizontal thermosiphon/natural units the boiling fluid is almost always on the shell side, with the heating medium in the tubes. In the vertical units the reboiling of the fluid is in the tubes. For kettle units, the boiling is in the shell. Collins suggests a "rule of thumb" that if the viscosity of the reboiler is less than 0.5 centipoise (cp), the vertical thermosiphon should be considered, but when the viscosity is more than 0.5 cp, the horizontal reboiler is probably more economical. Because reboilers are used extensively with bottoms boiling of distillation columns, the horizontal units have some advantages.

- High surface area.
- Process is on the shell side, with possibly less fouling, or easy access for cleaning the outside tubes.
- Tubes have easy access for cleaning on tube side, when fouled.
- Greater flexibility for operator handling high liquid rates.
- Lower boiling point elevation than vertical units.

For a distillation column bottoms heating, the bottoms liquid from the column flows under system pressure and liquid head into and through the shell side of the horizontal thermosiphon reboiler. The two-phase (liquid vapor) mixture flows from the reboiler back into the distillation column either on the bottom tray or just under this tray into the column vapor space above the bottoms liquid, with the vapor passing upward into/through the bottom or first tray. The density difference between the liquid in the column and the twophase mixture in the heat exchanger (reboiler) and the riser (outlet piping from the shell side of reboiler) cause the thermosiphon circulation through the reboiler. According to Yilmaz, the horizontal thermosiphon reboilers compared to kettle reboilers are less likely to be fouled by the process due to their better circulation and lower percent vaporization. Vertical thermosiphon reboilers with process through the tubes, are less suitable than horizontal units when heat transfer requirements are large due to mechanical considerations; that is, the vertical units may often determine the height of the first distillation tray above grade. Also per Yilmaz, moderate viscosity fluids boil better in horizontal units than in vertical units. Low-finned tubing used in horizontal units can improve the boiling characteristics on the shell side. Due to the high liquid circulation rate for horizontal thermosiphon units, the temperature rise for the boiling process fluid is lower than for kettle reboilers (these are not thermosiphon). Ultimately this leads to higher heat transfer rates for the horizontal thermosiphon units.Hahne and Grigull present a detailed study of heat transfer in boiling.

Type of reboiler	Advantages	Disadvantages
Kettle type	One theoretical tray Ease of maintenance Vapor disengaging Low skirt height Handles viskosity greater than 5.10^{-4} Pa.s Ease of control No limit on vapor load	Extra piping and space High cost Fouls with dirty fluids High residence time in heat zone for degradation tendency of some fluids Low residence time surge section of reboiler
Vertical once-through type	Once theoretical tray Simple piping and compact Not easily fouled Less cost than kettle	Difficult maintenance High skirt height No control of circulation Moderate controllability
Vertical naturally circulation	Good controllability Simple piping and compact Less cost than Kettle	No theoretical tray Accumulation of high bowling point components in feed line, i.e., temperature may be slightly higher than tower bottom

		Too high liquid level above design could cause reboiler to have less capacity Fouls easier Difficult maintenance High skirt height
Horizontal once-through	One theoretical tray Simple piping and compact Not easily fouled Lower skirt height than vertical Less pressure drop than vertical Langer tubes possible Ease of maintenance Less cost than Kettle	No control of circulation Moderate controllability High skirt height
Horizontal naturally circulation	Ease of maintenance Lower skirt height than vertical Less pressure drop than vertical Longer tubes possible Less cost than Kettle	No theoretical tray Extra space and piping as compared to vertical Fouls easier as compared to vertical Accumulation of higher boiling point components in feed line, i.e., temperature may be slightly higher than tower bottom
Forced circulation	One theoretical tray Handles high viscous solids-containing liquids Circulation controlled Higher transfer coefficient	Highest cost with additional piping and pumps Higher operating cost Requires additional plant area

A number of obvious advantages and disadvantages exist for either the horizontal or vertical thermosiphon reboiler. For horizontal units, Yilmaz states that the TEMA types X, G, and H are in more common usage, and types E and J are often used. The selection depends on the heat transfer, fouling, and pressure drop on the shell side. The X Shell is considered to have the lowest comparative pressure drop, then H, G, and J, with E having the best ΔP. The circulation through the thermosiphon loop described earlier depends on the pressure balance of the system, including the static pressure of the liquid level and the inlet pressure drop and exit two-phase pressure drops to and from the reboiler, plus the pressure drop through the unit itself.

Yilmaz recommends that the maximum velocity in the exit from the horizontal thermosiphon reboiler be the work of Collins:

$$V_{max} = 77.15\,(\rho_{tph})^{-0.5}$$

where

v_{max} = maximum velocity in exit from reboiler, m/sec

ρ_{tph}= homogeneous two-phase density, kg/m3

The arrangement of baffle plates and nozzles, 96C, are important to prevent:
(a) tube vibration, (b) maldistribution of the process boiling fluid, and (c) poor heat transfer coefficients due to uneven and stratified flow resulting in uneven and "dry spot" heat transfer from nonuniform tube wetting, and others. The work of Heat Transfer Research, Inc., has contributed much to the detailed technology; however, this information is proprietary and released only to subscribing member organizations. Yilmaz comments that several "unexpected" results have developed from the current horizontal reboiler research studies.

• These units provide higher heat fluxes at the same mean temperature difference.
• These units are superior in thermal performance to vertical tube thermosiphon units.
• These units are superior in thermal performance to kettle reboilers.

Kern deserves a lot of credit for developing design methods for many heat transfer situations and in particular the natural circulation phenomena as used for thermosiphon Reboilers.

The *horizontal natural circulation* systems do not use a kettle design exchanger, but rather a 1-2 (1 shell side, 2 tubeside passes) unit, with the vaporized liquid plus liquid not vaporized circulating back to a distillation column bottoms vapor space or, for example, to a separate drum where the vapor separates and flows back to the process system and where liquid recirculates back along with make-up "feed" to the inlet of the horizontal shell and tube reboiler.

A large portion of vaporization operations in industry are handled in the horizontal kettle unit. The kettle design is used to allow good vapor disengaging space above the boiling

surface on the shell side and to keep tubesheet and head end connections as small as possible. Services include vaporizing (reboiling) distillation column bottoms for reintroducing the vapor below the first tray, vaporizing refrigerant in a closed system (chilling or condensing on the process steam side), and boiling a process stream at constant pressure. The tube side may be cooling or heating a fluid or condensation of a vapor.

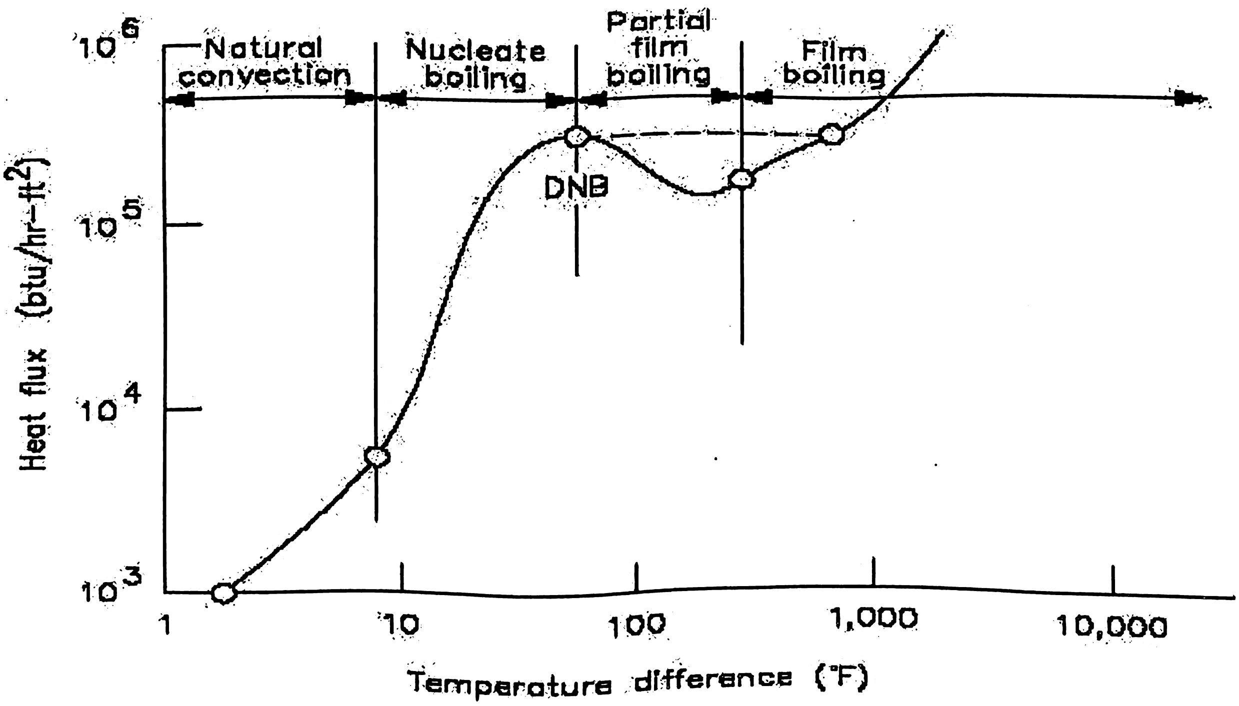
Physically the main shell diameter should be about 40% greater than that required for the tube bundle only. This allows the disengaging action.

The kettle unit used in the reboiling service usually has an internal weir to maintain a fixed liquid level and tube coverage. The bottoms draw-off is from the weir section.

The reboiling handled in horizontal thermosiphon units omits the disengaging space because the liquid-vapor mixture should enter the distillation tower where disengaging takes place. The chiller often keeps the kettle design but does not use the weir because no liquid bottoms draw off when a refrigerant is vaporized.

4. Boiling heat-transfer fundamentals

The mechanism of heat transfer from a submerged surface to a pool of liquid depends on the temperature difference between the heated surface and the liquid. At low-temperature differences, when the liquid is below its boiling point, heat is transferred by natural convection. As the surface temperature is raised incipient boiling occurs, vapour bubbles forming and breaking loose from the surface. The agitation caused by the rising bubbles, and other effects caused by bubble generation at the surface, result in a large increase in the rate of heat transfer. This phenomenon is known as nucleate boiling. As the temperature is raised further the rate of heat transfer increases until the heat flux reaches a critical value. At this point, the rate of vapour generation is such that dry patches occur spontaneously over the surface, and the rate of heat transfer falls off rapidly. At higher temperature differences, the vapour rate is such that the whole surface is blanketed with vapour, and the mechanism of heat transfer is by conduction through the vapour film. Conduction is augmented at high temperature differences by radiation.



The maximum heat flux achievable with nucleate boiling is known as the critical heat flux. In a system where the surface temperature is not self-limiting, such as a nuclear reactor fuel element, operation above the critical flux will result in a rapid increase in the surface temperature, and in the extreme situation the surface will melt. This phenomenon is known as "burn-out". The heating media used for process plant are normally selflimiting; for example, with steam the surface temperature can never exceed the saturation temperature. Care must be taken in the design of electrically heated vaporisers to ensure that the critical flux can never be exceeded. The critical flux is reached at surprisingly low temperature differences; around 20 to 30ŽC for water, and 20 to 50ŽC for light organics.

4.1. Estimation of boiling heat-transfer coefficients

In the design of vaporisers and reboilers the designer will be concerned with two types of boiling: pool boiling and convective boiling. Pool boiling is the name given to nucleate boiling in a pool of liquid; such as in a kettle-type reboiler or a jacketed vessel. Convective boiling occurs where the vaporising fluid is flowing over the heated surface, and heat transfer takes place both by forced convection and nucleate boiling; as in forced circulation or thermosyphon reboilers.

Boiling is a complex phenomenon, and boiling heat-transfer coefficients are difficult to predict with any certainty. Whenever possible experimental values obtained for the system being considered should be used, or values for a closely related system

4.2. Pool boiling

In the nucleate boiling region the heat-transfer coefficient is dependent on the nature and condition of the heat-transfer surface, and it is not possible to present a universal correlation that will give accurate predictions for all systems. Palen and Taborek (1962) have reviewed the published correlations and compared their suitability for use in reboiler design.

The correlation given by Forster and Zuber (1955) can be used to estimate pool boiling coefficients, in the absence of experimental data. Their equation can be written in the form:

$$h_{nb} = 0.00122\left[\frac{k_L^{0.79} C_{pL}^{0.45} \rho_L^{0.49}}{\sigma^{0.5} \mu_L^{0.29} \lambda^{0.24} \rho_v^{0.24}}\right](T_w - T_s)^{0.24}(p_w - p_s)^{0.75}$$

Where

h_{nb} = nucleate, pool, boiling coefficient, W/m^2. ^{0}C,

k_L = liquid thermal conductivity, W/m. ^{0}C,

C_{pL} = liquid heat capacity, J/kg. ^{0}C,

P_L = liquid density, kg/m^3,

μ_L = liquid viscosity, Ns/m^2,

λ = latent heat, J/kg,

ρ_v = vapor density, kg/m^3,

T_W = wall, surface temperature, ^{0}C,

T_S = saturation temperature of boiling liquid, ^{0}C,

P_w = saturation pressure corresponding to the wall temperature, Tw, N/ m^2,

P_s = saturation pressure corresponding to Ts, N/ m^2,

σ = surface tension, N/m.

The reduced pressure correlation given by Mostinski (1963) is simple to use and gives values that are as reliable as those given by more complex equations.

$$h_{nb} = 0.104(P_c)^{0.69}(q)^{0.7}\left[1.8\left(\frac{P}{P_c}\right)^{0.17} + 4\left(\frac{P}{P_c}\right)^{1.2} + 10\left(\frac{P}{P_c}\right)^{10}\right]$$

Where, P = operating pressure, bar,

Pc = liquid critical pressure, bar,

q = heat flux, W/m^2.

Note. $q = h_{nb}(T_w - T_s)$

Mostinski's equation is convenient to use when data on the fluid physical properties are not available.

Equations 12.62 and 12.63 are for boiling single component fluids; for mixtures the coefficient will generally be lower than that predicted by these equations. The equations can be used for close boiling range mixtures, say less than 5ŽC; and for wider boiling ranges with a suitable factor of safety.

4.3. Critical heat flux

It is important to check that the design, and operating, heat flux is well below the critical flux. Several correlations are available for predicting the critical flux. That given by Zuber *et al.* (1961) has been found to give satisfactory predictions for use in reboiler and vaporiser design. In SI units, Zuber's equation can be written as:

$$q_c = 0.131\lambda[\sigma g(\rho_L - \rho_v)\rho_v^2]^{1/4}$$

Where, q_c = maximum critical heat flux, W/m^2

g = gravitational acceleration, 9.81 m/s^2.

Mostinski also gives a reduced pressure equation for predicting the maximum critical heat flux:

$$q_c = 3.67 \times 10^4 P_c \left(\frac{P}{P_c}\right)^{0.35} \left[1 - \left(\frac{P}{P_c}\right)\right]^{0.9}$$

4.4. Film boiling

The equation given by Bromley (1950) can be used to estimate the heat-transfer coefficient for film boiling on tubes. Heat transfer in the film-boiling region will be controlled by conduction through the film of vapour, and Bromley's equation is similar to the Nusselt equation for condensation, where conduction is occurring through the film of
condensate.

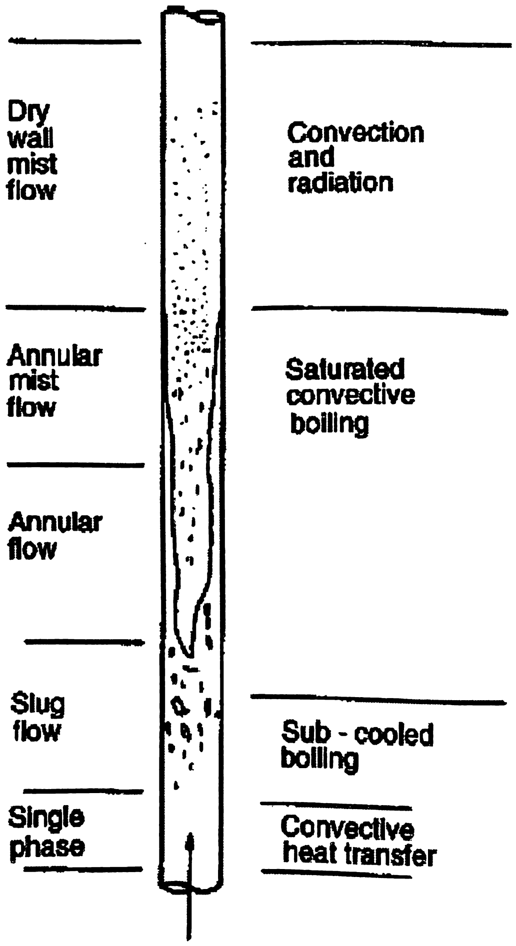
$$h_{fb} = 0.62 \left[\frac{k_v^3(\rho_L - \rho_v)\rho_v g \lambda}{\mu_v d_o (T_w - T_s)}\right]^{1/4}$$

where h_{fb} is the film boiling heat-transfer coefficient; the suffix *v* refers to the vapour phase and do is in metres. It must be emphasised that process reboilers and vaporizers will always be designed to operate in the nucleate boiling region. The heating medium would be selected, and its temperature controlled, to ensure that in operation the temperature difference is well below that at which the critical flux is reached. For instance, if direct heating with steam would give too high a temperature difference, the steam would be used to heat water, and hot water used as the heating medium.

4.5. Convective boiling

The mechanism of heat transfer in convective boiling, where the boiling fluid is flowing through a tube or over a tube bundle, differs from that in pool boiling. It will depend on the state of the fluid at any point. Consider the situation of a liquid boiling inside a vertical tube; Figure 12.55. The following conditions occur as the fluid flows up the tube.

1. Single-phase flow region: at the inlet the liquid is below its boiling point (sub-cooled) and heat is transferred by forced convection. The equations for forced convection can be used to estimate the heat-transfer coefficient in this region.
2. Sub-cooled boiling: in this region the liquid next to the wall has reached boiling point, but not the bulk of the liquid. Local boiling takes place at the wall, which increases the rate of heat transfer over that given by forced convection alone.



3. Saturated boiling region: in this region bulk boiling of the liquid is occurring in a manner similar to nucleate pool boiling. The volume of vapour is increasing and various flow patterns can form (see Volume 2, Chapter 14). In a long tube, the flow pattern will eventually become annular: where the liquid phase is spread over the tube wall and the vapour flows up the central core.

4. Dry wall region: Ultimately, if a large fraction of the feed is vaporised, the wall dries out and any remaining liquid is present as a mist. Heat transfer in this region is by convection and radiation to the vapour. This condition is unlikely to occur in commercial reboilers and vaporisers.

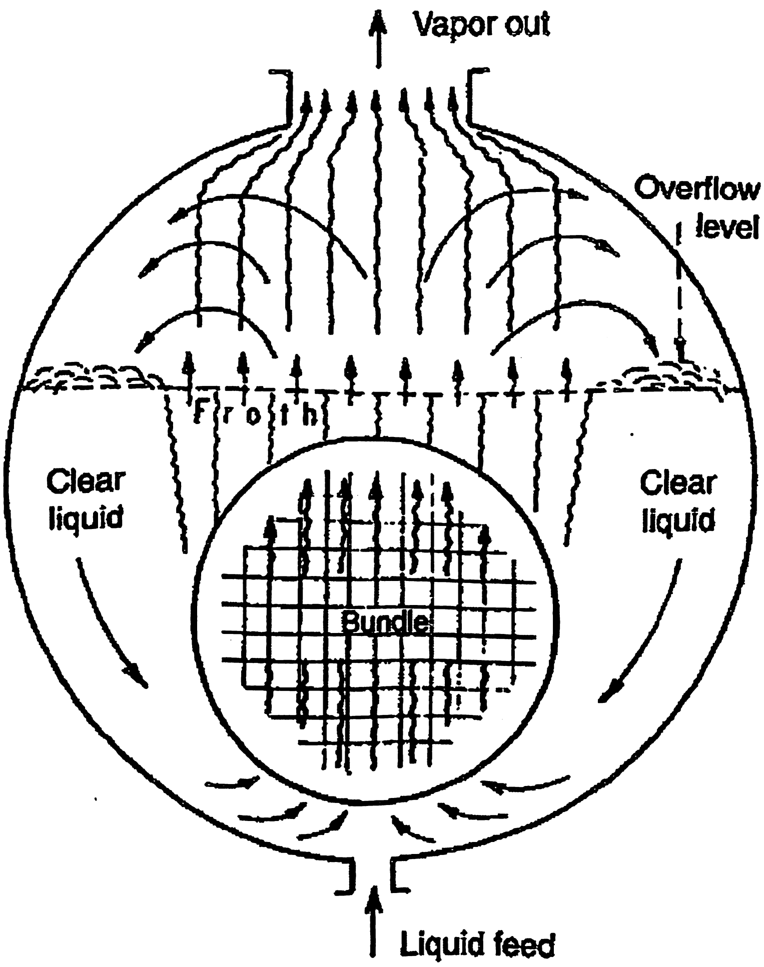
Saturated, bulk, boiling is the principal mechanism of interest in the design of reboilers and vaporisers.

A comprehensive review of the methods available for predicting convective boiling coefficients is given by Webb and Gupte (1992). The methods proposed by Chen (1966) and Shah (1976) are convenient to use in manual calculations and are accurate enough for preliminary design work.

5. Design of Kettle Reboilers

5.1. Design strategy

A schematic representation of the circulation in a kettle reboiler is shown in Figure 10.7. The circulation rate through the tube bundle is determined by a balance between the static head of liquid outside the bundle and the pressure drop across the bundle. A two-phase mixture exists in the bundle and the vapor fraction varies with position. Therefore, the bundle hydraulics are coupled with the heat transfer, and a computer model (such as that in the HTRI or HTFS software package) is required to perform these calculations. Since the circulation rate in a kettle reboiler is relatively low, the pressure drop in the unit is usually quite small. Therefore, a reasonable approximation is to neglect the pressure drop in the unit and size the bundle using the heat-transfer correlations given in Section 9.3. Since kettles utilize once-through operation, the feed rate is equal to the liquid flow rate from the bottom tray of the distillation column. Hence, the feed and return lines can be sized to accommodate the required liquid and vapor flows based on the available static head of liquid in the column sump. Because the flow in each line is single phase (liquid feed and vapor return), the hydraulic calculations are straightforward. Furthermore, the heat-transfer and hydraulic calculations are independent of one another, making the entire approximate design procedure relatively simple and suitable for hand calculations.



5.2. Mean temperature difference

In exchangers with boiling or condensing mixtures, the true mean temperature difference is not generally equal to *F(ATln)cf* because the stream enthalpy varies nonlinearly with temperature over the boiling or condensing range, violating an underlying premise of the F-factor method. Computer algorithms handle this situation by performing a zone analysis (incremental calculations) in which each zone or section of the exchanger is such that the stream enthalpy is nearly linear ithin the zone. For the approximate design procedure outlined above, however, an effective mean temperature difference for the reboiler is required. For kettle reboilers, Palen [1] recommends using the logarithmic mean temperature difference (LMTD) based on the exit vapor temperature as a conservative approximation for the mean temperature difference. That is, the LMTD is calculated assuming that the shell-side fluid temperature is constant and equal to the temperature of the vapor leaving the reboiler.

5.3. Fouling factors

Since heat-transfer coefficients are generally high in reboilers, the specified fouling allowance can account for a substantial fraction of the total thermal resistance. Therefore, it is important to use realistic values for the fouling factors in order to avoid gross over-design that could result in operational problems as well as needless expense. The recommendations of Palen and Small [5] are given in Table 10.2. TEMA fouling factors or those given in Table 3.3 may also be useful for some applications. As always, however, the best source for fouling factors is prior experience with the same or similar application.

5.4. Number of nozzles

In order to obtain a reasonably uniform flow distribution along the length of the tube bundle, an adequate number of feed and vapor return nozzles should be used. For a tube bundle of length L and diameter *Db*, the number, *Nn*, of nozzle pairs (feed and return) is determined from the following empirical equation [1,6]"

$N_n = L/5D_b$

The calculated value is rounded upward to the next largest integer.

Recommended Fouling Factors for Reboiler Design

Boiling-side stream	Fouling factor(h.ft^2. ^{0}F/Btu)
C1-C8 normal hydrocarbons	0-0.001
Heavier normal hydrocarbons	0.001-0.003
Diolefins and polymefizing hydrocarbons	0.003-0.005
Heating-side stream	
Condensing steam	0-0.0005
Condensing organic	0.0005-0.001
Organic liquid	0.0005-0.002

5.5. Shell diameter

The diameter of the K-shell is chosen to provide adequate space above the surface of the boiling liquid for vapor-liquid disengagement. A rule of thumb is that the distance from the uppermost tube to the top of the shell should be at least 40% of the shell diameter. A somewhat more rigorous sizing procedure is based on the following empirical equation for the vapor loading [5,6]:

$VL = 2290\rho_v(\sigma/\rho_L - \rho_v)$

Where

VL = vapor loading (lbm/h. ft^3)

ρ_v ρ_L = vapor & liquid densites (lbm/ft^3)

σ = surface tension (dyne/cm)

The vapor loading is the mass flow rate of vapor divided by the volume of the vapor space. The value given by Equation (10.2) is intended to provide a sufficiently low vapor velocity to allow gravitational settling of entrained liquid droplets. The dome segment area, *SA,* is calculated from the vapor loading as follows:

$SA = \square_V/L*VL$

Where

$\square_V$ = vapor mass flow rate(lbm/h)

L = lengthof tube bundle(ft)

VL (lbm/h. ft^3)

SA (ft^2)

Considering the K-shell cross-section shown in Figure 10.7, the dome segment area is the area of the circular segment that lies above the liquid surface. For known bundle diameter and dome segment area, the shell diameter can be determined (by trial and error) from the table of circular segment areas in Appendix 10.A. Since the liquid level is usually maintained slightly above the top row of tubes, the height of liquid in the shell is approximately equal to the bundle diameter plus the clearance between the bundle and the bottom of the shell. However, to account for the effect of foaming and froth formation, this height may be incremented by 3-5 in. for the purpose of calculating the shell diameter [6]. Demister pads can also be installed in the vapor outlet nozzles to further reduce entrainment.

5.6. Liquid overflow reservoir

With a kettle reboiler, surge capacity is provided by the liquid overflow reservoir in the kettle, as opposed to the column sump when a thermosyphon reboiler is used. The liquid holdup time in the overflow reservoir is usually significantly less than in the column sump due to the cost of extending the length of the K-shell, of which only the bottom portion is useable. The small size and limited holdup time can make the liquid level in the reservoir difficult to control, and can lead to relatively large fluctuations in the bottom product flow rate. These fluctuations can adversely affect the operation of downstream units unless a separate surge vessel is provided downstream of the reboiler, or the bottom product flows to storage. These problems can be avoided by eliminating the overflow weir in the kettle [7]. However, a drawback of this strategy is that incomplete separation of reboiler feed and reboiled liquid results in the (partial) loss of one theoretical distillation stage.

5.7. Finned tubing

Radial low-fin tubes and tubes with surface enhancements designed to improve nucleate boiling characteristics can be used in reboilers and vaporizers. They are particularly effective when the temperature driving force is small, and hence they are widely used in refrigeration systems. In addition to providing a large heat-transfer surface per unit volume, finned tubes can result in significantly higher boiling heat-transfer coefficients compared with plain tubes due to the convective effect of two-phase flow between the fins [1]. As the temperature driving force increases, the boiling-side resistance tends to become small compared with the thermal resistances of the tube wall and heating medium, and the advantage of finned tubes is substantially diminished. A quantitative treatment of boiling on finned and enhanced surfaces is beyond the scope of this book.

5.8. Steam as heating medium

When condensing steam is used as a heating medium, it is common practice to use an approximate heat-transfer coefficient on the heating side for design purposes. Typically, a value of 1500 Btu/h. ft^2. ^0F(8500W/m^2.K) is used. This value is referred to the external tube surface and includes a fouling allowance. Thus, for steam condensing inside plain tubes we have:

$$[(D_o/D_i)(1/h_i + R_{Di})]^{-1} \equiv 1500 \text{ Btu/h. ft}^2.{}^0F \equiv 8500 W/m^2.K$$

Some guidelines for sizing steam and condensate nozzles are presented in Table 10.3. The data are taken from Ref. [8] and are for vertical thermosyphon reboilers. However, they can be used as general guidelines for all types of reboilers of similar size.

Guidelines for Sizing Steam and Condensate Nozzles

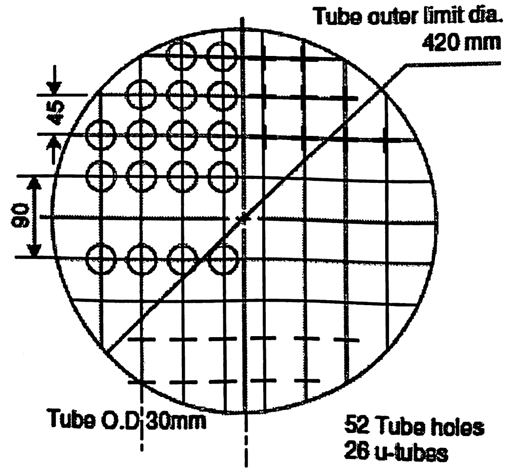
Shell OD (in.)	Heat-transfer Area(ft^2)	Nominal nozzle diameter (in.)	
		Steam	Condensate
16	130	4	1.5
20	215	4	2
24	330-450	6	3
30	525-1065	6-8	3-4
36	735-1520	8	4
42	1400-2180	8	4

5.9. Two-phase density calculation

In order to calculate the static head in the reboiler, the density of the two-phase mixture in the boiling region must be determined. For cross flow over tube bundles, this calculation is usually made using either the homogeneous model, Equation (9.51), or one of the methods for separated flow in tubes, such as the Chisholm correlation, Equation (9.63). Experimental data indicate that neither approach is particularly accurate [9], but there is no entirely satisfactory alternative. The homogeneous model is somewhat easier to use, but the Chisholm correlation will generally give a more conservative (larger) result for the static head.

Calculation for the design of kettle type reboiler:-

Design a vaporiser to vaporise 5000 kg/h n-butane at 5.84 bar. The minimum temperature of the feed (winter conditions) will be 0°C. Steam is available at 1.70 bar (10 psig).



Tube sheet layout, U-tubes

Calculation:-

Physical properties of n-butane at 5.84 bar:

boiling point = 56.1°C
latent heat = 326 kJ/kg
mean specific heat, liquid = 2.51 kJ/kg°C
critical pressure, P_c = 38 bar

Heat loads:

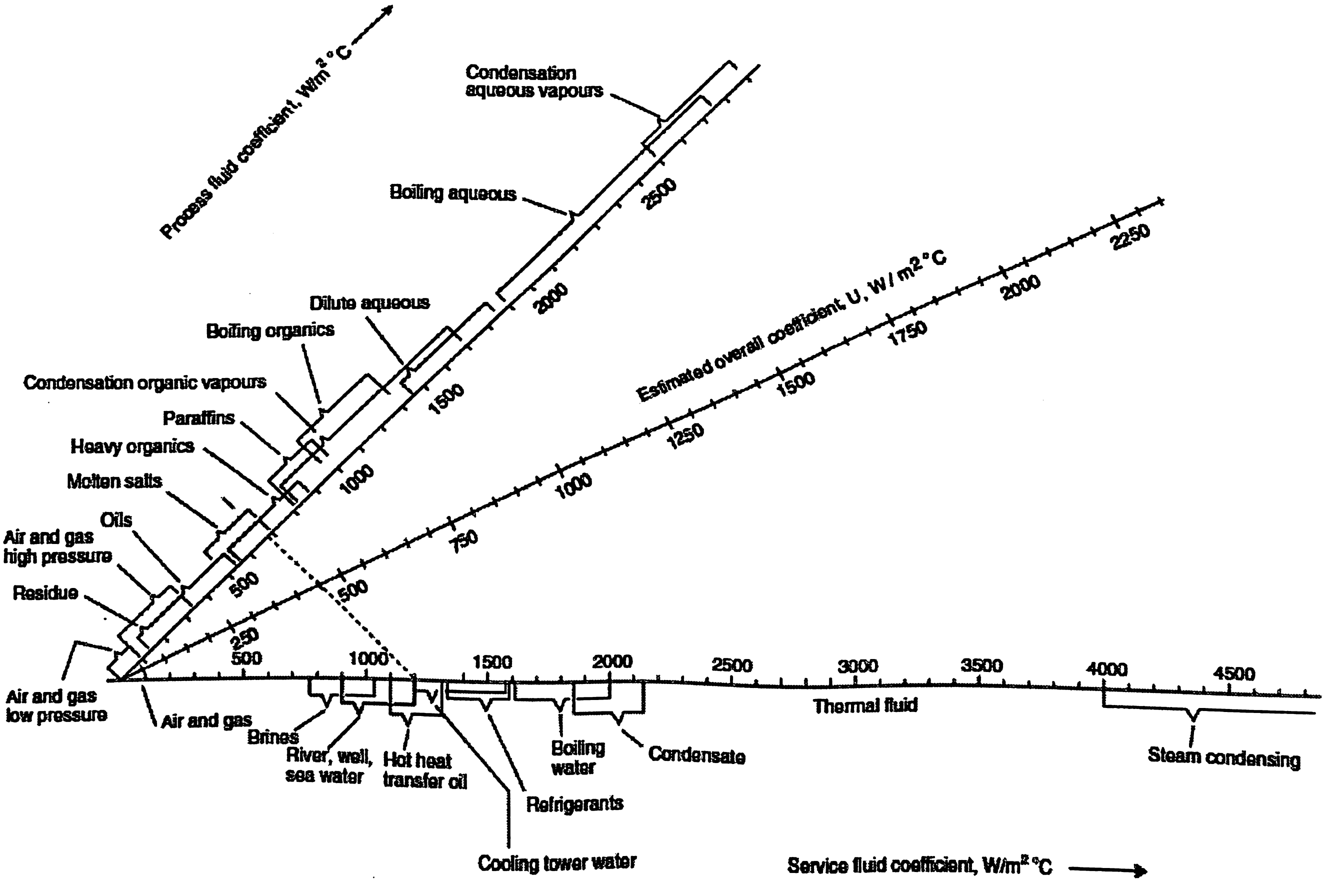
sensible heat (maximum) = (56.1 − 0)2.51 = 140.8 kJ/kg

$$\text{total heat load} = (140.8 + 326) \times \frac{5000}{3600} = 648.3 \text{ kW},$$

add 5 per cent for heat losses

maximum heat load (duty) = 1.05 × 648.3

= 681 kW



Overall coefficients (join process side duty to service side and read U from centre scale)

From above figure assume U= 1000W/m^2 ^{0}C

Mean temperature difference; both sides isothermal, steam saturation temperature at 1.7 bar = 115.2°C

$$\Delta T_m = 115.2 - 56.1 = 59.1°\text{C}$$

$$\text{Area (outside) required} = \frac{681 \times 10^3}{1000 \times 59.1} = 11.5 \text{ m}^2$$

Select 25 mm i.d., 30 mm o.d. plain U-tubes,

Nominal length 4.8 m (one U-tube)

$$\text{Number of U tubes} = \frac{11.5}{(30 \times 10^{-3})\pi 4.8} = 25$$

Use square pitch arrangement, pitch = 1.5 × tube o.d.

$$= 1.5 \times 30 = 45 \text{ mm}$$

Draw a tube layout diagram, take minimum bend radius

$$1.5 \times \text{tube o.d.} = 45 \text{ mm}$$

Proposed layout gives 26 U-tubes, tube outer limit diameter 420 mm.

Boiling coefficient

Use Mostinski's equation:

heat flux, based on estimated area,

$$q = \frac{681}{11.5} = 59.2 \text{ kW/m}^2$$

$$h_{nb} = 0.104(38)^{0.69}(59.2 \times 10^3)^{0.7}\left[1.8\left(\frac{5.84}{38}\right)^{0.17} + 4\left(\frac{5.84}{38}\right)^{1.2} + 10\left(\frac{5.84}{38}\right)^{10}\right]$$

$$= 4855 \text{ W/m}^{2\,0}\text{C}$$

Take steam condensing coefficient as 8000 W/m²°C, fouling coefficient 5000 W/m²°C; butane fouling coefficient, essentially clean, 10,000 W/m²°C.

Tube material will be plain carbon steel, $k_w = 55$ W/m°C

$$\frac{1}{U_o} = \frac{1}{4855} + \frac{1}{10{,}000} + \frac{30 \times 10^{-3} \ln \frac{30}{25}}{2 \times 55} + \frac{30}{25}\left(\frac{1}{5000} + \frac{1}{8000}\right)$$

$$U_o = \underline{\underline{1341 \text{ W/m}^2{}^\circ\text{C}}}$$

Close enough to original estimate of 1000 W/m²°C for the design to stand.

Myers and Katz (*Chem. Eng. Prog. Sym. Ser.* 49(5) 107–114) give some data on the boiling of n-butane on banks of tubes. To compare the value estimate with their values an estimate of the boiling film temperature difference is required:

$$= \frac{1341}{4855} \times 59.1 = 16.3^\circ\text{C } (29^\circ\text{F})$$

Myers data, extrapolated, gives a coefficient of around 3000 Btu/h ft²°F at a 29°F temperature difference = 17,100 W/m²°C, so the estimated value of 4855 is certainly on the safe side.

Check maximum allowable heat flux. Use modified Zuber equation.

Surface tension (estimated) = 9.7×10^{-3} N/m

$$\rho_L = 550 \text{ kg/m}^3$$

$$\rho_v = \frac{58}{22.4} \times \frac{273}{(273 + 56)} \times 5.84 = 12.6 \text{ kg/m}^3$$

$$N_t = 52$$

For square arrangement $K_b = 0.44$

$$q_c = 0.44 \times 1.5 \times \frac{326 \times 10^3}{\sqrt{52}}[9.7 \times 10^{-3} \times 9.81(550 - 12.6)12.6^2]^{0.25}$$

$$= 283{,}224 \text{ W/m}^2$$

$$= 280 \text{ kW/m}^2$$

Applying a factor of 0.7, maximum flux should not exceed $280 \times 0.7 = 196$ kW/m^2. Actual flux of 59.2 kW/m^2 is well below maximum allowable.

Layout

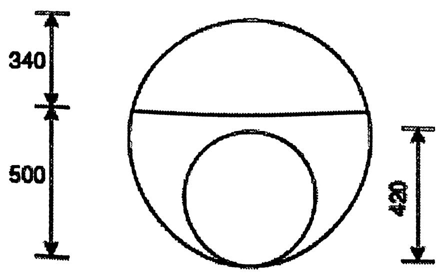
From tube sheet layout $D_b = 420$ mm.

Take shell diameter as twice bundle diameter

$$D_s = 2 \times 420 = 840 \text{ mm.}$$

Take liquid level as 500 mm from base,

$$\text{freeboard} = 840 - 500 = 340 \text{ mm, satisfactory.}$$



From sketch, width at liquid level = 0.8 m.
Surface area of liquid = $0.8 \times 2.4 = 1.9$ m^2.

Vapour velocity at surface $= \frac{5000}{3600} \times \frac{1}{12.6} \times \frac{1}{1.9} = \underline{\underline{0.06 \text{ m/s}}}$

Maximum allowable velocity

$$\hat{u}_v = 0.2\left[\frac{550 - 12.6}{12.6}\right]^{1/2} = \underline{\underline{1.3 \text{ m/s}}}$$

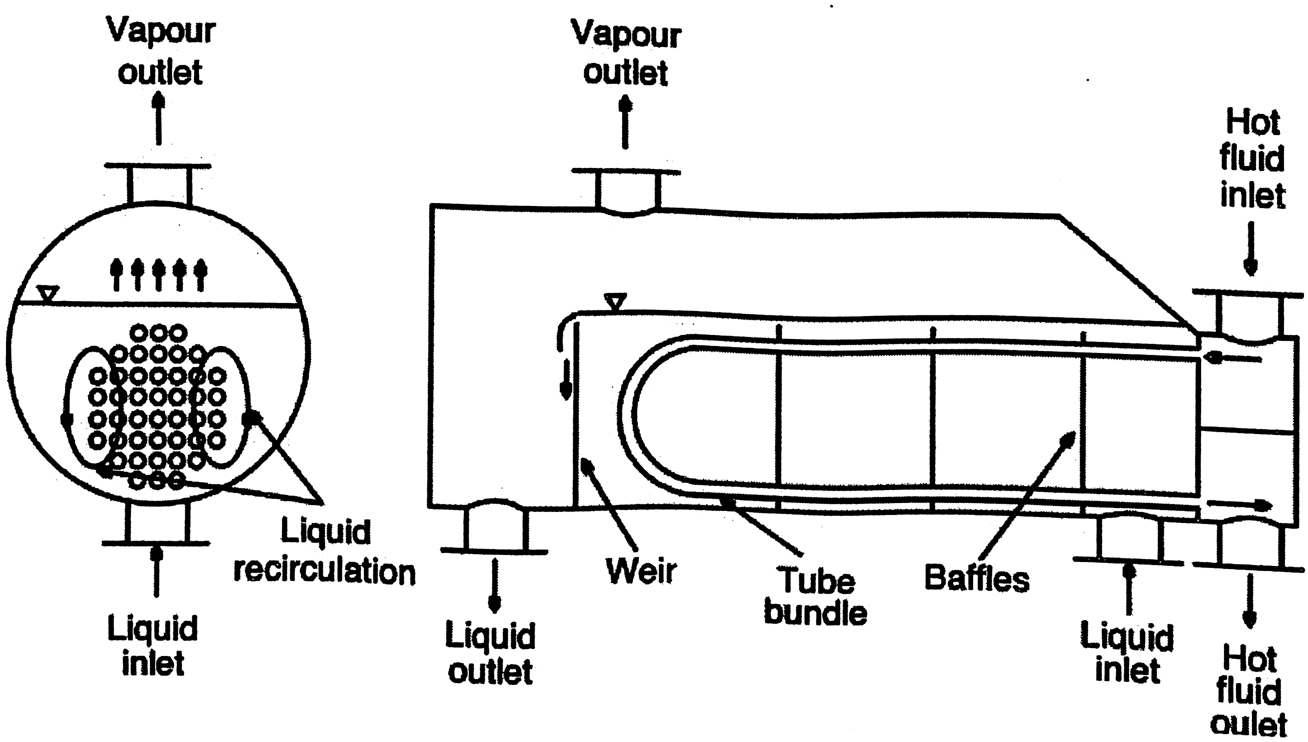
so actual velocity is well below maximum allowable velocity. A smaller shell diameter could be considered.

6. SIMULATIONS OF THE KETTLE REBOILER SHELL SIDE THERMAL-HYDRAULICS WITH DIFFERENT TWO-PHASE FLOW MODELS

A computational fluid dynamics approach is presented for the simulation and analyses of the kettle reboiler shell side thermal-hydraulics with two different models of two-phase flow – the mixture and two fluid model. The mixture model is based on solving one momentum equation for two-phase mixture flow and a closure law for the calculation of the slip between gas and liquid phase velocities. In the two fluid modeling approach the momentum balance is formed for each phase, while the gas-liquid interaction due to momentum exchange at the interface surface is predicted with an empirical correlation for the interface friction coefficient. In both approaches the two-phase flow is observed as two inter-penetrating continua. The models are solved for the two-dimensional geometry of the kettle reboiler shell side vertical cross section. The computational fluid dynamics numerical method based on the SIMPLE type algorithm is applied. The results of both liquid and vapor velocity fields and void fraction are presented for each modeling approach. The calculated void fraction distributions are compared with available experimental data. The differences in the modeling approaches and obtained results are discussed. The main finding is that the void fraction distribution and two-phase flow field strongly depends on the modeling of the slip between liquid and gas phase velocity in mixture model or on the interface friction model in two fluid model. The better agreement of the numerically predicted void fraction with the experimental data is obtained with the two fluid model and an interfacial friction model developed for the conditions of two-phase flows in large volumes of kettle reboilers or different designs of steam generators.

Shell and tube heat exchangers are among the most widely used types of heat exchangers. Different shell and tube heat exchangers are designed for vapour generation on the shell side. They are widely used in chemical, process, and energy power industry, in refregirations and air-conditioning equipments, and they are applied such as reboilers, steam generators, and evaporators. According to an estimate more than 50% of all heat exchangers used in process industries are used to boil fluids and involve two-phase flow on the shell side. In process industry we call them reboilers, while kettle reboilers are one of the most common reboiler types. Some developments of horizontal steam generators for nuclear power plants are based on the kettle reboiler design.

The evaporating fluid flows on the shell side, across a horizontal tube bundle. The heat is transferred to the boiling two-phase mixture from a hot fluid that circulates inside the tubes. The liquid level is controlled by a weir, so that the bundle is always submerged in liquid. The gap between the bundle and the shell allows internal recirculation of liquid. The liquid enters the bundle at its bottom only. The mass velocity of fluid across the bundle is increased by the recirculation of liquid, affecting the global heat transfer coefficient.



(Fig1: Schematic view of kettle type reboiler)

Previous investigations of the kettle reboiler shell side thermal-hydraulics have been performed with experimental and analytical models of various levels of complexity regarding the multidimensionality and thermal-hydraulic complexity of boiling two-phase flow conditions. Void fractions and pressure drops in one-dimensional upward two-phase flows across the tube bundles with various tubes' arrangements are presented. One dimensional investigations were per formed first, because the process of evaporation is complex and the vertical flow across the tube bundle is dominant. But, reboiler shell side thermal-hydraulics is strongly influence by multidimensional effects. It was shown that the vertical pressure change is not constant along the bundle, causing a lateral pressure change, which must be satisfied by a lateral flow. In a more realistic two-dimensional investigation is presented with information how variation of heat flux, weir height, bundle size and pressure affect the kettle reboiler processes. Two-dimensional numerical models of the kettle reboiler shell side thermal-hydraulics are presented.

The main findings in per formed researches are:

(a) The homogeneous model of two-phase flow provides too high values of the void fraction which means that

The gas and liquid phase velocity slip should be taken into account in a kettle reboiler design or analyses procedures, and

(b) The liquid phase circulation is organized on the reboiler shell side, where the intensity of circulation influences the heat transfer coefficient and the void fraction distribution.

This paper presents the possibilities of two commonly applied two-phase flow models for the prediction of the kettle reboiler shell side thermal-hydraulics. These are (a) the mixture model of two-phase flow with the application of the closure law for the prediction of the gas and liquid phase slip velocity, and (b) the two fluid model of two-phase flow with the closure law for the prediction of the gas and liquid phase interfacial friction.

6.1. Modeling approaches

Several assumptions are introduced in modeling the kettle reboiler shell side thermal-hydraulics:

(a) The shell side flow in the slab of the kettle reboiler vertical cross section (as presented with the left scheme in fig. 1) is two-dimensional;

(b) Steady-state conditions are modeled;

(c) The shell side two-phase mixture is saturated;

(d) The surface tension at the gas-liquid interface is neglected, as it is not important for bulk two-phase flow phenomena. Hence, pressure is the same for both phases within the numerical control volume;

(e) Flow governing equations are written in the non-viscous form, while the turbulent viscosity effects are taken into account indirectly through friction coefficients for the tube bundles flow resistance and two-phase interfacial friction force; and

(f) The porous medium concept is used in the simulation of two-phase flow within tube bundles. In the applied mixture model it is assumed that the porous media is 100% open to the fluid flow, while in the two-fluid model the real volumes of liquid and gas phase are taken into account. In both models, the resistance of the tube bundle to the two-phase flow is taken into account through the appropriate volumetric force.

6.2. MIXTURE MODEL

The mixture model solves the continuity equation for the mixture, the momentum equation for the mixture, and the volume fraction equation for the secondary phases, as well as algebraic expressions for the relative velocities (if the phases are moving at different velocities) [11]. The energy equation for the mixture is also a constituent of the mixture model, but here it is not included since the saturated liquid and two-phase flows on the reboiler shell side are considered.

The continuity equation for the two-phase mixture is:

$$\nabla \cdot (\rho_m \vec{v}_m) = 0 \qquad \text{......................(1)}$$

Where v_m is the mass-averaged velocity:

$$\vec{v}_m = \frac{\sum_{k=fg} \alpha_k \rho_k \vec{v}_k}{\rho_m} \qquad \text{........................(2)}$$

And ρ_m is the mixture density.

$$\rho_m = \sum_{k=fg} \alpha_k \rho_k \qquad \text{..........................(3)}$$

α_k is the volume fraction of phase k(liquid phase k= f or gas phase k = g).

The momentum equation for the mixture can be obtained by summing the individual momentum equations for both phases:

$$\nabla \cdot (\rho_m \vec{v}_m \vec{v}_m) = -\nabla p + \rho_m \vec{g} + \nabla \cdot (\alpha_g \rho_g \vec{v}_{drg} \vec{v}_{drg}) - \vec{F}_{wm} \quad \text{.....................(4)}$$

Where V_{drg} is the drift velocity of dispersed vapour phase.

$$\vec{v}_{drg} = \vec{v}_g - \vec{v}_m$$

........................(5)

The slip velocity is calculated with the following semi empirical correlation:

$$\vec{v}_{fg} = \frac{(\rho_m - \rho_g) d_g^2}{18 \mu_f f_{drag}} \vec{a} \quad \text{..................................(6)}$$

where d_g is the bubble diameter and ra is the mixture acceleration. The drag coefficient

f_{drag} is calculated with the empirical relations of Schiller and Naumann:

$$f_{drag} = \begin{cases} 1+0.15\,Re^{0.678}, & Re \le 1000 \\ 0.0183\,Re, & Re > 1000 \end{cases}$$

.....(7)

And acceleration a is of the the form:-

$$\vec{a} = \vec{g} - (\vec{v}_m \cdot \nabla)\vec{v}_m - \frac{\partial \vec{v}_m}{\partial t} = \vec{g} - \frac{D\vec{v}_m}{Dt}$$

........(8)

The volumetric force of tube bundle resistence to two phase mixture flow F_{wm} is calculated as

$$\vec{F}_{wm} = \sum_{e=1}^{2} \varsigma_e \frac{\rho_m v_{me}^2}{2} \frac{\vec{e}}{\Delta e}$$

.............................(9)

where vector e is a unit vector in the direction of the Cartesian coordinate axis, and delta e is the

width of the computational cell. The coefficient of the local pressure drop in e direction *Ve*

is calculated.

The vapour volume fraction is calculated from the continuity equation:

$$\nabla \cdot (\alpha_g \rho_g \vec{v}_m) = -\nabla \cdot (\alpha_g \rho_g \vec{v}_{dr\,g})$$

Conclusions

The mixture and two fluid models are applied to the simulation of the kettle reboiler shell side thermal-hydraulics. Results obtained with the mixture, based on the two-phase mixture continuity and momentum equation and corresponding semi-empirical closure laws for the vapour and liquid phase slip velocity, does not provide reliable results of the kettle reboiler shell side thermal-hydraulics. The lateral two-phase flow from the down comer to the tube bundle is suppressed and too high values of the void fraction are obtained. On the other hand, more complex two fluid model, based on the mass and momentum balance equations for each phase and corresponding closure laws for the interface momentum exchange due to the interface friction, provides much better agreement with the referent results of the void fraction distribution. Also, two fluid model provides more plausible results of the two-phase flow structure on the kettle reboiler shell side than the mixture model. The in ability of the mixture model to predict correctly the shell side thermal-hydraulics is due to the solving of one momentum equation for the two-phase mixture, and corresponding limitations in modelling the vapour and liquid phase sep a ration within the large volume of the kettle reboiler shell side with liquid phase circulation.

7. INSPECTION & MAINTENANCE OF HEAT EXCHANGER

7.1. INSPECTION OF HEAT EXCHANGER

7.1.1. DEFINITION

The term inspection can be defined as the process of examination of a material or a finished product using sensory organs, tools, equipments, instruments and gauges to assess the quality of a product.

The term inspection, as far as ASME Code Section and other referencing Code sections are concerned, applies to the functions performed by the Authorized Inspector, whereas the term examination applies to the quality control functions performed as stipulated in the quality manual by quality control staff of the company or the manufacturer.

7.1.2. OBJECTIVES OF INSPECTION

During manufacturing, Inspection has mainly mainly three principal objectives:

1. To provide assurance that there are no defects, indicating manufacturing was above the standard required in the specification.
2. To provide assurance that no defects are present that could impede subsequent processing inspections.
3. To provide assurance that no defects are present in the completed component that will pose safety problem.

7.1.3. INSPECTION & DESIGN

In the preliminary design stage, performance criteria and material selection should be made compatible with NDT, and the aim should be to provide maximum accessibility for inspection both during fabrication and in service. The design should include inspection in critical area where the fabrication process is likely to introduce defects or where service conditions will
impose critical stresses .

7.1.4. INSPECTION GUIDELINES

Some general guideline for the inspection is as follows:

1. Prepare inspection briefs in clear and concise formats. Assemble and incorporate into the inspection brief the setting plan, assembly drawings, tools, and instruments required for inspection .
2. Collect the document which is desired.

3. Inspection technique should be defined.
4. Find out the sequence of inspection.
5. Specify inspection of materials and components as soon as possible.
6. To establish the safety regulations of inspections.

7.1.5. SCOPE OF INSPECTION OF HEAT EXCHANGER,

In production process various processes are, inspectors examine work and document their observations.

The scope of inspection of heat exchangers is listed below:

1) Raw material identification and inspection.
2) Approve welding procedures by test plates as required.
3) Approve welders to be employed.
4) Edge preparation for welding, including visual check penetrant test for laminations.
5) Inspect weld preparations and setup for welding.
6) Inspection of back-gouged welded joints such as set-in nozzles, which are not readily radio graphed following welding.
7) Inspection of cladding by dye penetrant examination; verify chemistry following completion of the cladding; measure ferrite content.
8) Alignment of longitudinal and circumferential seams.
9) Tolerances on individual shell section.
10) Alignment of sections and components.
11) Root pass clearance before welding.
12) Examine soundness and general contour of welds.
13) Inspect prefabricated part shared items.
14) Check radiographic or other weld inspection technique.
15) Thinning of formed heads after forming.
16) Checking of tube sheet and baffle holes after drilling.
17) Tube sheet to shell setup prior to welding operation.
18) Check dimensions after postweld heat treatment.
19) Witnessing of leak testing or hydrostatic test.
20) Dimensional examination after hydrostatic test.
21) Stamping of the vessel and issue of certificates.

22)Packing and despatch.

Various stages of inspection should be selected to avoid heavy reworks at a later stage. But it should not lead to too many stages of inspection, which only lead to delays and rushing by workmanship to compensate for such delays; resulting in poor quality.

7.1.6. MATERIAL CONTROL & RAW MATERIAL INSPECTION

One of the important duties of inspectors is to inspect the raw materials like plates, forgings and tubes, and certify that they are as per purchase order and free from defects. The code requires goods to be accompanied by documents that detail the mill test reports and certifications.

A designated receiver should have the receiving procedure, the purchase order, and a checklist covering component dimensions, and examine for laminations, surface defects, transhipment damage, identification and verification of heat numbers, and test records supplied by vendors . A sound quality control program will rely on more than just a review of the mill test reports that accompany the incoming material. Such a program should include chemistry verification by spot NDT or destructive testing techniques. This may involve in situ x-ray examination, or laboratory wet-chemical or energy-dispersive evaluation .An easy way to avoid using the wrong materials in parts is to check composition using a portable spectroscope, which quickly identifies all major elements. The receiver signs in acceptable material for storage, and tags and segregates nonconforming materials, followed by identification, which includes a job number, serial number, and heat number, if relevant. Throughout production, identification follows the material or component, assuring traceability. All this work is carried out according to the quality control procedures laid down in the quality manual.

For all high-pressure applications, ultrasonic testing must be carried out to check for lamination and non-metallic inclusion. Plate edges are to be examined by magnetic or dye penetrated examination. Similarly, thicker forging must be ultrasonically examined.

7.1.7. DETAILED CHECKLIST FOR COMPONENTS

Before conducting the inspection, prepare a checklist of what to inspect, how, and when to inspect. Instruct the inspector to record deviations and their resolutions in an inspector's log Checklists detail steps in inspection of shell, channel, tube sheet, flanges, expansion joint,tube bundles, final assemblies, etc. A typical checklist for tubesheet, taken from a manufacturer's work, is given next.

7.1.8. CHECK LIST FOR TUBE SHEET

1) Outer diameter of the tube sheet
2) Diameter of the raised face shell side
3) Depth of the raised face shell side
4) Diameter of the raised face channel side
5) Depth of the raised face channel side
6) Thickness of the tube sheet
7) Width of the pass partition groove
8) Depth of the pass partition groove
9) Number and orientation of pass partitions
10)Size of the tube holes
11)Number and layout of tube holes
12)Outermost tube periphery diameter
13)Ligament

- Nominal ligament
- Number of holes below nominal ligament [4% of holes can be lower than TEMA minimum ligament]

14)Minimum ligament near pass partition
15)Depth of the welding groove
16)Expansion groove

  - Width
  - Depth
  - Location

17)Number of pulling eyes and sizes

18)Number of tie rods and sizing

19)Number of bolt holes and sizes

20)Neutral line marking

7.1.9. MASTER TRAVELER

During fabrication, a traveler that accompanies the part or component is sometimes the easiest way to carry out QC procedure .A drawing with all the welds numbered and marked with the points to be examined is a convenient and careful way to handle QC of welds. This document is known as a master traveler. The traveler tabulates operations for manufacture of any part or component. The traveler can continue to cover the complete vessel. From a production standpoint, however, it is often better to divide a complex vessel into components, with a traveler for every component and a separate sheet for the final assembly.

7.1.10. SCOPE OF THIRD PARTY INSPECTION

Third-party inspection agencies such as Lloyd' s Register and Bureau Varitas Quality International, among others, normally stipulate an involvement starting with approval of design, materials, fabrication, followed by inspection and testing.

In general, the scope of third-party inspection includes the following:

1. Approval of design and fabrication drawings to ensure that materials and fabrication details meet code requirements.
2. Material clearance for pressure parts.
3. Verification of WPSPQR and welder performance qualification tests and heat treatment.
4. Inspection during various stages of fabrication, principally by check points hold points/ witness points, indicated by (R) Review of record of inspection by third party; (H) Hold further process till review of record of inspection by third party; and (W) Witness of process by third party to ensure compliance with code requirements.
5. Examination of radiographs, and auditing of other non-destructive tests and heat-treatment procedures as required by the code.
6. Dimensional examination of the completed vessel.

7. Witnessing of leak test, hydrostatic, or any other special test as required by the code.
8. Stamping of the vessel and issue of certificates.

Lloyd's approach to quality assurance of welded structures is discussed by Frew. The approach is briefly described here. Appraisal at the design stage includes the calculation of thickness and an assessment of materials to be used, together with manufacturing and welding processes to be employed, the effect of fabrication, and welding and heat treatment processes on the materials used. Service conditions are taken into consideration. The efficacy of the fabricator's quality system is evaluated and suitable NDT methods are considered in relation to the joint geometries involved. Approval of fabrication takes into consideration the welding quality design, welder procedure qualification and production tests, postweld heat treatment (PWHT), etc.

7.1.11. HOLD POINTS & WITNES POINTS

Consideration should be given to the establishment of hold points and witness points, where an examination is to occur prior to the accomplishment of any further fabrication steps.

This is of vital importance for fabrication of pressure vessels and heat exchangers as per Code and or Standard. Through hold points and witness points, authorized code inspectors exercise control over the activities such as design calculations, drawings, receipt of materials and welding consumables, qualification of welding procedures and welders, joint design, work preparation before welding, examination during welding and after welding, NDT, non-conformance report (NCR), PWHT, hydrostatic tests, etc. A typical scheme for hold points/witness points and verification points is given in Table 2.

Table 2 Hold and Witness Points

Number	Stages of manufacture	H	W
1.	Drawing and design calculations approved	X	—
2.	Raw material for pressure parts clearance	X	—
3.	WPS/POR/welder qualifications	X	—
4.	Forming dimensions for shell and dished ends	X	—
5.	U-bends, qualification report	—	X
6.	Heat treatment chart for forming (if applicable)	—	X
7.	Fit up of pr. welds incl. attachments on pr. parts	X	—
8.	Air test for RF pads	—	X
9.	Shell ID check by template	—	X
11.	Radiography for pressure part welds	X	—
12.	MT/PT of nozzle and pressure parts attachment welds	—	X
13.	PWHT (if applicable) clearance for pressure part assly.	X	—
14.	Review of heat treatment charts	—	X
15.	NDT after heat treatment if applicable	X	—
16.	Destructive testing of production test plate	X	—
17.	Tube-sheet and baffle inspection after drilling	—	X
18.	Tube bundle skeleton before tubing	—	X
19.	Tube-to-tube-sheet joints, NDT/LT	—	X
20.	Pneumatic and hydro test for tube-to-tube-sheet joints	—	X
21.	Shell-side and tube-side hydrostatic test	X	—
22.	NCR clearance	X	—
23.	Painting of unit satisfactory	X	—
24.	Stamping and document folder clearance	X	—

7.2. MAINTAINANCE OF HEAT EXCHANGER

Heat transfer in which heat is to be transferred from one fluid to another, and the transfer surface is provided by thin-walled tubes. Whether an exchanger is used in the processing of a product, as in the petro-chemical and similar industries, or whether it is used to furnish hot water for an apartment house or for heating an office building, proper sizing is most mportant. Sizing affects not only the economics of the unit (first cost, operating cost, maintenance cost, and space requirements) but also its proper control.

If a unit is too small, it will not meet the demands at peak load. High flow rates may erode the tubes or create velocities which will cause vibration and failure of thin-walled tubes and other parts of the exchanger. Tube velocities should be limited to 6 feet per second for constant use, and are usually limited to 5 feet per second in general use. Shell velocities should not be over 4 feet per second when the shell is baffled. Too high velocities will scour the metal surfaces of their protective coating naturally formed leaving them vulnerable to corrosion.

If an exchanger is oversized, then it will be sluggish in operation .It may rapidly become fouled in some sections due to too low velocity and the depositing of silt, scale, or other impurities in the fluid being handled. Under such deposits chemical actions sometimes take place and thin tube walls are very vulnerable while thick sections, such as tubesheets and shell, can withstand quite severs corrosive attack before failure. In an exchanger with baffles in the shell, scale or other foreign matter sometimes builds up around the tubes where they pass through the holes in the baffles. Small crevices thus formed invite chemical action or electrolytic action, often eating holes right through the tubes at these points.

In an ideal exchanger operation the demand is constant, the heat supply is constant, and the rate of fouling is known. This is a usually the case in modern processing plants, and the exchanger can be designed economically to do the job efficiently over a period of time between planned shut down periods for cleaning and inspection. Measurement of the transferred is usually a simple operation and, if taken at various times, it is easy to derive the rate of fouling.

While adequate methods of maintenance are widely used in the highly organized process industries, a very large percentage of heat exchangers are not properly inspected and cleaned. The result is that at some time when least expected, and usually when least convenient, the unit has to be taken out of operation for cleaning, repair or complete replacement. When units are vital to an operation or when their shut-down would create a serious situation, some stand-by arrangement should be made.

Often the use of two smaller exchangers in parallel rather than one large one would allow a plant to carry on with half or two-thirds load, if one of the exchangers were out of commission for repair or inspection.Most of heat exchangers used in the hot water heating of buildings give very little trouble and require a minimum of maintenance over many years. This is because they are not subjected to intrusion of fouling fluids. The troublesome oxygen and other gases are purged on initial start-up, and the small amounts admitted with normal make-up water are easily controlled by low cost air separation devices installed in hydronic (water heating) systems.

Heat exchangers used in the supply of domestic hot water, however are sometimes troublesome. Most city and town water contains impurities in varying amounts, particularly soluble salts which crystallize out of solution in the 130°F to 180°F temperature range when heated. The scale thus formed settles throughout the system, but particularly in or on the heat exchanger tubes, and greatly decreases the efficiency of the heat transfer surface. A suitable watersoftener installation will usually help this problem. Also, if the salts produced are soft, they may be easily flushed out with water.

Most mechanical troubles with domestic water heaters, whether shell and tube or the common immersion tank heaters, are encountered at cold start-up.

A heat exchanger should be heated up slowly, with the cold fluid entering first and the hot fluid, water or steam, gradually brought in by manual control, until the required operating temperature is reached. Only then should the automatic control be cut in. In the case of steam as the heating medium, the steam trap should be manually bypassed until the exchanger is switched to automatic control. Costly damage can result if care is not exercised in the start-up of a heat exchanger. Water hammer often results when a large quantity of steam is allowed to condense rapidly in an enclosure. Thin-walled tubes are very vulnerable. Copper tubing is used extensively and is a relatively soft metal. Water hammer is a type of implosion effect particularly pronounced when low pressure steam is used, one reason being the high volume ratio of steam and water at low pressure. For instance:

Volume of 1lb of steam at 5 psig is about 20 cu ft

Volume of 1lb of water (condensate) is.0168 cu ft

This volume ratio of 1200 to 1 gives us some idea of how the tremendous hammer effect may be produced when there is enough transfer surface present to remove the latent heat of vaporization rapidly. Slugs of water are hurled about in the vacuum created by condensation, and one can visualize the damage possible to fragile tubes. When this hammer effect has occurred in the shell of an exchanger, the damage pattern is quite regular.

Tubes are crushed in on top of the tube bundle, usually at about two twothirds of the distance from the steam entry nozzle toward the other end of the tube bundle. So far, there seems to be no technical explanation for this phenomenon. From study and examination of damaged exchangers, and investigation of their operation, we have come to the conclusion the following is roughly what

happens: In a water heater using steam in the shell, when the demand for hot water ends, the steam control valve closes, but there is a good supply of steam left in the shell of the exchanger. As this stream condenses, the pressure drops, often below atmospheric or even practically to full vacuum. This prevents condensate from leaving the shell and sometimes even syphons in condensate from the line beyond the trap. Now, when the steam valve opens again and admits steam to the shell, the rapid condensation, as it strikes the cold condensate, causes steams of water to rise, hitting the top of the shell and bouncing onto the top tubes. Sometimes the breaks in the tubes look as though a 4"spike had been driven through the top side. Other times the tubes may be crushed as if with a blunt chisel over lengths of a few inches or up to two feet.

Usually, the installation of a vacuum breaker on the shell or in the steam inlet pipe adjacent to the shell will prevent this occurrence. Use a good trap of adequate size, and condensate piping of ample size. Be sure to size the trap to suit the steam pressure in the shell, not by the pressure of the main system. Float and thermostatic traps are recommended, so that air and incondensable gases are purged with the condensate.

When hammer has occurred in the tubes of an exchanger, the tubes are bulged in various locations and short bends often broken. Sometimes the tubes split if bulged far enough.

We know that the ultimate bursting strength of the tubing is in the neighbourhood of 2000 psi, so this is ample proof of the violence caused by water hammer.

7.2.1. CLEANING

If scaling or other fouling is expected, provisions in the piping can be made to allow connections for flushing out or chemical circulation cleaning. These openings, of course, would be normally plugged. In large plants where there are a number of exchangers it may be profitable to have a tank of cleaning fluid of suitable type and a circulating pump and rubber hose for periodic hook-up for flushing out of shell and/or tubes. Makers of commercial cleaning compounds would be glad to advice in this respect.

Then there are qualified organizations who can furnish a complete service of apparatus and experienced personnel to circulate inhibited acid solutions for the removal of hard scales and sludge not easily removed otherwise. Small exchangers that can be easily removed from the line, and small tube bundles, can be sent to organizations which do such cleaning on their premises.

8. Limitations and Drawbacks

Finding the criteria by which designers select a particular reboiler type, in practice, is not simple (Hewitt, 1994). It is many factors influences reboiler type selection. The most important factors are (The Distilllation Group, Inc., 2002):

- total duty required;
- fraction of tower liquid traffic vaporized;
- fouling tendency;
- temperature approach available;
- temperature approach required;
- working pressure;
- area available.

All this factors influence as well the configuration of reboilers. The decision which type of reboiler will be selected would be beginning with the list of advantages and disadvantages of each reboiler type. There are introduced the advantages and disadvantages of each individual reboiler in the Table 1.

The final selection would be carrying out on the basis of economic analysis. Often but is execute the selection on the basis of design difficulty and practice of the individual or company (Hewitt, 1994).

On the Figure 1 is showed the basic select algorithm (Love, 1992). This algorithm enables to choice easy the suitable type of reboiler in the few steps. Unfortunately this algorithm not covers all requirement of service and would be to use only as an auxiliary selection tool.

From Table 1 and Figure 1 it can be seen that for high viscous fluids or for solids-containing liquids to use of forced circulation type is preferred. If the viscosity is not too high can be use horizontal once-through reboiler. Other important factor of the selection is the equipment cost. The most expensive reboiler is the forced circulation and then Kettle reboiler.

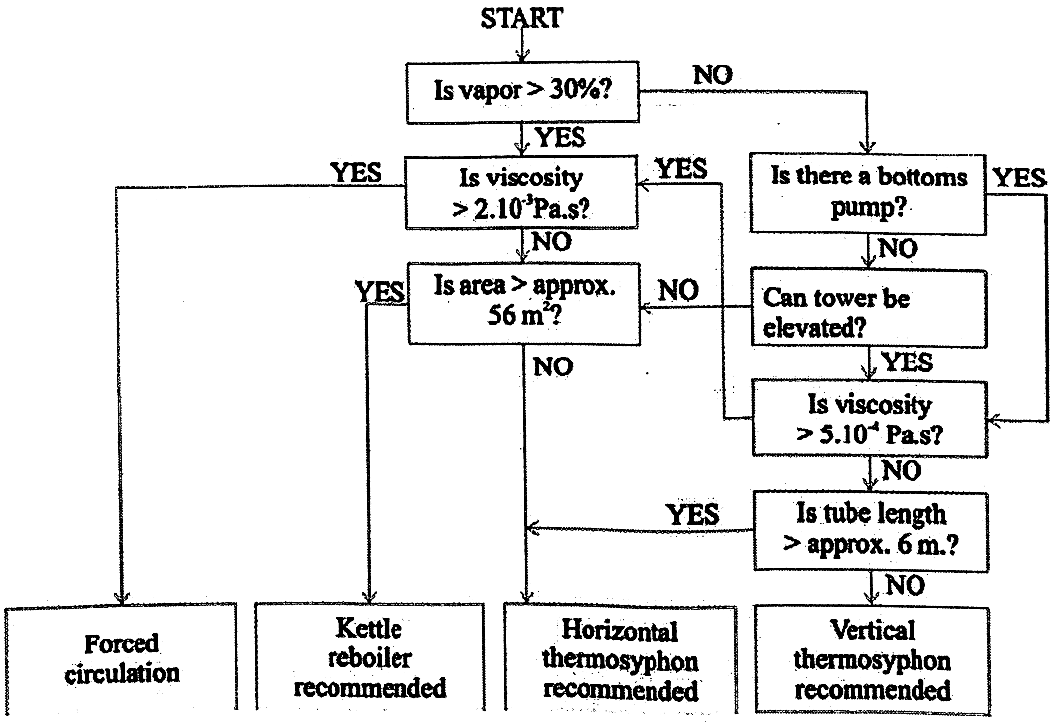


Fig. *Basic reboiler design selection algorithm*

Above described algorithm is the basic (instrumental) algorithm of reboiler selection. It is necessary to consider the other factors. The important factors that would probably be agreed by the most designers are as follows (Hewitt, 1994):

1. Most fouling fluid should be placed inside the tubes for easier cleaning. Thus, if the liquid being boiled tends to foul, a vertical thermosyphon reboiler should be used. Kettle reboilers tend to be the worst with regard to their fouling characteristics.
2. If the liquid being boiled is heat sensitive, a low residence time is required; a vertical thermosyphon is needed.
3. None of the reboilers is very suitable at very high pressures. A kettle will be very expensive because of the large-diameter shell, and the thermosyphon types may not operate satisfactorily because the density difference is too small. The circulation may be boosted by a pump in the inlet pipe to the reboiler.
4. For a vacuum system a horizontal thermosyphon reboiler is often preferred to a vertical thermosyphon because the bottom of the reboiler need not be so far below the liquid level in the distillation column. This will make the sensible heat duty lower.

5. A related point is that vertical thermosyphon reboilers may require the distillation column to be lifted to give the necessary working head. However, vertical thermosyphons require very little ground area.
6. Kettle reboilers are not suitable for foaming liquids.
7. Kettle reboilers are easier to design, at least on a rather crude basis. This is because the heat transfer aspects and the hydraulic factors are largely independent. Thermosyphons, however, need to be designed complete with the external pipework, or the required recirculation rate may not be attained.
8. Kettle reboilers are easiest to control and present no stability problems.
9. If the liquid is hazardous or toxicity, the internal reboiler is preferred.

The selection process (algorithm) was implemented on the basis of the flow chart (see Figure 1) and the additional criterions (recommendations) introduced in the paper into HGA database - Hot Gas Application (Kilkovsky et al., 2008) with use of Visual Basic for Application (VBA) environment in Microsoft Excel. This enables the selection of suitable type of reboiler.

The selection is conducted with the support table (like Table 2 below). The table contains given process requirements and the suitability is adding to each reboiler for given requirements. It can be use for example abbreviations according to: B – best; G – good operation; F – fair operation, but better choice is possible; Rd – risky unless carefully designed, but could be best choice in some cases; R – risky because of insufficient data; P – poor operation; E – operable but unnecessarily expensive.

In the software application is for each abbreviation assigned a numerical value – suitability for given application (0 – 100 %).

8.1. Guidelines for reboiler selection:

Process conditions	Reboiler Type			
	Kettle or Internal	Horizontal shell-side thermosyphon	Vertical tube-side thermosyphon	Forced Flow
Operating Pressure				
• Moderate	E	G	B	E
• Near critical	B-E	R	Rd	E
• Deep vacuum	B	R	Rd	E
Design ΔT				
• Moderate	E	G	B	E
• Large	B	R	G-Rd	E
• Small(mixture)	F	F	Rd	P
• Very small(Components)	B	F	P	P
Fouling				
• Clean	G	G	G	E
• Moderate	Rd	G	B	E
• Heavy	P	Rd	B	G
• Very Heavy	P	P	Rd	B
Mixture boiling range				
• Pure component	G	G	G	E
• Narrow	G	G	B	E
• Wide	F	G	B	E
• Very wide, with viscous liquid	F-P	G-Rd	P	B

8.2. Drawbacks of kettle type of reboilers

1. Extra piping and space
2. High cost
3. Fouls with dirty fluids
4. High residence time in heat zone for degradation tendency of some fluids
5. Low residence time surge section of reboiler

REFFERENCES:-

- LUDWIG, E. E. (1997) *Applied Process Design for Chemical and Petrochemical Plant*, Vol. 3, (june 13 th),3rd edn (Gulf), 156-174
- SINNOTT, R. K. (2005) *Chemical Engineering Design,* Vol. 6, 4th edn (Elsevier Butterworth-Heinemann), 750-755
- TREYBAL, Robert E. (1980) *Mass Transfer Operations,* 3rd edn(Mcgraw-Hill Internationals), 392-394
- SERTH Robert E.(1989): *Process Heat Transfer(Principles & Applications),* 6th edn(Trans Tech Publication),569-573
- *www.wikipedia.com*