

<p><b>KLM Technology Group</b></p> <p>Practical Engineering Guidelines for Processing Plant Solutions</p>	 <p><b>Engineering Solutions</b></p> <p><b>Consulting, Guidelines and Training</b></p> <p><a href="http://www.klmtechgroup.com">www.klmtechgroup.com</a></p>	<p>Page : 1 of 49</p>
		<p>Rev: 01</p>
	<p><b>Kolmetz Pocket Handbook</b></p> <p><b>Distillation Column Design</b></p>	<p>Rev 1 January 2026</p>
		<p>Co Author: Rev 1 Apriliana Dwijayanti</p> <p>Author / Editor Karl Kolmetz</p>

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4. **Pocket Handbooks**
5. **Unit Operations Manuals**
6. **Engineering Practice Magazine**
7. **Technical Articles**

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## INTRODUCTION

The purpose of this pocket handbook is to make readily available in a limited number of pages some of the more important distillation column system that are fundamental to the practice of the chemical engineering profession. The pocket handbook covers the basic elements in designing a typical distillation column system, which includes column internals selection and sizing.

The selection of column internals is discussed in this pocket handbook which is very critical in distillation column design. There is a wide variety of trays and packings in the market. Each design has its strengths and weaknesses. Some general considerations are depicted to aid engineers in making the right choice of column internals.

In general select trays for high pressure and packings for low pressure. A few equations that are commonly used in the industry are illustrated in this pocket handbook to estimate the minimum number of stages, the minimum reflux ratio of a column and determining the diameter of the tower. Some design heuristics are also highlighted. These rules are based on design experiences and take into account both the safety and economical factors.

### Process Equipment Design Flaws

Many groups of process equipment follow the “Kolmetz Universal Law of Project Stupidity”. A law strictly followed by most engineering and non-engineering projects.

“Save money and poorly design the process equipment by awarding it to the low-cost bidder. Loose money for the next twenty years on plant capacity, maintenance reliability, and excess energy.”

According to this law, awarding a process equipment contract to the lowest bidder may save you money in the short term, but it can cost you heavily in the long run. You may end up losing money for the next twenty years on plant capacity, maintenance reliability, and excess energy. So, next time you are tempted to cut corners, remember the Kolmetz Law of Project Stupidity.

Typically, process equipment is awarded to the lowest bidder with very low standards of guarantees. Typical guarantees by the manufacturers are hydraulic capacity only, and this test must be carried out within three to six months, while the process equipment is

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still clean and new. Typical process guarantees are by the process engineering company which includes capacity and purities, again the performance test must be carried out within three to six months.

Imagine buying a car and receiving a three-to-six-month warranty and only good gas mileage for the first six months. You would think the car manufacturer was taking advantage of you, yet this is what we do for heat exchangers, and cars are much more complex than heat exchangers.

Typically for distillation the cheapest trays are purchased, typically sieve deck trays, which have low capacity and efficiency. Then the tower must be taller and diameter larger due to the poor choice of internals. Kolmetz Law in action – we saved USD 50,000 on trays and spend USD 1.0 million on larger vessels, foundations and piping. Also add the higher energy cost and lower purities over 20 years maybe another USD 1.0 million. We saved USD 50,000 and lost 2.0 million.

What are things that should be included in process equipment design that are not being utilized because of the sweetheart guarantees and low-cost bidders.

1. KLM is a recognized expert in Process Equipment Design, only utilize groups with technical expertise. This guideline has sizing examples in the document and then in an excel spreadsheet.
2. KLM only partners with high quality suppliers, often from the same factories as the Original Equipment Manufacturers (OEM) and has senior inspectors to ensure your equipment is installed correctly
3. Ensure correct metallurgy. Do not use Stainless Steel in Acid or Caustic Solution Services as some Stainless Steel is not resistant to attack. Many vendors only supply stainless steel even though they know that this might be the wrong metallurgy for your application.
4. Review Galvanic Corrosion Potential for extended life. If you have polar liquids (water, acids, caustics) and a carbon steel vessel, stainless steel will experience bi-metallic corrosion with reduced life.

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5. Review the failures of the non-technical suppliers.

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## DISTILLATION

Distillation is by far the most important separation process in the petroleum and chemical industries. It is the separation of key components in a mixture by the difference in their relative volatility, or boiling points. It is also known as fractional distillation or fractionation.

In most cases, distillation is the most economical separating method for liquid mixtures. However, it can be energy intensive. Distillation can consume more than 50% of a plant's operating energy cost. There are alternatives to distillation process such as solvent extraction, membrane separation or adsorption process. On the other hand, these processes often have higher investment costs. Therefore, distillation remains the main choice in the industry, especially in large-scale applications.

Early distillation consisted of simple batch stills to produce ethanol. Crude ethanol was placed in a still and heated, and the vapor drawn from the still was condensed for consumption. Lamp oil was later produced using the same method, with crude oil heated in batch stills.

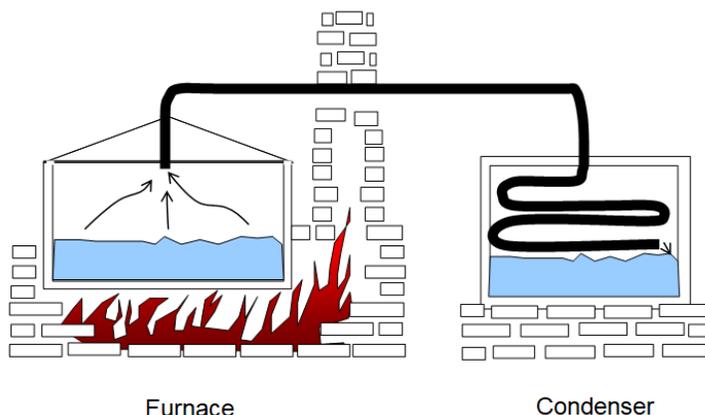


Figure 1 : Batch Still Distillation Process

Figure 2 shows a schematic diagram of an example distillation column or fractionator. The feed enters the column as liquid, vapor or a mixture of vapor-liquid. The vapor phase that travels up the column is in contact with the liquid phase that travels down. At the top of the column, vapor enters the condenser where heat is removed. Some liquid is returned to the column as reflux to limit the loss of heavy components overhead. At each separation stage (each tray or a theoretical stage in the packing), the vapor enters from the stage below at a higher temperature while the liquid stream enters from the stage

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above at a lower temperature. Heat and mass transfer occur such that the exiting streams (bubble point liquid and dew point vapor at the same temperature and pressure) are in equilibrium with each other.

Column distillation is divided two stages, there are rectifying stages and stripping stages.

(A) Rectifying Stages. The process above the feed tray is known as rectification (where the vapor phase is continually enriched in the light components which will finally make up the overhead product).

(B) Stripping Stages. The process below the feed tray is known as stripping (as the heavier components are being stripped off and concentrated in the liquid phase to form the bottom product).

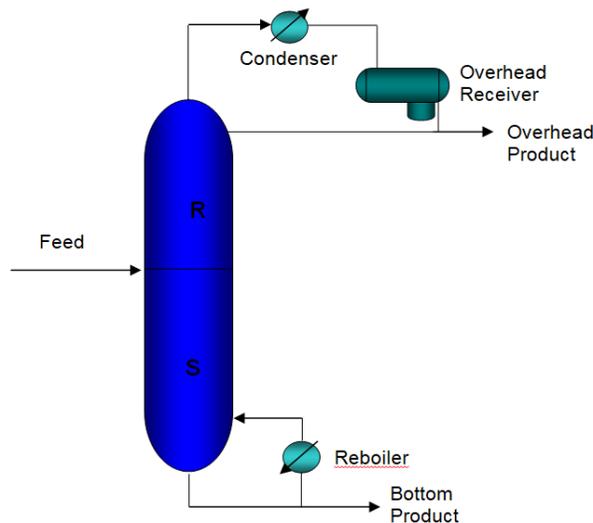


Figure 2 : Schematic Diagram of Distillation Column/ Fractionator

The condenser above the column can be either a total or partial condenser. In a total condenser (Figure 3a), all vapors leaving the top of the column is condensed to liquid so that the reflux stream and overhead product have the same composition.

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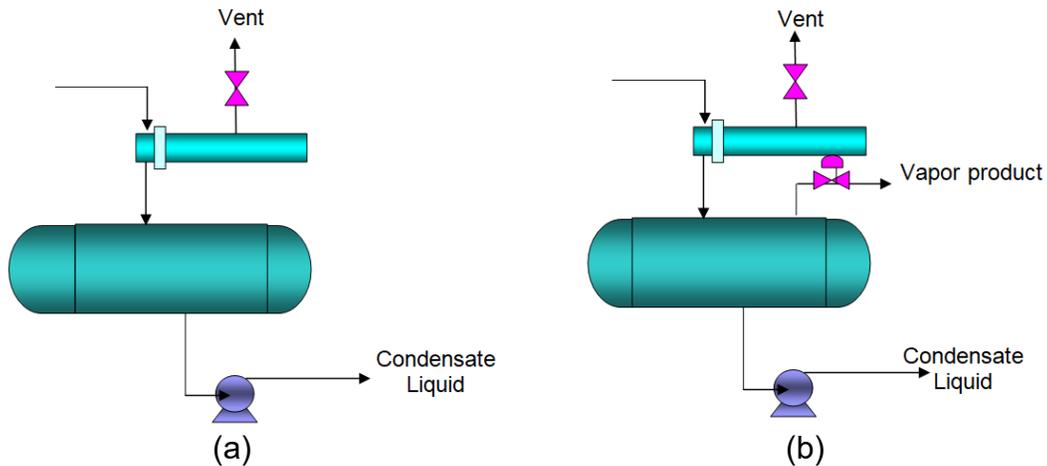


Figure 3 : Condenser type: (a) Total Condenser and (b) Partial Condenser

In a partial condenser (Figure 3b), only a portion of the vapor entering the condenser is condensed to liquid. In most cases, the condensed liquid is refluxed into the column and the overhead product drawn is in the vapor form. On the other hand, there are some cases where only part of the condensed liquid is refluxed. In these cases, there will be two overhead products, one a liquid with the same composition as the reflux stream while the other is a vapor product that is in equilibrium with the liquid reflux.

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## TYPES OF DISTILLATION PROCESSES

**Batch Distillation.** Batch distillation the feed to the column is introduced batch-wise. The column is first charged with a 'batch' and then the distillation process is carried out. When the desired task is achieved, the next batch of feed is introduced. Batch distillation is usually preferred in the pharmaceutical industries and for the production of seasonal products.

**Continuous Distillation.** Continuous distillation handles a continuous feed stream and capable of handling high throughputs. No interruption occurs during the operation of a continuous distillation column unless there is a problem with the column or surrounding unit operations. Besides, additional variations can be utilized in a continuous distillation column, such as multiple feed points and multiple product drawing points. Therefore, continuous columns are the more common of the two modes, especially in the petroleum and chemical industries.

**Extractive distillation.** In this type of process, an external solvent is added to the system to increase the separation. The external solvent changes the relative volatility between two 'close' components by extracting one of the components, forming a ternary mixture with different properties. The solvent is recycled into the system after the extracted component is separated from it.

**Dividing wall column (DWC).** DWC is thermally fully coupled, single-shell distillation column that allow the separation of a feed stream into three or more fractions and, respectively, products with high-purity streams. DWC actually incorporates two columns in the same shell, employing a dividing or partitioning wall that separates the feed side from the side product draw-off section. Therewith, the formation of entropy of mixing on the feed plate can be reduced and the energy requirement minimized accordingly. The dividing walls are made of thin, flat metal sheets, which are welded to the column shell and split the partitioned part of the column into two semicylindrical sections.

**Reactive distillation column.** The column may also have a catalyst bed and reaction occurring in it. The targeted component reacts when it is in contact with the catalyst, thereby separated from the rest of the components in the mixture.

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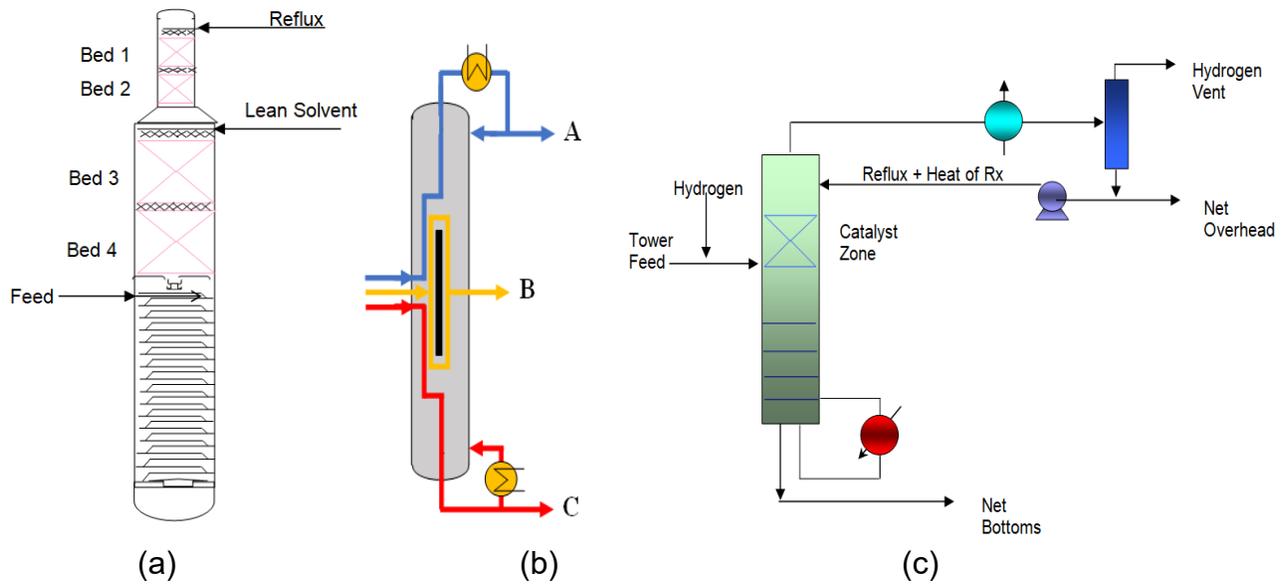


Figure 4 : (a) Extractive Distillation Column, (b) Divided Wall Column in one shell, and (c) Catalyst Distillation Column

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## DEFINITIONS

**Azeotrope**- Is a mixture of two or more pure compounds (chemicals) in such a ratio that its composition cannot be changed by simple distillation. This is because when an azeotrope is boiled, the resulting vapor has the same ratio of constituents as the original mixture of liquids.

**Bottoms** – The stream of liquid product collected from the reboiler at the bottom of a distillation tower.

**Bubble point** – The temperature at constant pressure (or the pressure at constant temperature) at which the first vapor bubble forms when a liquid is heated (or decompressed).

**Condenser**- Is a heat exchanger which condenses a substance from its gaseous to its liquid state.

**Dew point** – The temperature at constant pressure (or the pressure at constant temperature) at which the first liquid droplet forms when a gas (vapor) is cooled (or compressed).

**Distillate** – The vapor from the top of a distillation column is usually condensed by a total or partial condenser. Part of the condensed fluid is recycled into the column (reflux) while the remaining fluid collected for further separation or as final product is known as distillate or overhead product.

**Downcomer Area** - is the area available for the transport of liquid from one tray to the next tray below.

**Equation of state** – A relation between the pressure, volume and temperature of a system, from which other thermodynamic properties may be derived. The relation employs any number of 'constants' specific to the system. For example, for a pure component, the constants may be generalized functions of critical temperature, critical pressure and acentric factor, while for a mixture, mixing rules (which may be dependent on composition or density), are also used.

**Grid packing** - Systematically arranged packing use an open-lattice structure

**Heavy key** – The heavier (less volatile) of the two key components. Heavy key is collected at the bottoms. All non-key components heavier than the heavy key are known as the heavy components.

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**Key component** – A distillation column is assigned with two key components. The key components in the feed are the main components to be separated in that column. The volatility of the two key components must be in adjacent order when the volatilities of all the components in the feed are arranged in either ascending or descending order.

**K-value** – Vapor-liquid equilibrium constant or distribution coefficient. It is used in non-ideal (hydrocarbon) systems.

**Light key** – The lighter (more volatile) of the two key components. Light key is collected at the distillate. All non-key components lighter than the light key are known as the light components.

**Liquid distributor** – Equipment in packing column to maintaining a uniform flow of liquid throughout the column.

**Mass transfer** - The relative motion of species in a mixture due to concentration gradients.

**Open Area (or Hole Area)** - is the aggregate area available for vapor passage through the tray deck via perforations or valve and bubble cap slots. This is a critical factor in the tray operating range since high vapor velocity through the open area (hole velocity) will induce heavy liquid entrainment (as well as high pressure drop), but low hole velocity may allow liquid to "weep" or even "dump" through the tray deck to the tray below.

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

**Reflux ratio** – The ratio of the reflux stream to the distillate. The operating reflux ratio could affect the number of theoretical stages and the duties of reboiler and condenser.

**Relative volatility** – Relative volatility is defined as the ratio of the concentration of one component in the vapor over the concentration of that component in the liquid divided by the ratio of the concentration of a second component in the vapor over the concentration of that second component in the liquid. For an ideal system, relative volatility is the ratio of vapor pressures i.e.  $\alpha = P_2/P_1$

**Tray Pressure Drop** - may also be a limiting criterion particularly in low pressure services. The operating tray pressure drop is the sum of the dry pressure drop caused by the resistance to vapor flow through the tray open area and the head of clear liquid on the tray deck.

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**Tray Spacing** - is the vertical distance between adjacent tray decks. This effects both the height of spray that may be generated on the tray deck before liquid carryover and also the allowable head of liquid in the downcomers

**Vapor-liquid equilibrium-** Abbreviated as **VLE** by some, is a condition where a liquid and its vapor (gas phase) are in equilibrium with each other, a condition or state where the rate of evaporation (liquid changing to vapor) equals the rate of condensation (vapor changing to liquid) on a molecular level such that there is no net (overall) vapor-liquid interconversion

**Vapor pressure** – The pressure exerted by the vapor phase that is in equilibrium with the liquid phase in a closed system. For moderate temperature ranges, the vapor pressure at a given temperature can be estimated using the Antoine equation.

**Weir loading** – The normalized liquid flow rate leaving a tray pass divided by the length of the outlet weir of the same pass.

## NOMENCLATURE

B	Bottom product rate, moles/unit time	$V_{corr}$	Corrected vapor rate, moles/unit time
$b$	Bottoms product flow rate, ft <sup>3</sup> /min	$V_{max}$	Maximum volumetric flow rate, ft <sup>3</sup> /hr
C	Coefficient, ft/hr	$v_{max}$	Maximum velocity, ft/hr
CFS	Vapor loading, ft <sup>3</sup> /s	$R$	Reflux ratio
D	Distillate product rate, moles/unit time	$R_m$	Minimum reflux ratio
$D_T$	Tower diameter, ft	$S_F$	Separation factor,
$d$	Distillate flow rate, ft <sup>3</sup> /min	$T$	Temperature, °F
F	Feed rate, moles/unit time	$x$	Mole fraction in the liquid phase
$f_i$	Fugacity of component $i$	$X_B$	Bottom liquid rate, moles/unit time
H	Tower height, ft	$x_d$	Mole fraction in the distillate
$K$	Vapor-liquid equilibrium constant	$X_{Di}$	Mole fraction of component $i$ in the distillate
$L_o$	Reflux liquid, moles/unit time	$X_D$	Distillate liquid rate, moles/unit time
$L_S$	Liquid molar rate in the stripping section	$x_f$	Mole fraction in the feed
$N$	Number of theoretical stages	$X_{Fi}$	Mole fraction of component $i$ in the feed
$N_m$	Minimum number of theoretical stages	$x_w$	Mole fraction in the bottoms
$P$	Total system pressure, psi	$y$	Mole fraction in the vapor phase
$P^*$	Vapor pressure, psi		
Q	Reboiler duty, Btu/hr		
$Q_c$	Condenser duty, Btu/hr		
q	Thermal condition of feed		
$V_{calc}$	Calculated vapor rate, moles/unit time		

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**Greek letters**

- $\alpha$  relative volatility
- $\gamma$  activity coefficient
- $\phi$  vapor phase fugacity coefficient
- $\beta$  volatility factor
- $\rho$  density, lb/ft<sup>3</sup>

**Superscripts**

- L liquid phase
- V vapor phase

- b exponent

**Subscripts**

- avg average
- HHK heavy component
- HK heavy key
- i* component *i*
- j* component *j*
- LK light key
- LLK light component
- top top section of column

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