

EFFECT OF REFLUX RATIO ON SEPARATION OF AZEOTROPIC MIXTURES IN  
BATCH DISTILLATION COLUMN

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## ABSTRACT

The purpose of this study is to investigate the effect of different reflux ratio on separation of azeotropic mixtures. The azeotropic mixtures used were Ethanol/Water, MTBE/Methanol and IPA/Water. The experimental studied were conducted using Bubble Cap Distillation with 10 numbers of stages at 1 atm. The composition of feed mixtures used were 40:60 v/v. In terms of reflux ratios it was set at 1.1, 1.2, 1.3 and 1.4. The product was collected from each experiment and analyzed using refractometer to determine its concentration. The standard curve of binary mixtures of each mixtures were used for quantifying the composition in the collecting samples. From the results obtained, best reflux ratio for Ethanol/Water is 1.1 (95.8%), 1.2 for IPA/Water ( 57.64 mol%) and 1.2 for MTBE/Methanol (47.57%). The results obtained were compared with the vapour composition of binary mixtures for ordinary distillation process which are without reflux ratio. By comparing the result with the data of the vapor composition for ordinary distillation, the best reflux ratio was determined. These binary mixtures cannot be separated completely by ordinary distillation because of closed boiling point between each component which formed the azeotrope. When two mixtures were mixed, the intermolecular attraction forces in all liquid may cause the mixture to form certain inseparable composition (where vapour and liquid composition) at equilibrium are equal. Further separation can be achieved by controlling the reflux ratio of the distillation process to improve the separation efficiency. This study verified that reflux ratio influence the efficiency of the column.

## ABSTRAK

Tujuan kajian ini ialah untuk mengkaji kesan nisbah refluks yang berbeza kepada pemisahan campuran-campuran azeotrop. Campuran azeotrop yang digunakan adalah Ethanol/Water, MTBE/Methanol dan IPA/Water. Kajian dijalankan menggunakan Penyulingan Berperingkat "Bubble Cap" dengan 10 nombor peringkat-peringkat pada 1 atm. Komposisi campuran-campuran masuk yang digunakan adalah 40:60 v/v. Dari segi nisbah refluks, ia telah diset pada 1.1, 1.2, 1.3 and 1.4. Produk yang diperolehi bagi setiap ujikaji dikumpulkan dan dianalisis dengan menggunakan refraktometer. Lengkungan piawai bagi setiap campuran binari telah digunakan untuk menentukan komposisi sampel yang telah dikumpulkan. Daripada keputusan-keputusan diperolehi, nisbah refluks terbaik bagi Ethanol/Water ialah 1.1 (95.8%), 1.2 untuk IPA/Water (57.64mol%) dan 1.2 untuk MTBE/Methanol (47.57%). Keputusan-keputusan ini telah dibandingkan dengan kandungan wap setiap campuran binari untuk proses penyulingan biasa iaitu tanpa nisbah refluks untuk menentukan nisbah refluks yang terbaik. Campuran binari ini tidak boleh dipisahkan oleh penyulingan biasa kerana penutupan takat didih antara setiap komponen yang membentuk azeotrop. Ketika dua campuran ini dicampurkan, kekuatan daya tarikan antara molekul dalam semua cecair boleh menyebabkan campuran untuk membentuk komposisi tertentu yang tak boleh dipisahkan (komposisi wap dan cecair) pada keseimbangan adalah sama. Pemisahan lebih lanjut dapat dicapai dengan mengawal nisbah beserta refluks daripada proses penyulingan untuk meningkatkan kecekapan pemisahan. Kajian ini ditentusahkan yang nisbah refluks mempengaruhi kecekapan lajur.

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**LIST OF ABBREVIATIONS**

D	Distillate Flow Rate
$X_D, Y_D$	Composition or Mole Fraction
B	Bottom Flow Rate
R, L	Reflux
L	Liquid Flow



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## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Introduction**

Distillation is defined as a process in which a liquid or vapor mixture of two or more substances is separated into its component fractions of desired purity, by the application and removal of heat (Tham, 2006). Distillation is the most widely used separation method in the chemical and petrochemical industries. Some environmental applications of distillation are the separation of organic solvent/water mixtures and water removal for volume reduction prior to disposal of hazardous waste mixtures (Richard and Patricia, 2004).

Distillation is an equilibrium-limited separation which uses heat as an energy-separating agent. It is applied when two or more relatively volatile liquids, that vaporize at different temperatures, need to be separated or fractionated into almost pure product streams. Distillation separates components of a liquid mixture based on their different boiling points. When the boiling points of the entering species are significantly different, distillation can easily separate the feed into almost pure product streams of each component. However, as the boiling points become closer, distillation requires a large number of equilibrium stages to perform the separation (Richard and Patricia, 2004).

The separation in a distillation process is governed by a difference in the composition of a liquid and vapor phase. The difference is usually characterized by a difference in actual vapor pressures, or volatilities, of the liquid-phase components (Richard and Patricia, 2004).

There are many types of distillation columns, each designed to perform specific types of separations, and each design differs in terms of complexity. One way of classifying distillation column type is to look at how they are operated whether in batch or continuous columns. In batch operation, the feed to the column is introduced batch-wise. That is, the column is charged with a batch and then the distillation process is carried out. When the desired task is achieved, a next batch of feed is introduced. In contrast, continuous columns process a continuous feed stream. No interruptions occur unless there is a problem with the column or surrounding process units. They are capable of handling high throughputs and are the most common of the two types (Tham, 2006).

In mixtures containing two or more components where their concentrations are compared in the vapor and liquid phase, concentrations of each component are often expressed as mole fractions. A mole fraction is number of moles of a given component in an amount of mixture in a phase divided by the total number of moles of all components in the amount of mixture in that phase. Binary mixtures are those having two components while three component mixtures could be called ternary mixtures (Richard and Patricia, 2004).

Commercially, distillation has a number of uses. It is used to separate crude oil into more fractions for specific uses such as transport, power generation and heating. Water is distilled to remove impurities, such as salt from seawater. The application of distillation can roughly be divided in four groups which are for laboratory scale, industrial distillation, distillation of herbs for perfumery and medicinals (herbal distillate), and food processing. The latter two are distinctively different from the former two in that in the processing of beverages the distillation is not used as a true purification method but more to transfer all volatiles from the source materials to the distillate (Richard and Patricia, 2004).

Because it is prevalent throughout industry, there are numerous advantages to distillation as a separation technology. The process flow sheets are relatively simple and no mass-separating agent is required. The capital costs are low as is the risk associated with lesser known technologies. There is an abundance of data describing vapor-liquid equilibrium for many systems. Usually, distillation can be designed

using only physical properties and vapor-liquid equilibrium (VLE) data, so scale-up is often very reliable (Richard and Patricia, 2004).

The primary disadvantage of distillation is its lack of energy efficiency. It is not a useful technique for systems containing an azeotrope or those with close boiling points. An azeotrope occurs when the vapor and liquid compositions of a system become identical such that, without altering the system, no further separation is possible. Distillation also cannot be applied to feed streams which are sensitive to thermal degradation or that polymerize at elevated temperatures. Operating the column under vacuum, however, can reduce or eliminate these problems (Richard and Patricia, 2004).

## **1.2 Problem Statement**

Industrial production of chemicals involves purification and recovery of the products, by-products and unreacted raw materials. Distillation is clearly the dominating separation process, accounting for more applications than all the others combined (extraction, adsorption, crystallization, membrane-based technologies and so forth). In fact, distillation columns consume more than 95% of the total energy used in separations in chemical process industries.

All liquid mixtures have forces of intermolecular attraction. That is why they form liquids and not gases. The molecular interactions when two or more components are mixed may cause the mixture to form certain “inseparable” compositions where the vapor and liquid compositions at equilibrium are equal within a given pressure and temperature range. These specific mixture compositions are called azeotropes. Azeotropy is not a rare phenomena in distillation. The existence of azeotropes complicates the structure of this operating envelope, and the resulting distillation behavior of multicomponent azeotropic mixtures may be very complex (Hilmen and Eva-Katrine, 2000).

Optimizing batch distillation operations can have a significant economic impact, especially when the separation of high value chemicals involved. The

control variable for optimizing a batch distillation product is the reflux ratio policy which is the variation of the reflux ratio with time. The alternative is to optimize the reflux ratio policy to maximize the amount of product with a specified composition in a given length of time or minimize the distillation time required to produce a given amount of product with a specified composition. The optimum operation of column is one that maximizes an overall objective function, such as annual profit (Fouad, 2005).

Reflux used to enhance the separation process. In simple terms, refluxing is causing the liquid to condense and re-evaporate in the column prior to finally exiting via the condenser. The number of times that cause the vapor to reflux before exiting the column is called the reflux ratio. Careful control of the reflux ratio through control of the heat input and the speed of cooling water allows you control over the purity of your distillate. Operating the column at a constant reflux rate results in a distillate with a continuously changing the composition. The composition profile over time is determined by the reflux rate and the distillate rate while the sharpness of the separation is determined by the reflux ratio. It is important to remember that a slower distillation by increasing the reflux ratio will result in a more pure finished product (Fouad, 2005).

### **1.3 Objective**

The main objective of this study is to investigate the effect of reflux ratio on separation of azeotropic mixtures.

#### 1.4 Scopes of Study

In order to achieve the objective, the scopes of study are set as follows:

- i. To perform separation of Ethanol/Water, MTBE/Methanol and IPA/Water using Bubble Cap Distillation with 10 numbers of stages at 1 atm.
- ii. To study the effect of difference reflux ratios at 1.1, 1.2, 1.3 and 1.4 to separation efficiency of azeotropic mixtures.

#### 1.5 Rationale and Significance

Distillation is one of the primary tools that chemists and chemical engineers use to separate mixtures into their constituents. Because distillation cannot separate the constituents of an azeotrope, the separation of azeotropic mixtures (azeotrope breaking) is a topic of considerable interest. Reflux Distillation, in contrast, offers a very high degree of purity. This is because a longer column is used, where many of the components will not reach the top of the column.

As vapor rises in the distillation column, the temperature gradually decreases. This causes components with higher boiling points to reach a certain level in the column where they fall below their vaporization temperature, condense back into liquid, and descend in the column. This separates these components from the vapor with a lower boiling point as it continues to rise in the column. Each component separates from the rising vapor in this manner until, at the top of the column, have a single remaining product.

Nowadays, Ethanol, MTBE and IPA are the chemicals that usually used in industry and will involve separation process to get the purest product. But, mixtures of this chemicals with certain chemicals will form an azeotrope which can stop the separation process. This happened because of the effect of many factors and can be adjusted to encounter this problem. Reflux ratio is chosen to minimize the running

costs of the column. The total running cost consists of the cost of the reboiler steam and condenser cooling water plus the capital costs (interest) on the money spent building the column.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Distillation

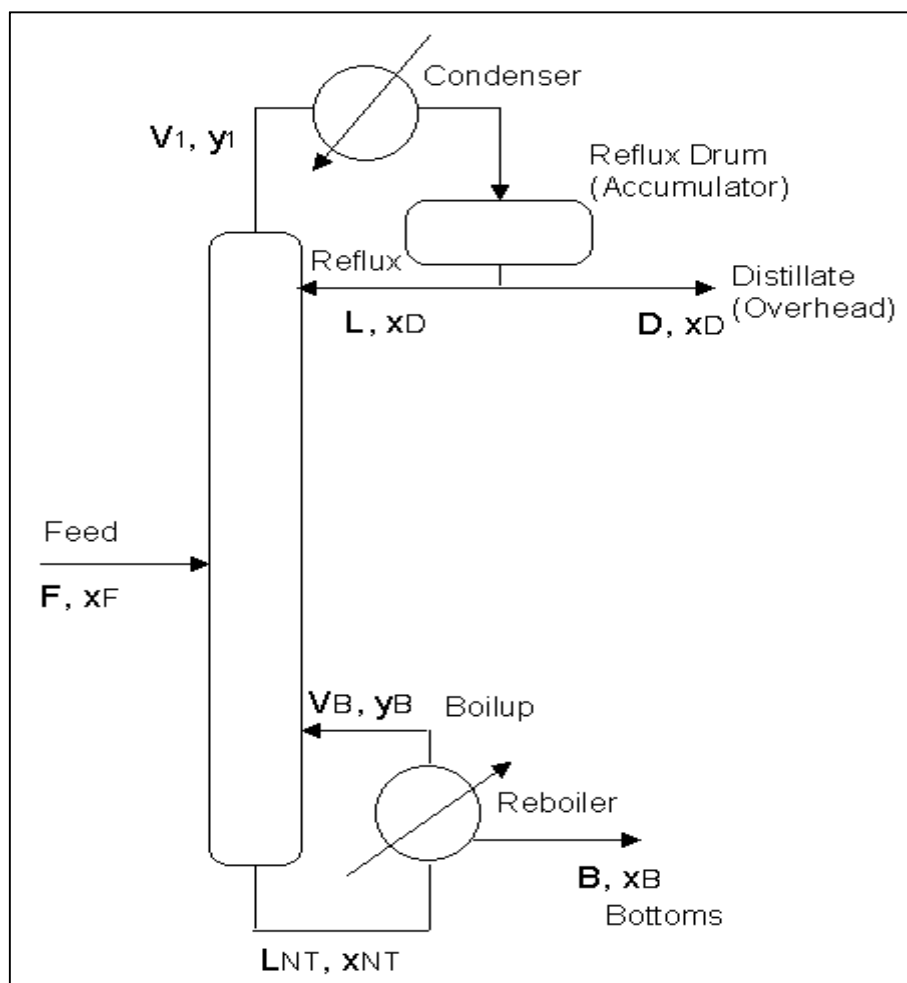
Distillation is the most widely used separation process in the chemical industry. It is also known as fractional distillation or fractionation. It is normally used to separate liquid mixtures into two or more vapor or liquid products with different compositions. Distillation is defined as a process in which a liquid or vapour mixture of two or more substances is separated into its component fractions of desired purity, by the application and removal of heat (Tham, 2006). The separation requires that a second phase be formed so that both liquid and vapor phases are present and can contact each other on each stage within a separation column, the components have different volatilities so that they will partition between the two phases to different extents and the two phases can be separated by gravity or other mechanical means (Seader and Ernest, 2006).

Distillation is an equilibrium stage operation. In each stage, a vapor phase is contacted with a liquid phase and mass is from vapor to liquid and from liquid to vapor. The less volatile (heavy or high boiling) components concentrate in the liquid phase and the more volatile (light) components concentrate in the vapor. By using multiple stages in series with recycle, separation can be accomplished (Price, 2003).

The feed to a distillation column may be liquid, vapor, or a liquid-vapor mixture. It may enter at any point in the column, although the optimal feed tray location should be determined and used. More than one stream may be fed to the system, and more than one product may be drawn. A column is divided into a series



of stages. These correspond to a cascade of equilibrium stages. Liquid flows down the column from stage to stage and is contacted by vapor flowing upward. Traditionally, most columns have been built from a set of distinct trays or plates, so these terms end up being essentially interchangeable with stages. Each tray in a distillation column is designed to promote contact between the vapor and liquid on the stage. Stages may be numbered from top down or bottom up (Price, 2003).



**Figure 2.1:** Distillation Column Schematic Diagram

As illustrated in Figure 2.1, the product leaving the top of the column are called the overhead product, the overhead, the top product, the distillate and also distillate product. Distillate product may be liquid or vapor (or occasionally both) depending on the type of condenser used. Most of the time the distillate flow rate is assigned the symbol  $D$ , and the composition  $X_D$  or  $Y_D$ . The product leaving the bottom of the column are called the bottom product or bottoms and given the symbol

B, with composition  $X_B$ . Vapor leaving the top of the column passes through a heat exchanger, the condenser, where it is partially or totally condensed. The liquid which results is temporarily held in the accumulator or reflux drum. A liquid stream is withdrawn from the drum and returned to the top tray of the column as reflux (R or L) to promote separation (Price, 2003).

The portion of the column above the feed tray is called the rectification section. In this section, the vapor is enriched by contact with the reflux. The portion of the column below the feed tray is called the stripping section. The liquid portion of the feed serves as the reflux for this section. The operating pressure of the column is typically controlled by adjusting heat removal in the condenser. There are two main categories of condenser, differentiated by the extent of condensation. In the total condenser, all of the vapor leaving the top of the column is condensed and the composition of the vapor leaving the top tray is the same as that of the liquid distillate product and reflux,  $X_D$ . But, the vapor is only partially liquefied and the liquid produced is returned to the column as liquid, and a vapor product stream is removed in a partial condenser (Price, 2003). A total condenser is used to obtain saturated liquid reflux and liquid distillate at a bubble-point temperature (Seader and Ernest, 2006). The base of the column is typically used as a reservoir to hold liquid leaving the bottom tray. A heat exchanger, the reboiler, is used to boil this liquid. The vapor which results, the boilup (V) is returned to the column on one of the bottom three or four trays (Price, 2003).

In normal operation, there are five handles that can be adjusted to manipulate the behavior of a distillation column which are the feed flow, two product flows, the reflux flow and the boilup flow (or reboiler heat input). A normal column has a temperature gradient and a pressure gradient from bottom to top. Distillation is based on the fact that the vapour of a boiling mixture will be richer in the components that have lower boiling points. Therefore, when this vapour is cooled and condensed, the condensate will contain more volatile components. At the same time, the original mixture will contain more of the less volatile material. Distillation columns are designed to achieve this separation efficiently (Tham, 2006).

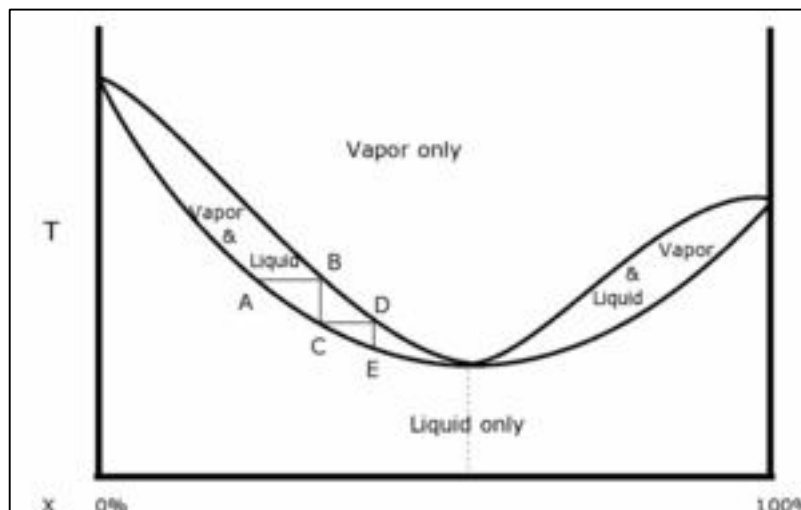
Distillation have the important aspects that seem to be missed from the manufacturing point of view which are it is the most common separation technique,

it consumes enormous amounts of energy (both in terms of cooling and heating requirements) and it can contribute to more than 50% of plant operating costs. The best way to reduce operating costs of existing units, is to improve their efficiency and operation via process optimization and control. To achieve this improvement, a thorough understanding of distillation principles and how distillation systems are designed is essential (Tham, 2006).

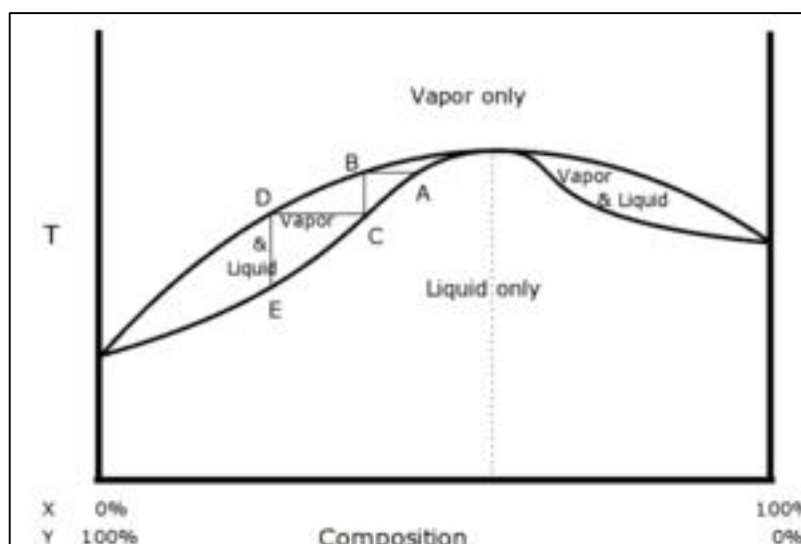
## **2.2 Azeotrope**

An azeotrope is a mixture of two or more chemicals where the equilibrium vapor and liquid compositions are equal and cannot be changed by simple distillation at a given temperature and pressure. More specifically, the vapor has the same composition as the liquid and the mixture boils at a temperature other than that of the pure chemicals' boiling point (Hilmen, 2000). Departures from Raoult's Law frequently manifest themselves in the formation of azeotropes, particularly for mixtures of close-boiling point species of different chemical types whose liquid solutions are nonideal (Seader and Ernest, 2006).

Azeotropes are formed by liquid mixtures exhibiting maximum or minimum boiling points. These represent, respectively, negative or positive deviations from Raoult's Law. Vapor and liquid compositions are identical at the azeotropic composition, thus all  $K$ -values are 1 and no separation of species can take place. If only one liquid phase exists, the mixture forms a homogeneous azeotrope while if more than one liquid phase is present, the azeotrope is heterogeneous. Heterogeneous azeotropes are always minimum boiling mixtures because activity coefficients must be significantly greater than 1 to cause splitting into two liquid phases (Seader and Ernest, 2006).



**Figure 2.2:** Phase Diagram of A Positive Azeotrope  
(<http://en.wikipedia.org/wiki/Azeotrope>)



**Figure 2.3:** Phase Diagram of A Negative Azeotrope  
(<http://en.wikipedia.org/wiki/Azeotrope>)

The term azeotropy was introduced to designate mixtures characterized by a minimum or maximum in the vapor pressure under isothermal conditions, or equivalently with an extremal point in the boiling temperature at constant pressure. This term has been used for liquid systems forming one or several azeotropes. The mixture whose composition corresponds to an extremal point is called an azeotrope. Systems which do not form azeotropes are called zeotropic (Hilmen, 2000).

### 2.3 Separation of Azeotropic Mixture

Separation of azeotropic mixtures is a topic of great industrial importance and distillation is the dominating unit operation for such separations. Most liquid mixtures of organic components form nonideal systems. The presence of some specific groups, particularly polar groups (oxygen, nitrogen, chlorine and fluorine), often results in the formation of azeotropes (Hilmen and Katrine, 2000). However, the presence of azeotropes and non-idealities in the phase behaviour of such mixtures complicates the separation.

In the pharmaceutical and fine/specialty chemical industry, the small-scale production and the requirement for flexibility indicates batch distillation as the best suited process. Among, various techniques to enhance distillation, heterogeneous azeotropic (heteroazeotropic) distillation is a very powerful and widely used one. Thus, there is a need for deeper understanding of the complex behaviour of the separation of heteroazeotropic mixtures in batch distillation columns (Skouras and Efstathios, 2004).

An azeotrope cannot be separated the constituents of an azeotrope by ordinary distillation since no enrichment of the vapor phase occurs at this point (Hilmen, 2000). Therefore, the separation of azeotropic mixtures involve the other methods by introducing an additional agent, called entrainer. Entrainer will affect the volatility of one of the azeotrope constituents more than another and will form a ternary azeotrope. But, the use of entrainer might cause unwanted impurity in the product and side streams because azeotropic distillation is a very energy-consuming process (Veerle *et.al*, 2004).

Azeotropic mixtures may often be effectively separated by distillation by adjusting the reflux ratio of the system (Hilmen and Katrine, 2000). To be able to develop separation processes for azeotropic mixtures, there is a need for insight into the fundamental phenomena of azeotropic phase equilibria. The vapor-liquid envelope of the equilibrium temperature surfaces defines the feasible operating region in which any real distillation process must operate.

## 2.4 Characteristic of Azeotropic Mixtures

In this research, three binary mixtures which are Ethanol/Water, MTBE/Methanol and IPA/Water are investigated. The following are the characteristic of these binary azeotropic mixtures.

### 2.4.1 Ethanol/Water Mixture

Ethanol also called ethyl alcohol is a volatile, flammable and colorless liquid. Ethanol is a straight chain alcohol and its molecular formula is  $C_2H_5OH$ . Its empirical formula is  $C_2H_6O$ . An alternative notation is  $CH_3-CH_2-OH$ , which indicates that the carbon of a methyl group ( $CH_3-$ ) is attached to the carbon of a methylene group ( $-CH_2-$ ), which is attached to the oxygen of a hydroxyl group ( $-OH$ ). It is a constitutional isomer of dimethyl ether. Ethanol is often abbreviated as EtOH, using the common organic chemistry notation of representing the ethyl group ( $C_2H_5$ ). Ethanol has boiling point temperature at  $78.4^\circ C$  while water has boiling point temperature at  $80^\circ C$ . Mixtures of ethanol and water form an azeotrope at approximately 89 mole% ethanol and 11 mole% water or a mixture of about 96 volume% ethanol and 4% water at normal pressure and temperature (351 K). This azeotropic composition is strongly temperature and pressure dependent and vanishes at temperatures below 303 K. Ethanol is slightly more refractive than water, having a refractive index of 1.36242 (at  $\lambda=589.3$  nm and  $18.35^\circ C$ ) (<http://en.wikipedia.org/wiki/Ethanol>).

### 2.4.2 MTBE/Methanol Mixture

Methyl tert-butyl ether, also known as methyl tertiary butyl ether and MTBE, is a chemical compound with molecular formula  $C_5H_{12}O$ . MTBE is a volatile, flammable and colorless liquid that is immiscible with water. MTBE has a minty odor vaguely reminiscent of diethyl ether, leading to unpleasant taste and odor in

water. MTBE is used inorganic chemistry as a relatively inexpensive solvent with properties comparable to diethyl ether but with a higher boiling point and lower solubility in water. MTBE has boiling point temperature at 55.2°C while water and methanol have boiling point temperature at 80°C and 64.7°C respectively. MTBE forms azeotropes with water at 52.6°C, 96.5% MTBE and methanol at 51.3°C, 68.6% MTBE ([http://en.wikipedia.org/wiki/Methyl\\_tert-butyl\\_ether](http://en.wikipedia.org/wiki/Methyl_tert-butyl_ether)).

### 2.4.3 IPA/Water Mixture

Isopropyl alcohol (also propan-2-ol, 2-propanol and also IPA) is a common name for isopropanol, a colorless and flammable chemical compound with a strong odor. It has the molecular formula  $C_3H_7OH$  and is the simplest example of a secondary alcohol, where the alcohol carbon is attached to two other carbons. It is an isomer of propanol. Isopropyl alcohol has boiling point temperature at 82°C while water has boiling point temperature at 80°C. Isopropyl alcohol and water form an azeotrope and simple distillation gives a material which is 87.9% by weight isopropyl alcohol and 12.1% by weight water ([http://en.wikipedia.org/wiki/Isopropyl\\_alcohol](http://en.wikipedia.org/wiki/Isopropyl_alcohol)).

## 2.5 Parameters Affecting Column Performance

### 2.5.1 Reflux Ratio

The reflux ratio,  $R$ , is a key variable in the performance of a distillation column. The reflux ratio is the ratio of the liquid flow,  $L$  in the rectifying section to the distillate flowrate. The gradient of the rectifying section operating line is a function  $(R/R+1)$  of the reflux ratio (Richard and Patricia, 2004). Reflux ratio will control the product purity and determine the energy which is required in reboiler and can affect the separation efficiency. By controlling the speed of boil, it can affect the purity of the product and can be improved by slowing the boil. The composition profile over time is determined by the reflux rate and the distillate rate. The lightest

component starts at its highest value, followed by concentration peaks of components with descending volatility. The sharpness of the separation is determined by the reflux ratio. Since, the reflux rate is limited by hydraulics considerations, higher reflux ratios would require lowering the distillate rate, thus lengthening the distillation cycle (Fouad, 2005).

For a given separation, increasing the reflux ratio will increase the gradient of the rectifying operating line and move its intercept with the y-axis downwards, moving it away from the equilibrium line and therefore decreasing the number of stages required to achieve the separation. Alternatively for a fixed number of stages (real column) adjusting the reflux ratio will control the purity of the distillate, the higher the reflux ratio the purer the distillate (Richard and Patricia, 2004). There is an inverse relationship between the reflux ratio and the number of theoretical stages. For a new design, of course the reflux ratio and number of theoretical stages can both be varied to achieve an optimum balance.

For an existing column, the number of trays used is fixed, hence higher distillate concentration (mole fraction,  $X_D$ ) can only be obtained by increasing the reflux ratio. The effect of reflux ratio on column performance may also be inspected using enthalpy-composition diagram. As the reflux ratio is increased, the gradient of operating line for the rectification section moves towards a maximum value of 1. Physically, what this means is that more and more liquid that is rich in the more volatile components are being recycled back into the column. Separation then becomes better and thus less trays are needed to achieve the same degree of separation. Minimum trays are required under total reflux conditions, there is no withdrawal of distillate (Fouad, 2005).

On the other hand, as reflux is decreased, the operating line for the rectification section moves towards the equilibrium line. The 'pinch' between operating and equilibrium lines becomes more pronounced and more and more trays are required. This is easy to verify using the McCabe-Thiele method. The limiting condition occurs at minimum reflux ratio, when an infinite number of trays will be required to effect separation. Most columns are designed to operate between 1.0 to 1.5 times the minimum reflux ratio because this is approximately the region of



minimum operating costs (more reflux means higher reboiler duty) (Seader and Ernest, 2006).

### **2.5.2 Feed Conditions**

The state of the feed mixture and feed composition affects the operating lines and hence the number of stages required for separation. It also affects the location of feed tray. During operation, if the deviations from design specifications are excessive, then the column may no longer be able handle the separation task. To overcome the problems associated with the feed, some column are designed to have multiple feed points when the feed is expected to containing varying amounts of components (Tham, 2006).

### **2.5.3 Column Diameter**

Most of the above factors that affect column operation is due to vapour flow conditions, either excessive or too low. Vapour flow velocity is dependent on column diameter. Weeping determines the minimum vapour flow required while flooding determines the maximum vapour flow allowed, hence column capacity. Thus, if the column diameter is not sized properly, the column will not perform well. Not only will operational problems occur, the desired separation duties may not be achieved (Tham, 2006).

### **2.5.4 State of Trays and Packings**

The actual number of trays required for a particular separation duty is determined by the efficiency of the plate, and the packings if packings are used. Thus, any factors that cause a decrease in tray efficiency will also change the performance of the column. Tray efficiencies are affected by fouling, wear and tear

and corrosion and the rates at which these occur depends on the properties of the liquids being processed. Thus appropriate materials should be specified for tray construction (Tham, 2006).

### **2.5.5 Feed Tray Position**

As the feed stage is moved lower down the column, the top composition becomes less rich in the more volatile component while the bottoms contains more of the more volatile component. However, the changes in top composition is not as marked as the bottoms composition. It should not be used to generalise to other distillation systems, as the effects are not straightforward (Tham, 2006).

### **2.5.6 Weather Conditions**

Most distillation columns are open to the atmosphere. Although many of the columns are insulated, changing weather conditions can still affect column operation. Thus the reboiler must be appropriately sized to ensure that enough vapour can be generated during cold and windy spells and that it can be turned down sufficiently during hot seasons. The same applies to condensers (Tham, 2006).

These are some of the more important factors that can cause poor distillation column performance. Other factors include changing operating conditions and throughputs, brought about by changes in upstream conditions and changes in the demand for the products. All these factors, including the associated control system, should be considered at the design stages because once a column is built and installed, nothing much can be done to rectify the situation without incurring significant costs (Tham, 2006).