

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	  <a href="http://www.klmtechgroup.com">www.klmtechgroup.com</a>	Page : 1 of 82
		Rev: 03
		Rev 1 Feb 2007 Rev 2 April 2008 Rev 3 Feb 2011
KLM Technology Group #03-12 Block Aronia, Riverria Condovilla, Taman Tampoi Utama Jalan Sri Perkasa 2 81200 Johor Bahru Malaysia	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Author: Rev 1 Chew Yin Hoon Rev 2 Ai Li Ling Rev 3 Aprilia Jaya
		Checked by:  Karl Kolmetz

## TABLE OF CONTENTS

### INTRODUCTION

Scope	6
Distillation	7
Distillation History	7
Types of Distillation Processes	9
Mode of Operation	10
Column Internals	11
Types of Distillation Column	15
A. Tray Column	15
A.1 Tray Hydraulic	18
B. Packed Column	21
B.1 Packed Hydraulic	23
General Design Consideration	26
The Selection of Column Internals	28
<b>DEFINITIONS</b>	<b>34</b>

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 2 of 82
		Rev: 03
		Feb 2011

**NOMENCLATURES** 36

**THEORY**

**(A) Vapor-Liquid Equilibrium (VLE)** 38

(I) Ideal Behavior in Both Phases 38

(II) Liquid Phase Non-Idealities 39

(a) Local composition equations 40

(b) Activity coefficient estimation methods 40

(III) High-Pressure Systems 41

(a) Vapor fugacity coefficient, liquid activity coefficient 41

(b) Vapor and liquid fugacity coefficients 42

**(B) Phase Distribution** 42

(I) Incompressible liquid 43

(II) Negligible Poynting correction 43

(III) Vapor obeying the ideal gas law 43

(IV) Ideal liquid solution 44

(V) Other methods to determine *K*-values 44

**(C) Distillation Calculations** 45

(I) Product specifications 45

(II) Column operating pressure 45

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 3 of 82
		Rev: 03
		Feb 2011

(III) Operating Reflux Ratio and Number of Stages	47
(a) Minimum reflux ratio	48
(b) Minimum stages	49
(c) Number of actual theoretical stages	51
(IV) Tower Diameter	57
(a) Trayed columns	57
(b) Packed columns	60
(V) Efficiency Tower	65
(a) Trayed Efficiency	65
(b) HETP	68

#### **APPLICATION**

<b>Example 1: Determination of Theoretical Stages and Reflux Ratio</b>	70
<b>Example 2: Trayed Column Diameter Determination</b>	74
<b>Example 3: Packed Column Diameter Determination</b>	75
<b>Example 4: Trayed Column Efficiency Determination</b>	77
<b>Example 5: HETP Determination</b>	79

<b>REFERENCES</b>	81
-------------------	----

#### **SPECIFICATION DATA SHEET**

<b>Metric Unit</b>	82
<b>British Unit</b>	83

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 4 of 82
		Rev: 03
		Feb 2011

## CALCULATION SPREADSHEET

Tower Diameter Sizing- Trayed Column Spreadsheet.xls	84
Tower Diameter Sizing- Packed Column Spreadsheet.xls	85

## LIST OF TABLE

Table 1: Pressure drop in difference services	32
Table 2: Common temperature differences for difference types of medium in condenser and Reboiler.	45
Table 3: Packing Factors ( $F_p$ )	64
Table 4: Constant n for HETP Correlation	70

## LIST OF FIGURE

Figure 1: Batch Still Distillation Process	8
Figure 2: Still Distillation in Series	8
Figure 3: Extractive Distillation Column	9
Figure 4: Catalyst Distillation Column	10
Figure 5: Schematic Diagram of Distillation Column/ Fractionator.	10
Figure 6: Rectifying Stages	12
Figure 7: Stripping Stages	13
Figure 8: Total Condenser	14
Figure 9: Partial Condenser	14
Figure 10: Work of Tray	15
Figure 11: Types of Tray Distillation Column (a) Bubble Cap Tray, )b) Sieve Tray	

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 5 of 82
		Rev: 03
		Feb 2011

<b>(c) Valve Tray</b>	16
<b>Figure 12: Kind of Baffle Tray; (a) Shed Deck Tray, (b) Side to Side Tray, (c) Disk and Donuts Tray</b>	17
<b>Figure 13: Operating Region of Tray</b>	18
<b>Figure 14: Type of Downcomer</b>	21
<b>Figure 15: Types of Packed Column; (a) Random Packed Column, (b) Grid Packed Column, (c) Structured Packed Column</b>	22
<b>Figure 16: Operating Area of Packed Column</b>	23
<b>Figure 17: Stacked Packing to Support Random Packing</b>	32
<b>Figure 18: Orifice Type Distributor</b>	33
<b>Figure 19: Liquid Redistributors</b>	33
<b>Figure 20: Relationship between Reflux Ratio and Number of Stages</b>	45
<b>Figure 21: Application of McCabe-Thiele to VLE Diagram</b>	52
<b>Figure 22: Constructing of Operating Line for Stripping Section</b>	53
<b>Figure 23: Example of a Seven Stage Distillation</b>	54
<b>Figure 24: Erbar-Maddox Correlation of Stage Vs Reflux</b>	56
<b>Figure 25: Internal of Bubble-caps Trays Column</b>	56
<b>Figure 26: Souders-Brown Correlation for Approximation Tower Sizing</b>	59
<b>Figure 27: Valve Tray Column Diameter</b>	61
<b>Figure 28: Packed Column Pressure Drop Correlation</b>	62
<b>Figure 29: Internal of Packing Column</b>	63
<b>Figure 30: O'Connell Column Efficiency</b>	66

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 6 of 82
		Rev: 03
		Feb 2011

## INTRODUCTION

### Scope

This design guideline covers the basic element in designing a typical distillation column, which includes column selection and sizing.

In designing a distillation column, the thermodynamics of the vapor and liquid phases must be understood. The vapor-liquid equilibrium (VLE) determines the minimum number of stages required to achieve the degree of separation needed. The minimum reflux ratio also depends on the VLE data of the mixture.

A few equations that are commonly used in the industry are illustrated in this guideline to estimate the minimum number of stages and the minimum reflux ratio of a column based on the VLE data, such as the Fenske-Underwood equation. Some design heuristics are also highlighted. These rules are based on design experiences and take into account both the safety and economical factors.

The selection of column internals is very critical in distillation column design. There is a wide variety of trays and packing in the market. Each design has its strengths and weaknesses. However, the quotations from vendors are sometimes contradictory and confusing. This could lead to a wrong choice of column internal. Therefore, some general considerations are depicted to aid engineers in making the right choice of column internals.

A distillation column is sized by determining the diameter of the tower. An initial estimation of the tower diameter can be done based on the vapor and liquid loadings in the column.

Included in this guideline is an example of the data sheet used in the industry and a calculation spreadsheet for the engineering design.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 7 of 82
		Rev: 03
		Feb 2011

## 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.

## Distillation History

The history of distillation dated back to centuries ago. Forbes has chronicled the full history of distillation in 1948<sup>1</sup>. Reputedly, it was the Chinese who discovered it during the middle of the Chou dynasty. It was later introduced to India, Arabia, Britain and the rest of the world.

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.

The next progression in the history of distillation was to continually feed the still and recover the light product. Further advancements include placing the stills in series and interchanging the vapor and liquid from each still to improve recovery. This was the first type of counter-current distillation column that we have today.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>	Page 8 of 82
	<b>(ENGINEERING DESIGN GUIDELINES)</b>	Rev: 03
		Feb 2011

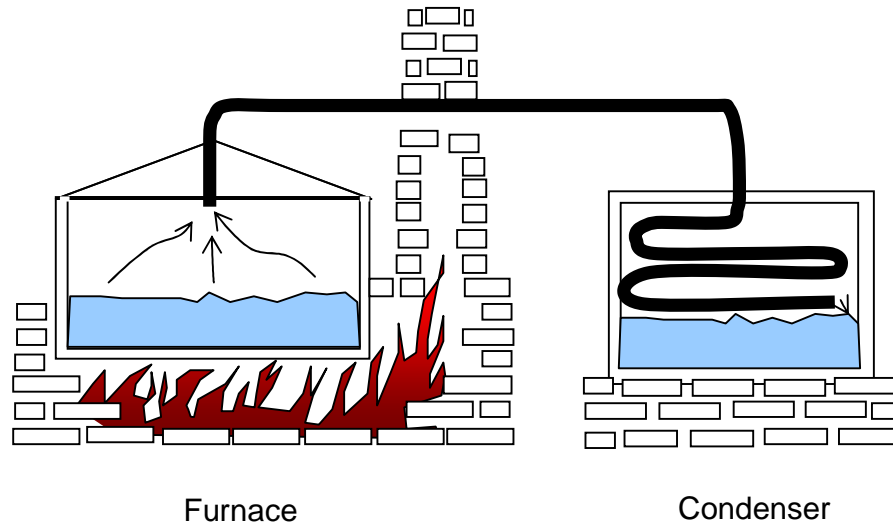


Figure 1: Batch Still Distillation Process

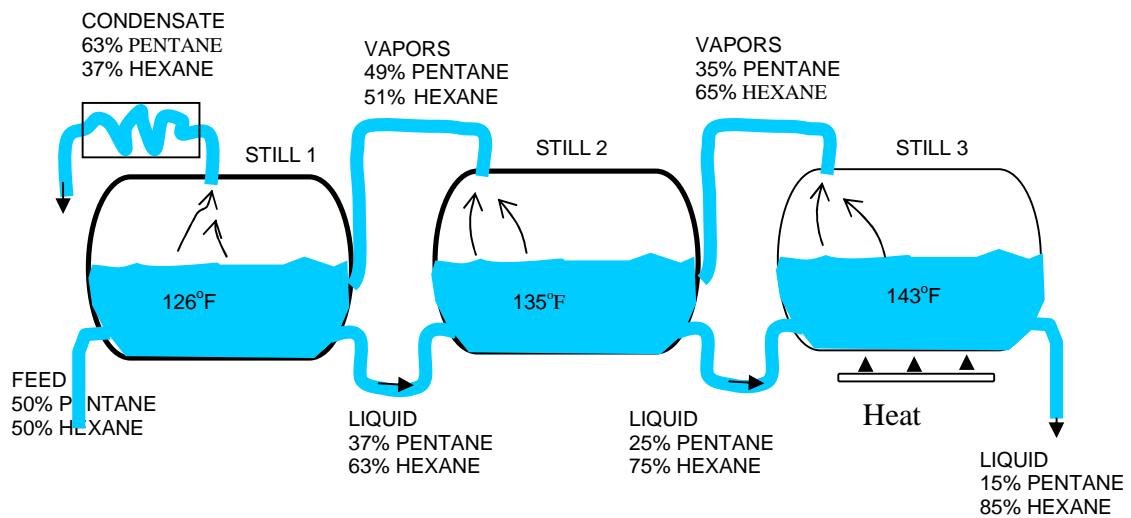


Figure 2: Still Distillation in Series

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.



<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 9 of 82
		Rev: 03
		Feb 2011

## Types of Distillation Processes

There are many types of distillation processes. Each type has its own characteristics and is designed to perform specific types of separations. These variations appear due to difficulty in separation when the physical properties of the components in a mixture are very close to one another, such as an azeotropic mixture.

One type of variation of the distillation processes is 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.

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

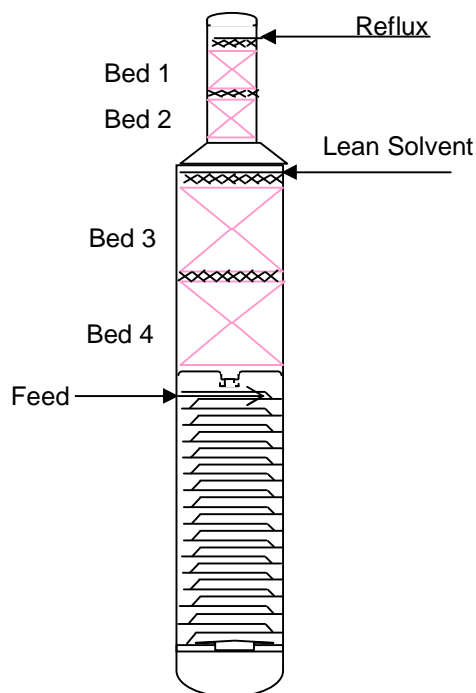


Figure 3: Extractive Distillation Column

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 10 of 82
		Rev: 03
		Feb 2011

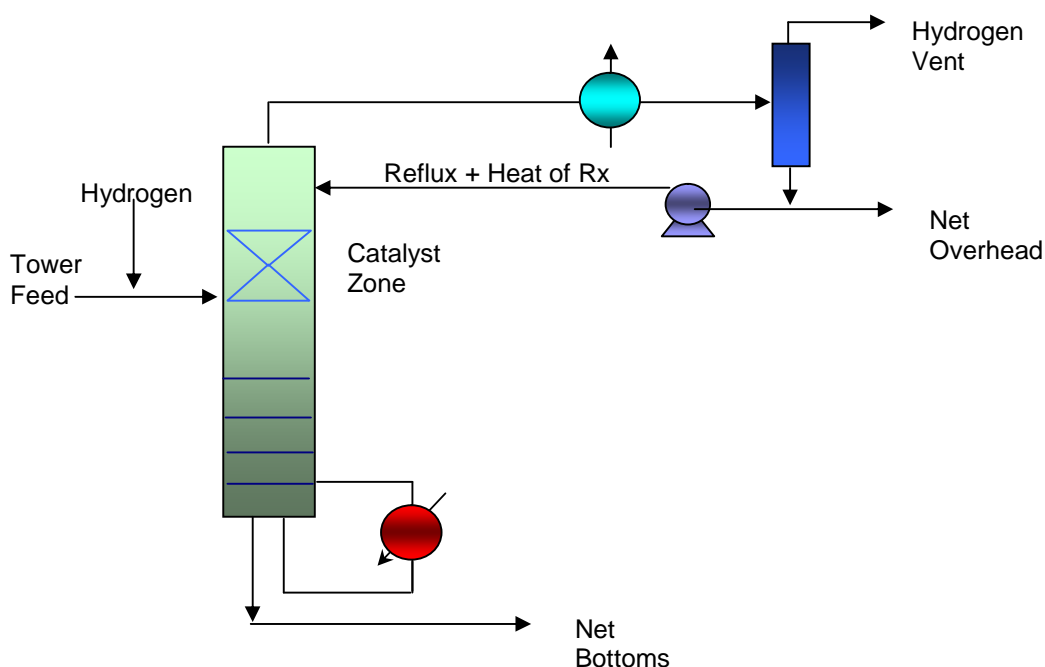


Figure 4: Catalyst Distillation Column

### Mode of Operation

Distillation towers can be classified into two main categories, based on their mode of operation. The two classes are batch distillation and continuous distillation.

In 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.

On the other hand, continuous distillation handles a continuous feed stream. No interruption occurs during the operation of a continuous distillation column unless there is a problem with the column or surrounding unit operations. Continuous columns are capable of handling high throughputs. 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.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 11 of 82
		Rev: 03
		Feb 2011

## Column Internals

Column internals are being equipped into distillation columns to provide better mass and heat transfers between the liquid and vapor phases in the column. These include trays, packings, distributors and redistributors, baffles and etc. They promote an intimate contact between both phases. The type of internals selected would determine the height and diameter of a column for a specified duty because different designs have various capacities and efficiencies. The two main types of column internals discussed in this guideline are trays and packing.

There are many types of trays or plates, such as sieve, bubble-cap and valve trays. Packing, on the other hand, can be categorized into random and structured packing. In random packing, rings and saddles are dumped into the column randomly while structured packing is stacked in a regular pattern in the column.

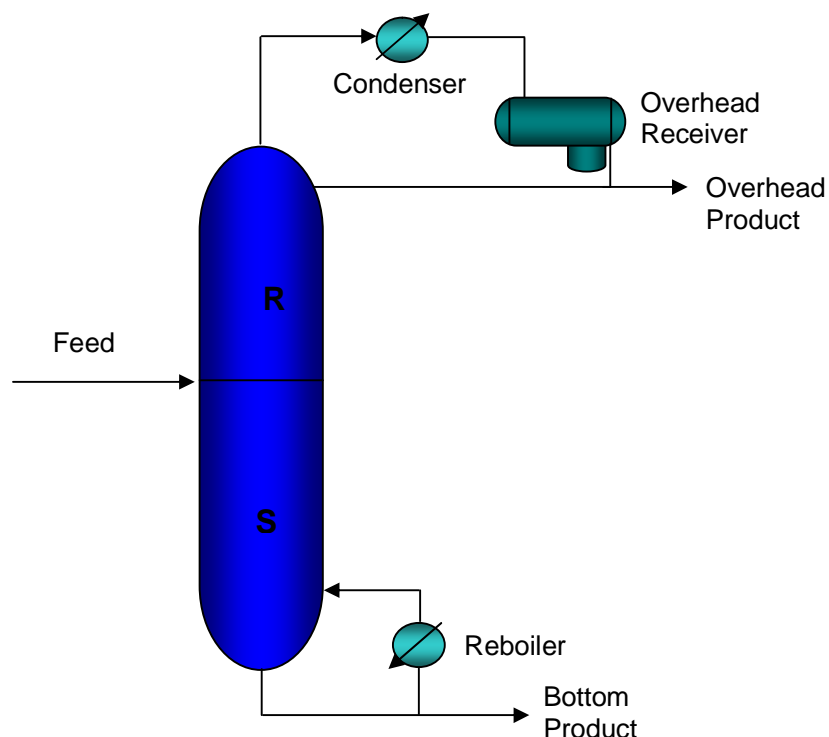


Figure 5: Schematic Diagram of Distillation Column/ Fractionator.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 12 of 82
		Rev: 03
		Feb 2011

Figure 5 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. Column distillation is divided into 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). A liquid recycle condenses the less volatile components from rising vapor. To generate the liquid recycle, cooling is applied to condense a portion of the overhead vapor into its name reflux.

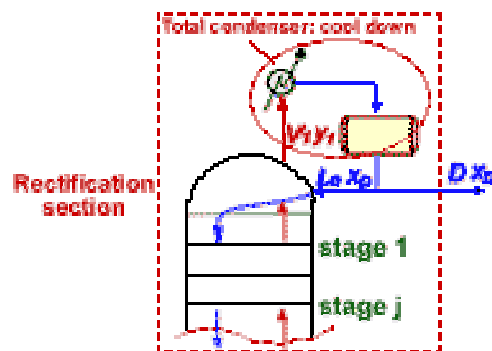


Figure 6: Rectifying stages

### (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). 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.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 13 of 82
		Rev: 03
		Feb 2011

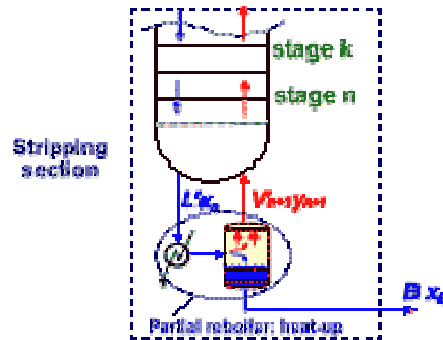


Figure 7: Stripping stages

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 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.

### (C) Condenser

The condenser above the column can be either a total or partial condenser. In a total condenser (Figure 8), all vapors leaving the top of the column is condensed to liquid so that the reflux stream and overhead product have the same composition. In a partial condenser (Figure 9), 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.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 14 of 82
		Rev: 03
		Feb 2011

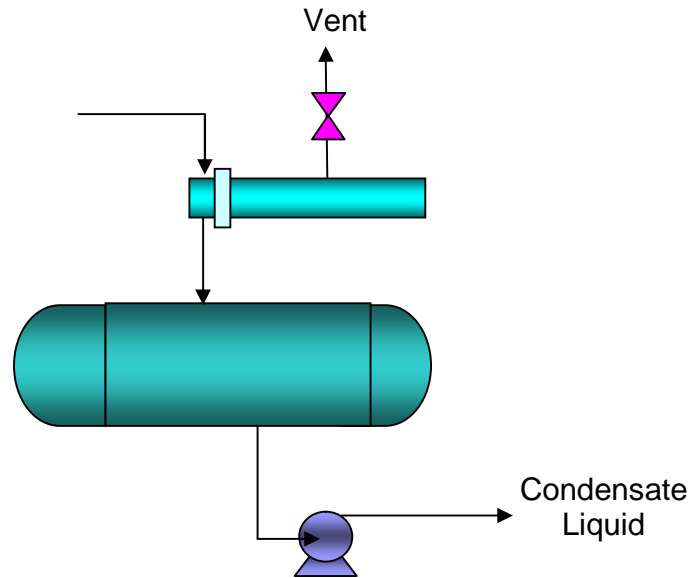


Figure 8: Total Condenser

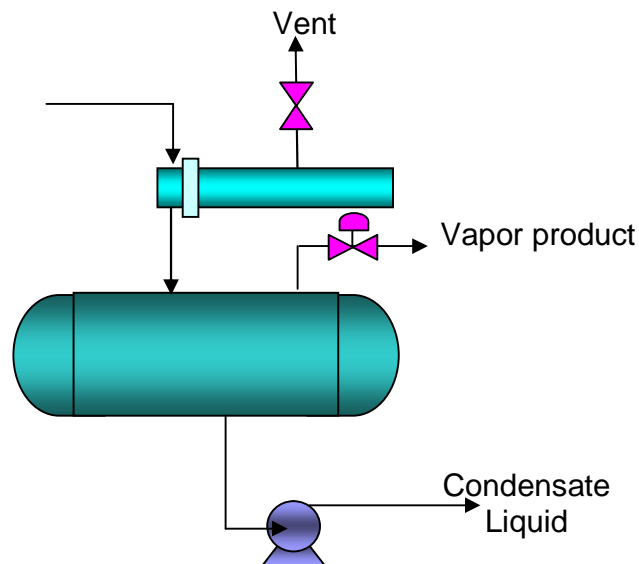


Figure 9: Partial Condenser

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 15 of 82
		Rev: 03
		Feb 2011

## Types of Distillation Column

There are many types of distillation column. Each type has its own characteristic and is designed to perform its efficiency

### A. Tray Column

Tray Columns utilize a pressure and temperature differential to separate the products. For most tray columns, the weir holds a liquid level of each tray. Liquid enters from the down-comer of the tray above. The vapor must overcome this liquid head to move up the column. On the tray the vapor and liquid are contacted becomes bubble or froth where the mass transfer takes place and then above the tray they are separated where froth flows over the outlet weir and vapor with the light volatile compound is disengaged.

Tray column performs well in high liquid and vapor loading. Tray have higher pressure drop than packed, and It also have high resistance to corrosion. There are five major types of tray column.

#### 1. Bubble Cap Tray

A bubble cap tray is perforated flat which has a riser (chimney) for each hole cover with a cap mounted. Usually equipped with slots to allow the passage of vapor then the vapor will contact with liquid forming bubble on the next tray. It is able to operate at low vapor and liquid rates (less than 2 gpm per foot of average of flow width).

#### 2. Sieve Deck Tray

Sieve deck tray is perforated plate with holes punched into the plate usually has holes 3/16 in to 1 in diameter. Vapor comes out from the holes to give a multi orifice effect. The vapor velocity keeps the liquid from flowing down through the holes (weeping). The number and hole size are based on vapor flow up the tower. The liquid flow is transported down the tower by down-comers, a dam and overflow device on the side on the plate. Sieve deck tray has a minimum capacity approximately 70%

#### 3. Dual flow tray

Dual flow is a sieve tray without downcomer. It designed with enough open area on the tray deck to eliminate stagnation and promote back missing. Vapor move up to the tray above through the hole while the liquid turn down in the same hole that result mal-distribution and low efficiency.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 16 of 82
		Rev: 03
		Feb 2011

#### 4. Valve Tray

Valve Tray is using valve which is rise as vapor rate increase and then reduce as vapor rate fails, this stop the liquid from weeping. Valve can be round or rectangular, with or without caging structured. Valve disk rise as vapor rate increase. Valve tray has minimum capacity approximately 60%.

#### 5. Baffle Tray

The down-comers require a disengaging area to separate the liquid from the vapor. This area requires a minimum distance that normally sets the tray spacing. The liquid is required to travel across the deck to the next down-comer. Baffle tray has three type's tray, there are Shed Decks, Side to Side Trays, Disk and Donuts Tray.

##### a. Shed Decks

Shed Deck trays are angle irons beam of various size from two to ten inches that are placed in rows across the column. The trays are rotated 90° from tray to tray to distributed vapor-liquid. It has 50% open area and make the efficiency is very low.

##### b. Side to Side Trays

Side to side tray is trays that allow the liquid to splash from side to side. The Vapor flowing upward through the curtain of liquid leaving the tray above. Liquid fouling potential is low as with efficiency.

##### c. Disk and Donuts Trays

Disk and donut trays are slightly sloped trays that allow the liquid to splash from inner circle ring to outer circle ring. Fouling potential of this tray is low along with the efficiency.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.



<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 17 of 82
		Rev: 03
		Feb 2011

## A.1 Tray Hydraulic

Tray design is combination theory and practice. Tray dimension are kept within the range of values known to give satisfactory performance. The basic requirements of a tray are that should:

1. Provide good vapor-liquid contact
2. provide sufficient liquid holdup for good mass transfer (high efficiency)
3. have sufficient area and spacing to keep the entrainment and pressure drop within acceptable limits
4. have sufficient downcomer area for the liquid to flow freely from tray to tray

Satisfactory operation will be achieved only over a limited range of vapor and liquid flow rates. In high vapor rate is the condition of flooding where pressure drop increases then make the efficiency decreases. Flooding condition can be achieved by the excessive carryover of liquid to the next tray. This kind of flooding is called entrainment or jet flooding. In low vapor rate is the weeping condition. Weeping occurs when the vapor flow is insufficient to maintain a level of liquid on the plate and if liquid rate is high in this condition, downcomer flooding can be achieved because the downcomer is not able to handle the high loading of liquid. The area between flooding and weeping is operation area.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 18 of 82
		Rev: 03
		Feb 2011

For both the vapor and liquid loading, lower and upper limits exist. Hydraulic mechanism should control these limits. The operating area of a column should be chosen by carefully considering these limitations. Below is discuss the hydraulic parameters to control the limitations.

### 1. The maximum vapor line

The maximum vapor line is defined by a maximum useful capacity line which is a function of the liquid rate or weir loading and has a slope downward as liquid rate increases. In a constant dry tray pressure drop, the minimum vapor line can be flat.

### 2. The maximum liquid line

The maximum liquid line is defined by the maximum allowable weir loading or a maximum allowable downcomer velocity which is a function of aeration going on into the top of the downcomer and be influenced by the vapor rate. In high vapor rate, the maximum liquid rate that can enter the downcomer top decreases. While as vapor rate increases, the minimum liquid load must increase to ensure that the liquid does not go spray regime.

### 3. Pressure drop

Capacity of tray depend on pressure gradient through the column, otherwise the vapor would not flow. This gradient is normally expressed in terms of pressure drop. Pressure drop controlled the path of vapor through the tray above and liquid flow. There are two main components to the pressure drop: the "dry tray" drop caused by restrictions to vapor flow imposed by the holes and slots in the trays and the head of the liquid that the vapor must flow through. When the dry tray pressure drop exceeds 20% of the available tray spacing, it result entrainment reaching the tray above. It is important especially when the tray spacing is small (less than 15 inches).

Tray have a higher pressure drop than packing, it can be imposed on tray design. Many designs need to operate at minimum potential pressure drop to:

- (a) Ensure the relative ensure the relative volatility stays high,
- (b) High temperature does not enhance fouling or polymerization,
- (c) Pressure limitations (i.e. discharging to atmosphere), and
- (d) Degradation of desired product.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 19 of 82
		Rev: 03
		Feb 2011

#### 4. Height of weir

The height of weir is responsible for the pressure drop and the separation efficiency of a tray. The height of weir depends on kind of tray. The weir height is determined by the requirement of the liquid depth on the tray which is controlled by the depth of seal over the vapor passage.

#### 5. Downcomer

The downcomer is a vertical channel that connects a tray with the next tray below which carries froth and creates residence time which helps the vapor disengage from the froth. The amount of froth in the downcomer is measured as downcomer froth backup which is a function of the pressure drop across the tray deck the froth level on the tray itself and any frictional losses in the downcomer and its clearance. Downcomer assist the froth generation improve efficiency. If the downcomer can not handle the liquid loading, downcomer flooding can be achieved that can reduce efficiency.

#### 6. Clear liquid height

The clear liquid height is the height is the height to which the aerated mass would collapse in the absence of vapor flow. Clear liquid height gives a measure of the liquid level on tray, and is used in efficiency, pressure drop, downcomer backup, weeping.

#### 7. Turndown

The turndown is the ratio of the normal operating vapor through put that usually at the excessive weeping limit. The normal operating throughput is a safe margin away from the relevant flooding limit.

### B. Packed Column

Packed column utilize packing to contact between the phases (liquid-vapor) on the surface. Packed column performs well at low pressure, low liquid and vapor loading that make packed column have the most efficient in these terms. At high flow parameters the capacity and efficiency can significantly reduce, also in heavy fouling applications and corrosive condition. Packed column has less pressure drop than tray column and it reduce foaming since generates thin films instead of fine droplets for mass and heat transfer. Packed column is divided by Random, Structured and Grid Packed Columns

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 20 of 82
		Rev: 03
		Feb 2011

which is generate a mass transfer area by providing a large surface area over (50%) which the liquid can transfer heat and mass to the vapor.

#### 1. Random Packed Column

Random packing is packing of specific geometrical shapes which are dumped into the tower and orient themselves randomly. Random packing has more risk than structured packing and less ability to handle maldistributed liquid.

#### 2. Structured Packed Column

Structure Packed column is crimped layers or corrugated sheets which is stacked in the column. Each layer is oriented at 70° to 90° to the layer below. Structured packed offers 30% capacities higher than random packed for equal efficiency up to 50% higher at the same capacity,

#### 3. Grid Packed Column

Grid packed column is systematically arranged packing use an open-lattice structure. This device is composed of panels that promote mass transfer and enhance entrainment removal. They have high open area, resulting in high capacity, low pressure drop, and high tolerance to fouling.

### B.1 Packed Hydraulic

Packed tower operated under vapor-liquid counter current conditions and becoming increasingly important in environmental protection technologies. Among these, packing has received the greatest attention owing to their good performance. That why the knowledge of the hydraulic characteristic are essential for design of packing tower to get the best optimizing performance of packing for maximizing theoretical stages per height of column, minimizing pressure drop per theoretical stage of separation, and maximizing the operating range of the column.

The operation area of packing is limited by the maximum loading which depend on the characteristic of phase, the type and geometry of the internal. Figure16 show the operating area of packed column.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 21 of 82
		Rev: 03
		Feb 2011

The upper limit is called flooding point and the lower limit dewetting point. Reaching the loading point, the down flowing liquid phases holdback by the up flowing gas phase result a higher liquid in the bulk and increase the gas pressure drop then gives the flooding point. It make the liquid can not flow downwards. While in the other side the vapor passes as single phase without contact to the liquid on the column. A strong segregation of the phases and a rapid increase of the pressure drop. Furthermore increase the loading and decrease of the efficiency

The area between loading point and flooding point is the operation area. The vapor can not pass the column without contact with liquid. Where the vapor is dispersed, some liquid is hold back. Because of high turbulence of both phases result a good mass transfer and high separation efficiency.

The lower limit is the minimum liquid flow or limit of wetting of the internals. With decreasing wetting of the internal, the mass transfer is reduced and separation efficiency of the column decreases. The lower limit is influenced by physical properties of the mixture to be separated as well as from material and geometry of the internals.

To control these limitations is used hydraulic mechanism. The study on hydraulic on packing included the pressure drop over the dry and wetted (irrigated) packing as well as dynamic (free draining) liquid hold up.

### 1. Pressure drop

The pressure drop is entirely by frictional losses through a series of opening and therefore is proportional to the square of the gas flow rate. In random packing, the opening are randomly sized and located, and pressure drop is due to expansion, contraction, and changes of direction. In structured packing, the openings are regular and uniform size and pressure drop is due to changes in direction.

If a packed with gas flow is wetted on the surface of the internal liquid films are produced. The downflowing liquid reduced the relative voids volume, the free are for passing vapor is reduced and the vapor pressure drop is increases. Increasing wetting density will increase the liquid below loading zone which independent from vapor velocity.

### 2. Liquid holdup

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 22 of 82
		Rev: 03
		Feb 2011

The liquid holdup is the fraction of liquid held up in packed column. The volume of liquid holdup volume is often needed for calculating packed bed support beam loadings as well as for determining how much liquid drains to the bottom of a tower when the vapor rate is stopped.

### 3. Liquid rate

At lower liquid rates, irrigation to the bed is poor result poor efficiency. When liquid is well distributed in the column result the minimum wetting rate of the packing. Below minimum wetting the falling liquid film breaks up, some of the packing surface unwets, and the efficiency drops. When liquid distributor is poor, it will take more liquid to wet the entire packing bed.

### 4. Vapor rate

When vapor rate increases, column operation moves into the loading region. Efficiency improves because of the greater liquid holdup, but this improvement is short-lived. As the flood point is approached, the efficiency passes through the maximum and the drops because of excessive entrainment. When vapor rate decreases, it will decrease pressure drop per theoretical stage, but will increase column diameter.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 23 of 82
		Rev: 03
		Feb 2011

## General Design Consideration

A tower design is normally divided into two main steps, a process design followed by a mechanical design. The purpose of the process design is to calculate the number of required theoretical stages, column diameter and tower height. On the other hand, the mechanical design focuses on the tower internals and heat exchanger arrangements.

Many factors have to be considered in designing a distillation column such as the safety and environmental requirements, column performance, economics of the design and other parameters, which may constrain the work.

The first step in distillation column design is to determine the separation sequences, which depends on the relative volatility and concentration of each component in the feed. King has outlined a few design rules as follows:

- 1) Direct sequences that remove the components one by one in the distillate are generally favored.
- 2) Sequences that result in a more equal-molar division of the feed between distillate and bottoms products should be favored.
- 3) Separations where the relative volatility of two adjacent components is close to unity should be performed in the absence of other components; ie, reserve such a separation until the last column in the sequence.
- 4) Separations involving high-specified recovery fractions should be reserved until last in the sequence.

Once the separation sequence is decided, engineering calculations follow to determine the number of theoretical stages, operating parameters and tower dimensions. In general, the steps included in distillation calculations are summarized into the following:

- 1) Performing a material balance for the column
- 2) Determining the tower operating pressure (and/or temperature)
- 3) Calculating the minimum number of theoretical stages using the Fenske equation
- 4) Calculating the minimum reflux rate using the Underwood equations

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 24 of 82
		Rev: 03
		Feb 2011

- 5) Determining the operating reflux rate and number of theoretical stages
- 6) Selection of column internals (tray or packings)
- 7) Calculating the tower diameter and height

The theoretical explanation and sample calculations of each step above are discussed in detail in later sections.

Some general design rules (from Cheresources.com) that should be considered are as follows:

- 1) Distillation is usually the most economical method of separating liquids.
- 2) For Ideal mixtures (low pressure, medium temperature, and non-polar), relative volatility is the ratio of vapor pressures i.e.  $\alpha = P_2/P_1$
- 3) Tower operating pressure is determined most often by the temperature of the available cooling medium in the condenser or by the maximum allowable reboiler temperature.
- 4) Tower Sequencing
  - A. Easiest separation first – least trays and reflux
  - B. When neither relative volatility nor feed concentrations vary widely, remove components one by one as overhead products.
  - C. When the adjacent ordered components in the feed vary widely in relative volatility, sequence the splits in order of decreasing volatility.
  - D. When the concentration in the feed varies widely but the relative volatilities do not, remove the components in the order of decreasing concentration in the feed.
- 5) Economically optimum reflux ratio is about 120% to 150% of the minimum reflux ratio.
- 6) The economically optimum number of stages is about 200% of the minimum value.
- 7) A safety factor of at least 10% above the number of stages by the best method is advisable.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.



<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 25 of 82
		Rev: 03
		Feb 2011

- 8) A safety factor of at least 25% about the reflux should be utilized for the reflux pumps.
- 9) Reflux drums are almost always horizontally mounted and designed for a 5 min holdup at half of the drum's capacity.
- 10) For towers that are at least 3 ft (0.9 m) in diameter, 4 ft (1.2 m) should be added to the top for vapor release and 6 ft (1.8 m) should be added to the bottom to account for the liquid level and reboiler return.
- 11) Limit tower heights to 175 ft (53 m) due to wind load and foundation considerations.
- 12) The Length/Diameter ratio of a tower should be no more than 30 and preferably below 20.
- 13) A rough estimate of reboiler duty as a function of tower diameter is given by:

$$Q = 0.5 D^2 \text{ for pressure distillation}$$

$$Q = 0.3 D^2 \text{ for atmospheric distillation}$$

$$Q = 0.15 D^2 \text{ for vacuum distillation}$$

Where,

$Q$  : Energy in Million Btu/hr

$D$  : Tower diameter in feet.

### The Selection of Column Internals

The selection of column internals has a big impact on the column performance and the maintenance cost of a distillation tower.

There are several choices of column internals and the two major categories are trays and packing. The choice of which to utilize depends on the

- 1) pressure,
- 2) fouling potential,
- 3) liquid to vapor density ratio,

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 26 of 82
		Rev: 03
		Feb 2011

- 4) liquid loading, and
- 5) most importantly the life cycle cost.

Trays can be divided into many categories, such as baffle trays, dual flow trays, conventional trays, high capacity trays, multiple downcomer trays and system limit trays. According to some rules of thumb, trays should be selected if:

- 1) the compounds contain solids or foulants
- 2) there are many internal transitions
- 3) liquid loads are high
- 4) there is a lack of experience in the service
- 5) vessel wall needs periodic inspection
- 6) there are multiple liquid phases

On the other hand, packing divisions include grid packing, random packing, conventional structured packing, and high capacity structured packing. The rules of thumb for selecting packing are:

- 1) the compounds are temperature sensitive
- 2) pressure drop is important (vacuum service)
- 3) liquid loads are low
- 4) towers are small in diameter
- 5) highly corrosive service (use plastic or carbon)
- 6) the system is foaming
- 7) the ratio of tower diameter to random packing is greater than 10

Some design guidelines should be considered when designing a tray tower, such as follows:

- 1) Constriction factor  
The constriction factor should not be less than 0.6. This parameter shall be checked only for the side downcomer.
- 2) Tray spacing.  
Overall column heights depend on tray spacing. Tray spacing should be from 18 to 24 inches, with accessibility in mind (Generally, for a tower diameter of 4 feet and above, the most common tray spacing is 24 inches to allow easy access for

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 27 of 82
		Rev: 03
		Feb 2011

maintenance. However, for a tower diameter below 4 feet, a tray spacing of 18 inches is adequate as the column wall can be reached from the manway.)

- 3) Peak tray efficiencies usually occur at linear vapor velocities of 2 ft/s (0.6 m/s) at moderate pressures, or 6 ft/s (1.8 m/s) under vacuum conditions.
- 4) A typical pressure drop per tray is 0.1 psi (0.007 bar). Max Dry pressure drop in height of hot liquid less than 16% of tray spacing.
- 5) Tray efficiencies for aqueous solutions are usually in the range of 60-90% while gas absorption and stripping typically have efficiencies closer to 10-20%
- 6) Sieve tray holes  
The generally vary are 0.25 to 0.50 in. diameter with the total hole area being about 10% of the total active tray area. Maximum efficiency is 0.5 in and 8%. that large holes are recommended for fouling and corrosive services and a spray regime.
- 7) Valve trays  
Valve tray typically has 1.5 in and 2 in. diameter holes each with a lifting cap. 12-14 caps/square foot of tray is a good benchmark. The disk typically rises 3/16 to 7/16 in above the tray deck and 10 % open area of fully open valves.
- 8) Weir height  
The most common weir heights are 2 to 3 in and the weir length is typically 75% of the tray diameter. For vacuum operation is recommended 0.25 to 0.5 in to reduce the pressure drop.
- 9) Weir loading  
The maximum recommended weir loading is 13 gpm/inch. At high weir loadings, trays will have high pressure drop, high froth height and potential downcomer limitations. At lower weir loading, picket fencing may be required.
- 10) Downcomer clearance  
It is recommended 1.5 in. At low liquid loading the clearance can be reduced to secure a proper distribution of the liquid on the active area, but lower than 1 in are not recommended. At high liquid loading the clearance can be increased up to the weir height to minimize the head loss and the jetting.
- 11) Downcomer velocity and residence time

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 28 of 82
		Rev: 03
		Feb 2011

The velocities is range from 0.1-0.7 ft/s, the maximum velocity needs to be low enough to prevent downcomer flooding. The minimum residence time is 3 s and the best residence time is 5 s. the residence time needs to be long enough to allow adequate vapor-liquid disengagement.

#### 12) Flow path length

The flow path length is measured from the downcomer exit to the outlet weir. Minimum size is typically 16 to 18 inches. High flow path length will enhance the efficiency while the low flow path length will increase weir load.

#### 13) Open area

Open area typically 0.04 to 0.15. lower values may result hydraulic limitation and mass transfer efficiency reduced while higher value result less the tray efficiency.

The packed tower design concepts are listed below:

- 1) Packed towers almost always have lower pressure drop compared to tray towers.
- 2) Packing is often retrofitted into existing tray towers to increase capacity or separation.
- 3) For gas flow rates of 500 ft<sup>3</sup>/min (14.2 m<sup>3</sup>/min), use 1 in (2.5 cm) packing, for gas flows of 2000 ft<sup>3</sup>/min (56.6 m<sup>3</sup>/min) or more, use 2 in (5 cm) packing.
- 4) Ratio of tower diameter to packing diameter should usually be at least 15
- 5) Due to the possibility of deformation, plastic packing should be limited to an unsupported depth of 10-15 ft (3-4 m) while metal packing can withstand 20-25 ft (6-7.6 m).
- 6) Liquid distributor should be placed every 5-10 tower diameters (along the length) for pall rings and every 20 ft (6.5 m) for other types of random packing.
- 7) For redistribution, there should be 8-12 streams per sq. foot of tower area for towers larger than three feet in diameter. They should be even more numerous in smaller towers.
- 8) Packed columns should operate near 70% flooding.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 29 of 82
		Rev: 03
		Feb 2011

9) Height Equivalent to Theoretical Stage (HETS) for vapor-liquid contacting is 1.3-1.8 ft (0.4-0.56 m) for 1 in pall rings and 2.5-3.0 ft (0.76-0.90 m) for 2 in pall rings.

11) Packing support is used to carry the weight of the wet packing while allowing free passage of the gas and liquid. Gas inlets are provided above the level where the liquid flows from the bed.

12) Liquid distributor is used to maintaining a uniform flow of liquid throughout the column. For small diameter columns, a central open feed pipe or one fitted with a spray nozzle may well be adequate.

13) Liquid redistributors

Redistributors are used to collect liquid that has migrated to the column walls and redistribute it evenly over the packing and also out any maldistribution. Liquid distributor combine with packing support and liquid distributor is shown in figure 19

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 30 of 82
		Rev: 03
		Feb 2011

## 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.

**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.

**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.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 31 of 82
		Rev: 03
		Feb 2011

**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.

**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.  $\alpha = P_2/P_1$

**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.

**Open area** - The ratio of the hole area divided by the bubbling area.

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 32 of 82
		Rev: 03
		Feb 2011

Constriction factor at the bottom downcomer - The ratio of the outlet weir length over the tower diameter.

**The downcomer clearance** - The distance between the bottom edge of the downcomer apron and the tray deck

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.



<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 33 of 82
		Rev: 03
		Feb 2011

## NOMENCLATURES

B	Bottom product rate, moles/unit time
$b$	Bottoms product flow rate, ft <sup>3</sup> /min
C	Coefficient, ft/hr
CFS	Vapor loading, ft <sup>3</sup> /s
D	Distillate product rate, moles/unit time
$D_T$	Tower diameter, ft
$d$	Distillate flow rate, ft <sup>3</sup> /min
F	Feed rate, moles/unit time
$f_i$	Fugacity of component $i$
H	Tower height, ft
$H_{BP}$	Enthalpy of bubble point feed stream, Btu/hr
$H_{VF}$	Enthalpy of vaporized feed stream, Btu/hr
$K$	Vapor-liquid equilibrium constant
$L_o$	Reflux liquid, moles/unit time
$L_R$	Liquid molar rate in the rectification section
$L_S$	Liquid molar rate in the stripping section
$N$	Number of theoretical stages
$N_m$	Minimum number of theoretical stages
$P$	Total system pressure, psi
$P^*$	Vapor pressure, psi
$Q$	Reboiler duty, Btu/hr
$Q_c$	Condenser duty, Btu/hr
$q$	Thermal condition of feed
$V_1$	Vapor rate at overhead column, moles/unit time
$V_{calc}$	Calculated vapor rate, moles/unit time
$V_{corr}$	Corrected vapor rate, moles/unit time
$V_{max}$	Maximum volumetric flow rate, ft <sup>3</sup> /hr
$v_{max}$	Maximum velocity, ft/hr
$R$	Reflux ratio
$R_m$	Minimum reflux ratio
$S_F$	Separation factor,
$T$	Temperature, °F
$x$	Mole fraction in the liquid phase
$X_B$	Bottom liquid rate, moles/unit time
$x_d$	Mole fraction in the distillate
$X_{Di}$	Mole fraction of component $i$ in the distillate
$X_D$	Distillate liquid rate, moles/unit time
$x_f$	Mole fraction in the feed

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	<b>Distillation Column Selection and Sizing</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 34 of 82
		Rev: 03
		Feb 2011

$X_{Fi}$  Mole fraction of component  $i$  in the feed  
 $x_w$  Mole fraction in the bottoms  
 $y$  Mole fraction in the vapor phase

### 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  
 bottom bottom section of column  
 HHK heavy component  
 HK heavy key  
 $i$  component  $i$   
 $j$  component  $j$   
 LK light key  
 LLK light component  
 top top section of column

This design guideline are believed to be as accurate as possible, but are very general not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.