

# **PLANT DESIGN FOR THE MANUFACTURE OF STYRENE**

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Technology degree in Chemical Engineering

By

**B. SANTHOSH NAIDU (Reg. No. 37190015)**



**DEPARTMENT OF CHEMICAL ENGINEERING**

**SCHOOL OF BIO AND CHEMICAL ENGINEERING**

## **SATHYABAMA**

**INSTITUTE OF SCIENCE AND TECHNOLOGY  
(DEEMED TO BE UNIVERSITY)**

**Accredited with Grade "A" by NAAC JEPPIAAR  
NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119**

**APRIL – 2021**



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DEPARTMENT OF CHEMICAL ENGINEERING

## **BONAFIDE CERTIFICATE**

This is to certify that this Project Report is the bonafide work of B. **SANTHOSH NAIDU (37190015)** who carried out the project entitled "**PLANT DESIGN FOR THE MANUFACTURE OF STYRENE**" under our supervision from on February, 2020 to April, 2021.

Internal Guide

Dr. S. SATHISH M.E., Ph.D;

Head of the Department

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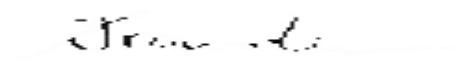
Submitted for Viva voce Examination held on \_\_\_\_\_

Internal Examiner

External Examiner

## **DECLARATION**

I **B. SANTHOSH NAIDU** (Reg.No.37190015) hereby declare that the Project Report entitled "**PLANT DESIGN FOR THE MANUFACTURE OF STYRENE**" done by me under the guidance of Dr. S.SATHISH M.E.,Ph.D .,at Sathyabama institute of science and technology, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Chemical Engineering



**SIGNATURE OF THE CANDIDATE**

**DATE:**  
**PLACE:**  
**CHENNAI**

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I am pleased to acknowledge our sincere thanks to Board of Management of **SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

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I would like to express my sincere and deep sense of gratitude to our Project Guide **Dr. S.SATHISH.,(M.E.,Ph.D.,)** **Department of Chemical Engineering** for his valuable guidance, suggestions and constant encouragement paved way for the successful completion of our project work.

I wish to express my thanks to all Teaching and Non-teaching staff members of the Department of Chemical Engineering who were helpful in many ways for the completion of the project.

## ABSTRACT

The production of styrene is a 28billions dollar industry worldwide. There is a significant demand for it and cutting costs even a few cents per pound will yield large saving. These savings can then be passed to the consumer and will ultimately make styrene products (like polystyrenes and ABS polymers) available to more people worldwide. We believe it is feasible to simulate a process for producing styrene that will make this possible. The idea is to use cheaper raw materials, namely ethane instead of ethylene, and utilize the fundamentals of the process, such as a dehydrogenation unit, to convert the ethane to ethylene in the process. An advantage to the new process is that it starts with a less expensive raw material, ethane instead of ethylene.

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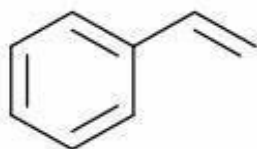


## CHAPTER 1

### INTRODUCTION

The project is intermediate for preparation of manufacture of styrene. In 1839 the German apothecary Eduard Simon isolated a volatile oil from the resin (called storax or styrax) of the American sweetgum tree (*Liquidambar styraciflua*). He called the oil "Styrol"(now styrene). He also noticed that when Styrene was exposed to air, light or heat, it gradually transformed into a hard rubber-like substance, which he called "Styrolxyd" (Styrol oxide, now "polystyrene"). By 1845, the German chemist August Hofmann and his student John Blyth (1814-1817) had determined Styrol's empirical formula  $C_8H_8$ . They had also determined that simons Styrolxyd which they renamed Metastyrol at the same empirical formula as styrol.

The modern method for production of styrene by dehydrogenation of ethylbenzene was first achieved in the 1930s. The production of styrene increased dramatically during the 1949s. When it was used as a feedstock for synthetic rubber. Because styrene is produced on such a large scale ethylbenzene is in turn prepared on a prodigious scale.



**Figure 1.1 Styrene Structural Formula**

Styrene is a colourless oily liquid that evaporates easily and has a sweet smell, although high concentration will have a less pleasant odour, melts at -306 degree C. Post -World War period witnessed a boom in styrene demand due to its application in the manufacture of synthetic rubber. This led to a dramatic increase in styrene capacity. Styrene has wide application in producing plastic and synthetic rubber industry. It is mostly used in manufacturing of polystyrene, acrylonitrile-butadiene-styrene. Styrene, acrylonitrile, styrene-butadiene rubber and latices, unsaturated polyester resins and miscellaneous uses like textile auxiliaries, pigment binders polyester resin, aromatic and intermediate industries.

Styrene was isolated in the 19<sup>th</sup> century from distillation of storax. Although styrene was known to polymerize no commercial applications were attempted for many years because the polymers was brittle and cracked easily. The simultaneously development of process

the manufacture of styrene the dehydrogenation of ethylbenzene by Dow chemical and company and BASF represented the breakthrough in styrene technology. In 1937 both these companies were manufacturing a high purity monomer which could be polymerized to a stable clear colourless plastic. During world war 2 styrene become important in the manufacturing of synthetic rubber and large scale plants were built. Later Peace time uses styrene based plastics especially crystalline and high impact polystyrene have accounted for its continuing rapid growth

### 1.1 PROPERTIES OF STYRENE:

- Styrene is a volatile highly flammable compound. Styrene is a clear colourless oily liquid is a member of a series of unsaturated aromatic monomers.
- Styrene vapours are heavier than air. At concentration normally encountered in the work place the air and styrene mixtures is not significantly heavier than clean air.
- Styrene evaporates more rapidly at high temperatures. The evaporation rate at 30 degree C is twice that at 20degree C.
- Styrene can be smelled at very low concentrations. Prolonged exposure to styrene reduces a person ability to smell it.
- Styrene liquid is soluble in body fat and can be absorbed through the skin. However studies have shown that the styrene present in polyester resin is not easily absorbed through the skin. Inhalation is therefore the major route of exposure.
- All sources of ignition must be removed from areas where these materials are used and stored other safety measure include.

Uses of sparking ventilation fans and electrical equipment and no smoking permitted

- Resins and liquid styrene should be stored in cool dry well area out of direct sunlight and in a part of the workspace from the production area.
- Styrene when released into soil can decompose by 95% in up to 16 weeks trace amount can still be detected even two years after fact
- The short half life of styrene in air and surface water can range from 2.5 to 9 hours.

## **1.2 APPLICATIONS OF STYRENE:**

Styrene will continue to be a top 50-growth chemical due to its many uses and economical potential. As the number of plants in production continues to increase, so does the need to regulate styrene production and disposal. Even though environmental and physical effects can be devastating without regulation the inherent benefits of styrene are visible.

### **STYRENE PLASTICS:**

Plastic based on resins made by the polymerization of styrene or co-polymerization of styrene with other unsaturated compounds the begin in greatest amount by weight.

Styrene plastics are easy to process and offer excellent price and perform ratios. Polystyrene is used everywhere as packaging materials or containers. In the construction industry it is used to produce pipe products, tanks, lighting fixtures, insulation and various corrosion resistant and rubber products.

### **STYRENE RUBBER PLASTICS:**

Composition based on rubbers and styrene plastics the styrene plastic begin in greatest amount by weight.

### **ACRYLONITRILE BUTADINE STYRENE(ABS):**

Plastic containing polymers or blends of polymers or both in which the maximum butadiene content is 6% the minimum acrylonitrile content is 15% the minimum styrene or substituted content or both is 15% and the maximum content all other monomers is not more than 5% plus lubricants stabilizers and colorants. Styrofoam is kind of plastic a polymer made of styrene molecules. The polymer and the entrapped gas interface with heat flow through the material. Then it shows an insulating property

### **STYRENE IN FOOD PACKAGING:**

The performance and price factor of polystyrene makes it ideal for using it as a packaging material. To prevent the food from spoiling as well as protect it from damage during transport storage as well as through the process of sale and all of this while maintaining the hygiene. Various blends with allow solutions to be produced for applications. These includes films, trays and cups.

### **STYRENE IN HOME:**

Used in a broad variety of kitchen application both as a primary material of construction as well as for component use. The inner things of fridges and freezers are typically made of products such as ABS or HIPS where toughness chemical resistance and stiffness are all required for items such as microwaves cookers and extraction units for

cooking styrene plastics are more likely to be just as a component such as buttons and dials.

#### STYRENE IN MEDICINE:

Many vaccines must be maintained at low temperatures. Easy enough when you have a freezer but a big challenge when your task is transport a batch of vaccines to another continent in tropical elements. The thermal insulation properties of expanded polystyrenes maintain the required temperature inside the sealed package for 72 hours. In hospital settings single use food service materials are the preferred option and the sanitary qualities of polystyrene single serve containers are a primary benefit of polystyrene food packaging and service material for hospital use.

#### STYRENE IN TRANSPORTATION:

The convenience and safety you enjoy in driving your car as well as the benefits of lorry transport aircraft and construction machinery all depend on styrene. Styrene based plastic materials are not only used in the automotive industry for their use easy process ability or the reduction of the vehicle assembly time and cost help achieve. Styrene is also used to give better road hugging ability especially on wet roads.

#### STYRENE IN SYSTEMS:

Toughness heat scratch impact resistance smart surface finish creative design cost effectiveness these are the qualities of styrene plastics. One of the world leaders in computer design and manufacture of a conducted case study on the need to combine in their product top quality easy of manufacture of cost effectiveness. In making their decision the manufacture considered ABS key environmental performance attributes including energy conversion ease of disassembly of materials and recyclables of components and materials.

#### STYRENE IN REFRIGERATION:

Polystyrene tailored properties and easy processing combined with its unbeatable cost effectiveness make it ideal material for use in refrigeration equipment. Whether for superb high gloss surface or for any of the wide variety of accessories inside the refrigeration the properties of polystyrene are equal to the task. Matt or coloured transparent or opaque.

## **CHAPTER 2**

### **LITERATURE SURVEY**

#### **2.1 MANUFACTURING PROCESS AND SELECTION:**

Many different techniques have been investigated for the manufacture of styrene monomer. The following methods have been used or seriously considered for commercial production

Dehydrogenation of ethyl benzene;

Oxidation of ethyl benzene to ethyl benzene hydro peroxide, which reacts with propylene oxide after which the alcohol is dehydrated to styrene.

Oxidative conversion of ethylbenzene to phenyl ethanol via acetophenone and subsequent dehydration of alcohol.

Side-chain chlorination of ethylbenzene followed by dichlorination.

Pyrolysis of petroleum recovery from various petroleum process

The first two methods are only two commercial utilized routes to styrene production was practiced by Union-Carbide Corporation but later replaced with a dehydrogenation process. Manufacture of styrene directly from petroleum streams is difficult and costly. The two commercial important routes to styrene are based on ethyl benzene production by alkylation of benzene and ethylene. Research programs aimed at replacing expensive benzene and ethylene feed stocks with less costly alternatives have been carried out by a number of companies.

#### **2.2 PROCESS DESCRIPTION:**

The fresh ethylbenzene is mixed with the recycled ethylbenzene then it is mixed with steam and is fed to the primary and secondary dehydrogenation reactors. When steam exists the re-heater as a cool product it is then released to super heat steam is used for heating the mixture for the reaction in the secondary dehydrogenation reactor as well. These dehydrogenation reactors are designed to have low pressure and an even flow distribution. The dehydrogenation reactors are designed to have low pressure and even flow distribution. The reactors liquid waste is divided and condensed which then enters a vent gas compressor which further minimized pressure drop. This process has three

distillation towers that operate to reduce polymer formation to have low temperature and to operate vacuum conditions.

### **2.3 CATALYTIC DEHYDROGENATION OF ETHYLBENZENE:**

The majority of industrial production of styrene follows from the dehydrogenation of ethylbenzene. This dehydrogenation process involves the catalytic reaction of ethylbenzene. Fresh ethyl benzene is mixed with a recycle steam and vaporised. Steam is then added before feeding the effluents into a train 2-4 reactors. This process involves a highly endothermic reaction carried out in a vapour phase over a solid catalyst. Steam is used to provide heat of this reaction to prevent excessive coking or carbon formation to shift equilibrium of the reversible reaction towards the product and to clean the catalyst of any carbon that does form. The reactors run adiabatically in multiple reactors with steam added before each stage with typical yields of 88-94%.

Crude styrene from reactors is then fed into a distillation train. Because of the possibility of polymerization of styrene during distillation small residence time avoidance of high temperature and addition of inhibitor are necessary. The reaction is carried out at 600-650 Degree C with a contact time of about second between the feedstock and the catalyst.

### **2.4 REACTIONS:**

The process is favourable because the process reaction is equilibrium limited.

With the addition of the process can be controlled more over steam is recycled. So this process is economical.

Around 85% styrene is producing this process in industrial scales.

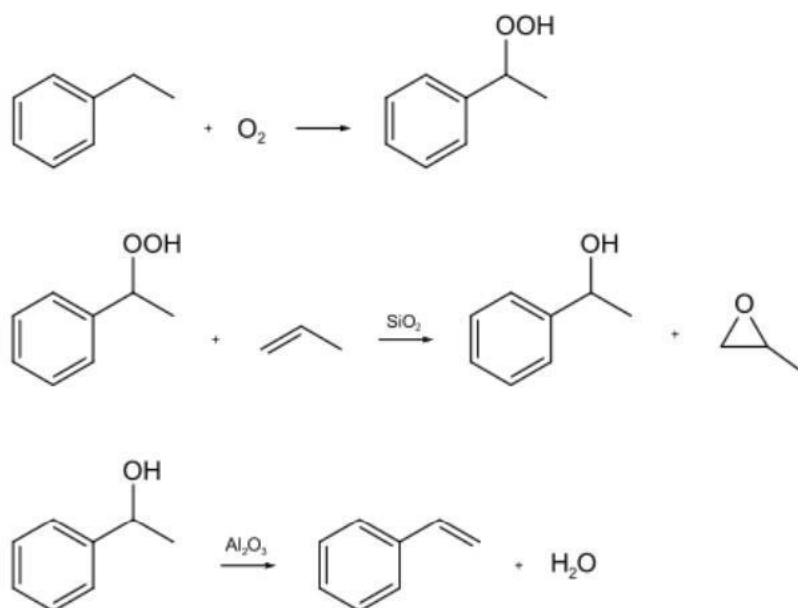
The best process to produce styrene Catalytic dehydrogenation of ethyl benzene. This process is primary commercialize process for production of styrene about 85% of the industrial process. Ethyl benzene is reacted with catalyst usually iron oxide ( $\text{Fe}_3\text{O}_4$ ). This process reaction is equilibrium limited and with the addition of steam the process can be controlled during the process the steam does not react with ethylbenzene and the catalyst which prevents coking from happen. The advantages of diluting ethylbenzene with superheat

ted steam in this process are:

Supplies part of the heat needed for endothermic reaction.

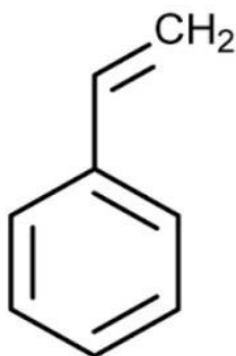
Decrease carbonaceous deposits by steam reforming reaction.

Avoid catalyst over reduction and deactivated by controlling the state of the iron.



Reaction Of Ethyl Benzene with Oxygen to Produce Propylene Oxide which then led to Production of Styrene

Figure2.4



Ethyl Benzene Molecular Structure

FIGURE 2.4.1:

## CHAPTER 3

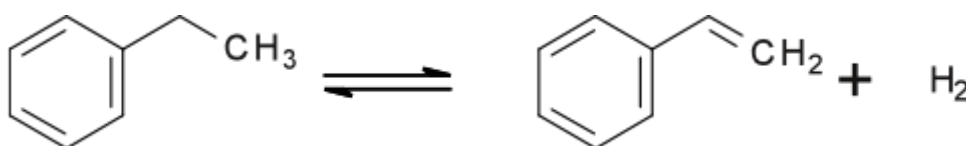
### AIM AND SCOPE

#### AIM:

The aim of this paper was to design a styrene plant that produce 30000 kg/hr of styrene using the catalytic dehydrogenation of ethylbenzene. This report determined whether the dehydrogenation of ethylbenzene is an effective both chemically and economically and viable method of producing styrene. To determine this by analysing the production process cost of the building and running a styrene plant and the chemistry involved.

#### SCOPE:

- ❖ Isothermally operated reactor for dehydrogenation of ethylbenzene to styrene (catalyst bed 30 mm diameter, 1.5 m length, about 600 degree C.)
- ❖ Distillation column (200 mbar, 30 mm diameter, Sulzer CY packing 3 m height equivalent to about 36 theoretical plates)
- ❖ Free rate about 250g/h ethylbenzene
- ❖ About 50% ethylbenzene recycling of the unconverted ethylbenzene into the reactor.



**FIGURE 3.1: REACTION TO ETHYLBENZENE TO PRODUCE STYRENE**

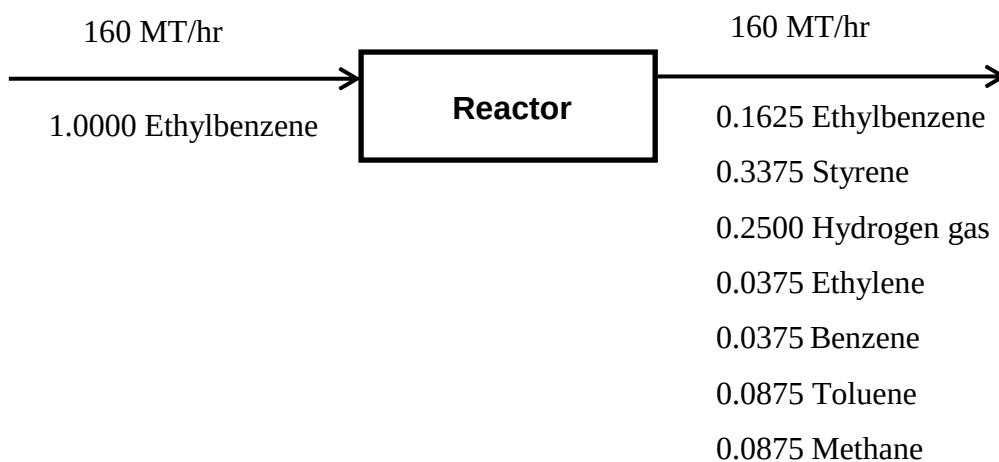
## CHAPTER 4

### METHODS AND ALGORITHM USED

#### 4.1 MATERIAL BALANCE:

The basis of the feed stream is 160MT/hr of ethylbenzene. The team made assumptions of the following condition at the reactor in order to produce about 54MT/hr of styrene :-

- 1) Fractional conversion of the ethylbenzene to styrene and benzene is about 37.5% of the feed,
- 2) The selectivity of styrene over benzene to be 90%,
- 3) Fractional conversion of ethylbenzene to toluene is about 14% of the ethylbenzene balance of the main reaction,
- 4) The total conversion of ethylbenzene is about 83.75% .



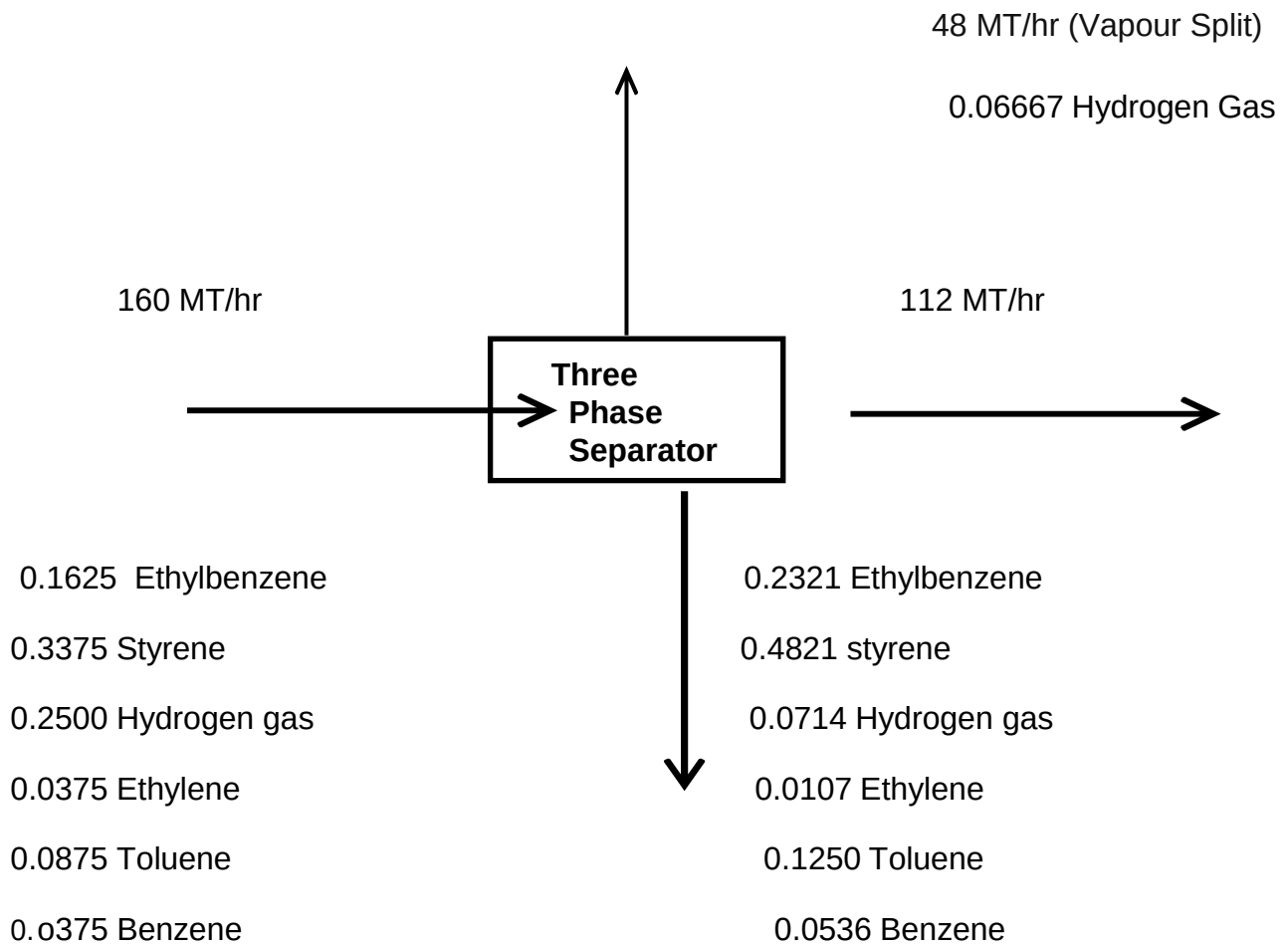
### Figure 4.1 – The Composition of The Components On The Reactor Streams

**Table 4.1 - The Mass Flow Rate and Composition of the Component Present At The Reactor**

| Input                                          |                        |             | Output                                         |                        |             |
|------------------------------------------------|------------------------|-------------|------------------------------------------------|------------------------|-------------|
| Component                                      | Mass Flow Rate (MT/hr) | Composition | Component                                      | Mass Flow Rate (MT/hr) | Composition |
| Ethylbenzene (C <sub>8</sub> H <sub>10</sub> ) | 160                    | 1.0000      | Ethylbenzene (C <sub>8</sub> H <sub>10</sub> ) | 26                     | 0.1625      |
|                                                |                        |             | Styrene (C <sub>8</sub> H <sub>8</sub> )       | 54                     | 0.3375      |
|                                                |                        |             | Hydrogen (H <sub>2</sub> )                     | 40                     | 0.2500      |
|                                                |                        |             | Ethylene (C <sub>2</sub> H <sub>4</sub> )      | 6                      | 0.0375      |
|                                                |                        |             | Benzene (C <sub>6</sub> H <sub>6</sub> )       | 6                      | 0.0375      |
|                                                |                        |             | Toluene (C <sub>7</sub> H <sub>8</sub> )       | 14                     | 0.0875      |
|                                                |                        |             | Methane (CH <sub>4</sub> )                     | 14                     | 0.0875      |
| Total                                          | 160                    | 1.0000      | Total                                          | 160                    | 1.0000      |

Since the production of styrene under high temperature using steam technology where the steam was first mix with the ethylbenzene before fed to the reactor, there are presence of water (H<sub>2</sub>O) molecule at the effluent stream, however since the molecule does not take part in the reaction and considered inert, it is negligible in the calculation.

The effluent of the reactor is then, fed to three-phase separator to remove the by- product gaseous and most of the water present in the effluent mixture. The efficiency of the separator is assumed to be 80%. Thus, about 80% of the by-product gases is removed while waste water is assumed to be completely removed.



**Figure 4.1.1 – The Composition of The Components On The Three-Phase Separator Streams**

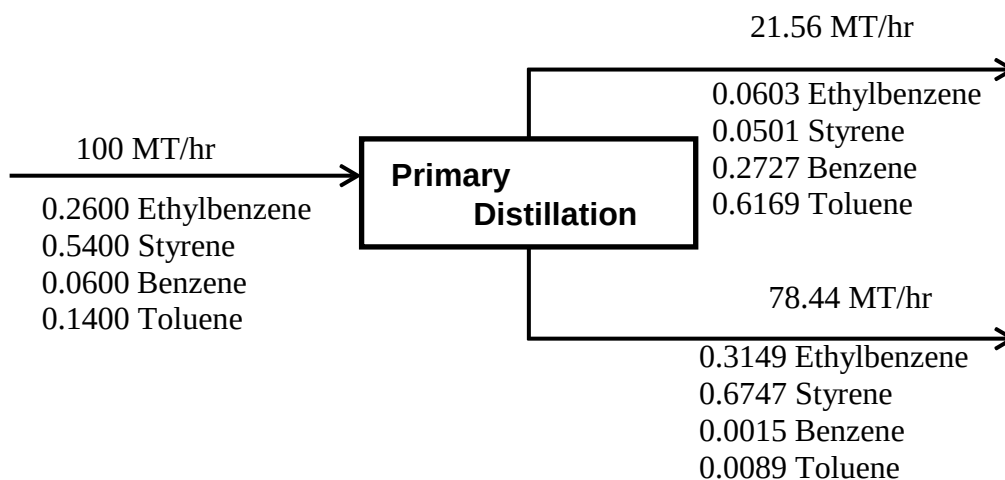
**Table 4.1.1 - The Mass Flow Rate and Composition of the Component Present At The Three-Phase Separator**

| Input to Three Phase Reactor                   |                        |             | Output To Flash Tank                           |                        |             | Output (Vapor Split)                      |                        |             |
|------------------------------------------------|------------------------|-------------|------------------------------------------------|------------------------|-------------|-------------------------------------------|------------------------|-------------|
| Component                                      | Mass Flow Rate (MT/hr) | Composition | Component                                      | Mass Flow Rate (MT/hr) | Composition | Component                                 | Mass Flow Rate (MT/hr) | Composition |
| Ethylbenzene (C <sub>8</sub> H <sub>10</sub> ) | 26                     | 0.1625      | Ethylbenzene (C <sub>8</sub> H <sub>10</sub> ) | 26                     | 0.2321      | Hydrogen (H <sub>2</sub> )                | 32                     | 0.6667      |
| Styrene (C <sub>8</sub> H <sub>8</sub> )       | 54                     | 0.3375      | Styrene (C <sub>8</sub> H <sub>8</sub> )       | 54                     | 0.4821      | Ethylene (C <sub>2</sub> H <sub>4</sub> ) | 4.8                    | 0.1000      |
| Hydrogen (H <sub>2</sub> )                     | 40                     | 0.2500      | Hydrogen (H <sub>2</sub> )                     | 8                      | 0.0714      | Methane (CH <sub>4</sub> )                | 11.2                   | 0.2333      |
| Ethylene (C <sub>2</sub> H <sub>4</sub> )      | 6                      | 0.0375      | Ethylene (C <sub>2</sub> H <sub>4</sub> )      | 1.2                    | 0.0107      |                                           |                        |             |
| Benzene (C <sub>6</sub> H <sub>6</sub> )       | 6                      | 0.0375      | Benzene (C <sub>6</sub> H <sub>6</sub> )       | 6                      | 0.0536      |                                           |                        |             |
| Toluene (C <sub>7</sub> H <sub>8</sub> )       | 14                     | 0.0875      | Toluene (C <sub>7</sub> H <sub>8</sub> )       | 14                     | 0.1250      |                                           |                        |             |
| Methane (CH <sub>4</sub> )                     | 14                     | 0.0875      | Methane (CH <sub>4</sub> )                     | 2.8                    | 0.0250      |                                           |                        |             |
| Total                                          | 160                    | 1.0000      | Total                                          | 112                    | 1.0000      | Total                                     | 48                     | 1.0000      |

The effluent of the three-phase reactor is then fed to flash tank, where all the remaining vapor split is assumed to be completely removed. Therefore, hydrogen gas, ethylene and methane is no longer present in the output stream of the flash tank.

The organic liquid split (composition of ethylbenzene, styrene, benzene and toluene) is separated using distillation columns where separation using the differences in boiling point is considered. The organic liquid split fed to the primary distillation column and the component with lower boiling point (Benzene-Toluene) goes to the overhead output stream while the higher boiling point to the bottom output stream (Ethylbenzene-Styrene). Assumptions on the primary distillation column are as follow :-

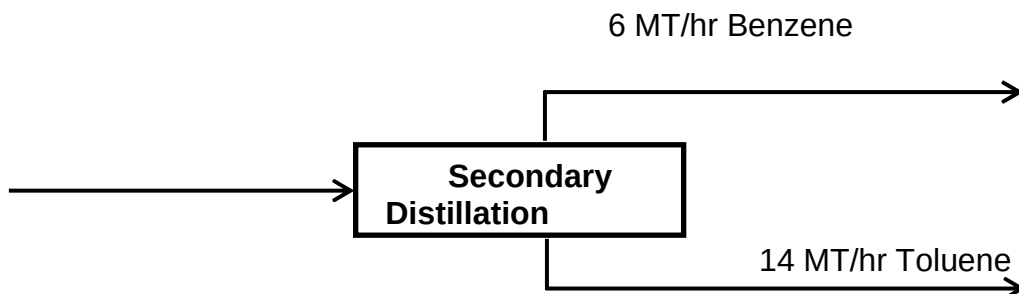
- 1) 98 wt% of Benzene from feed stream present at the overhead product stream,
- 2) 95 wt% of Toluene from feed stream present at the overhead product stream,
- 3) 98 wt% of Styrene from feed stream present at the bottom product stream,
- 4) 95 wt% of Ethylbenzene from feed stream present at the bottom product stream.



**Figure 4.1.2 – The Composition of The Components On The Primary Distillation Column Streams**

**Table.4.1.2 - The Mass Flow Rate and Composition of the Component Present At The Primary Distillation Column**

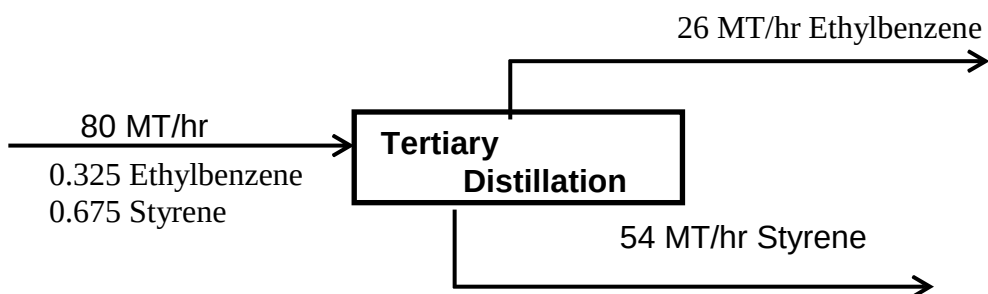
| Input                                          |                        |             | Overhead Output                                |                        |             | Bottom Output                                  |                        |             |
|------------------------------------------------|------------------------|-------------|------------------------------------------------|------------------------|-------------|------------------------------------------------|------------------------|-------------|
| Component                                      | Mass Flow Rate (MT/hr) | Composition | Component                                      | Mass Flow Rate (MT/hr) | Composition | Component                                      | Mass Flow Rate (MT/hr) | Composition |
| Ethylbenzene (C <sub>8</sub> H <sub>10</sub> ) | 26                     | 0.260       | Ethylbenzene (C <sub>8</sub> H <sub>10</sub> ) | 1.30                   | 0.0603      | Ethylbenzene (C <sub>8</sub> H <sub>10</sub> ) | 24.70                  | 0.3149      |
| Styrene (C <sub>8</sub> H <sub>8</sub> )       | 54                     | 0.540       | Styrene (C <sub>8</sub> H <sub>8</sub> )       | 1.08                   | 0.0501      | Styrene (C <sub>8</sub> H <sub>8</sub> )       | 52.92                  | 0.6747      |
| Benzene (C <sub>6</sub> H <sub>6</sub> )       | 6                      | 0.060       | Benzene (C <sub>6</sub> H <sub>6</sub> )       | 5.88                   | 0.2727      | Benzene (C <sub>6</sub> H <sub>6</sub> )       | 0.12                   | 0.0015      |
| Toluene (C <sub>7</sub> H <sub>8</sub> )       | 14                     | 0.140       | Toluene (C <sub>7</sub> H <sub>8</sub> )       | 13.30                  | 0.6169      | Toluene (C <sub>7</sub> H <sub>8</sub> )       | 0.70                   | 0.0089      |
| Total                                          | 100                    | 1.0000      | Total                                          | 21.56                  | 1.0000      | Total                                          | 78.44                  | 1.0000      |



**Figure 4.1.3– The Composition of The Components On The Secondary Distillation Column Streams**

**Table 4.1.3 – The Mass Flow Rate and Composition of the Component Present At The Secondary Distillation Column**

| Input                                    |                        |             | Overhead Output                          |                        |             | Bottom Output                            |                        |             |
|------------------------------------------|------------------------|-------------|------------------------------------------|------------------------|-------------|------------------------------------------|------------------------|-------------|
| Component                                | Mass Flow Rate (MT/hr) | Composition | Component                                | Mass Flow Rate (MT/hr) | Composition | Component                                | Mass Flow Rate (MT/hr) | Composition |
| Benzene (C <sub>6</sub> H <sub>6</sub> ) | 6                      | 0.3000      | Benzene (C <sub>6</sub> H <sub>6</sub> ) | 6                      | 1.0000      | Toluene (C <sub>7</sub> H <sub>8</sub> ) | 14                     | 1.0000      |
| Toluene (C <sub>7</sub> H <sub>8</sub> ) | 14                     | 0.7000      |                                          |                        |             |                                          |                        |             |
| Total                                    | 20                     | 1.0000      | Total                                    | 6                      | 1.0000      | Total                                    | 14                     | 1.0000      |



**Figure 4.1.4 – The Composition of The Components On The Tertiary Distillation Column Streams**

**Table 4.1.4 – The Mass Flow Rate and Composition of the Component Present At The Tertiary Distillation Column**

| Input                                          |                        |             | Overhead Output                                |                        |             | Bottom Output                            |                        |             |
|------------------------------------------------|------------------------|-------------|------------------------------------------------|------------------------|-------------|------------------------------------------|------------------------|-------------|
| Component                                      | Mass Flow Rate (MT/hr) | Composition | Component                                      | Mass Flow Rate (MT/hr) | Composition | Component                                | Mass Flow Rate (MT/hr) | Composition |
| Ethylbenzene (C <sub>8</sub> H <sub>10</sub> ) | 26                     | 0.3250      | Ethylbenzene (C <sub>8</sub> H <sub>10</sub> ) | 26                     | 1.0000      | Styrene (C <sub>8</sub> H <sub>8</sub> ) | 54                     | 1.0000      |
| Styrene (C <sub>8</sub> H <sub>8</sub> )       | 54                     | 0.6750      |                                                |                        |             |                                          |                        |             |
| Total                                          | 80                     | 1.0000      | Total                                          | 26                     | 1.0000      | Total                                    | 54                     | 1.0000      |

## 4.2 ENERGY BALANCE

Bubble Point:

Dew Point:

Where:

$x_i$  = concentration of

component  $i$  in liquid phase,  $y_i$  =  
concentration of component  $i$  in vapour phase,

$K_i$  = equilibrium constant of component  $i$ .

The  $K$  value is determined using Antoine Equation, where assumption of temperature is made to get the value of partial pressure. Then, the pressure obtained is divided with the pressure used for operating condition which is  $1\text{atm} = 101.325\text{kPa}$ .

**Antoine Equation :**

**Table 4.2.1– Antoine Constant For Component in Primary Distillation Column**

|              | A       | B        | C       |
|--------------|---------|----------|---------|
| Benzene      | 6.90565 | 1211.033 | 220.79  |
| Toluene      | 6.95464 | 1344.8   | 219.482 |
| Ethylbenzene | 6.95719 | 1424.255 | 213.206 |
| Styrene      | 6.9571  | 1445.58  | 209.44  |

## 4.3 Relative volatility :

Where,

Light key =  $K_{LK}$

Heavy key= $K_{HK}$

**Table 4.3 – Feed Temperature for Distillation Column 1**

| Feed , T = 128.8°C           |             |           |        |        |             |
|------------------------------|-------------|-----------|--------|--------|-------------|
| Column1                      | $x_i = y_i$ | p (mmHg)  | $K_i$  | $A_i$  | $y_i * a_i$ |
| <b>Benzene (light key L)</b> | 0.06        | 2763.7433 | 3.6365 | 4.4537 | 0.2672      |
| <b>Toluene</b>               | 0.14        | 1239.9412 | 1.6315 | 1.9981 | 0.2797      |
| <b>Ethylbenzene (basis)</b>  | 0.26        | 620.5471  | 0.8165 | 1.0000 | 0.2600      |
| <b>Styrene (heavy key H)</b> | 0.54        | 482.2484  | 0.6345 | 0.7771 | 0.4197      |
|                              |             |           |        |        | 1.2266      |

Assumption temperature of 128.8°C is acceptable since

**Table 4.3.1 – Top Temperature / Dew Point For Distillation Column 1**

| Top Temp (D) T = 100°C       |             |           |        |        |             |        |
|------------------------------|-------------|-----------|--------|--------|-------------|--------|
| Column1                      | $y_i = x_i$ | p (mmHg)  | $K_i$  | $a_i$  | $y_i / a_i$ | $X_i$  |
| <b>Benzene (light key L)</b> | 0.2727      | 1350.4913 | 1.7770 | 5.2559 | 0.0519      | 0.1540 |
| <b>Toluene</b>               | 0.6169      | 556.3219  | 0.7320 | 2.1651 | 0.2849      | 0.8460 |
| <b>Ethylbenzene (basis)</b>  | 0.0603      | 256.9493  | 0.3381 | 1.0000 | 0.0603      | 0.1790 |
| <b>Styrene (heavy key H)</b> | 0.0501      | 192.9744  | 0.2539 | 0.7510 | 0.0667      | 0.1981 |
|                              |             |           |        |        | 0.3368      | 1.3771 |

Assumption temperature of 100°C is acceptable since the

**Table 4.3.2 – Bottom Temperature / Bubble Point For Distillation  
Column 1**

| Bottom Temp (W) T=142.5°C |        |           |        |        |        |        |
|---------------------------|--------|-----------|--------|--------|--------|--------|
| Column1                   | xi     | p (mmHg)  | Ki     | Ai     | xi*ai  | Yi     |
| Benzene (B) (light key L) | 0.0015 | 3733.6541 | 4.9127 | 4.1588 | 0.0062 | 0.0074 |
| Toluene (T)               | 0.0089 | 1735.9537 | 2.2841 | 1.9336 | 0.0172 | 0.0203 |
| Ethylbenzene (EB) (basis) | 0.3149 | 897.7740  | 1.1813 | 1.0000 | 0.3149 | 0.3720 |
| Styrene (S) (heavy key H) | 0.6747 | 707.3567  | 0.9307 | 0.7879 | 0.5316 | 0.6280 |
|                           |        |           |        |        | 0.8465 | 1.0277 |

Assumption temperature at 142.5°C is acceptable since the

#### 4.4 MINIMUM NUMBER OF THEROTICAL STAGES

Where,

$X_{LD}$  = mole fraction of light key in distillate

$X_{LW}$  = mole fraction of light key in bottom

$X_{HD}$  = mole fraction of heavy key in

distillate  $X_{HW}$  = mole fraction of heavy key  
in bottom

$$X_{LD} \cdot D = (0.2727)(20) = 5.88 \quad \alpha_{LD} = 5.2559, \text{ at } T =$$

$$100^\circ\text{C} \quad X_{HD} \cdot D = (0.0501)(20) = 1.08 \quad \alpha_{LW} = 4.1588, \text{ at } T =$$

$$142.5^\circ\text{C} \quad X_{LW} \cdot W = (0.6747)(80) = 52.92 \quad \alpha_{L,av} = \sqrt{(\alpha_{LD})(\alpha_{LW})}$$

$$= 9.5343 \quad X_{HW} \cdot W = (0.0015)(80) = 0.12$$

#### 4.5: MINIMUM REFLUX RATIO:

Underwood equation is used to determine the minimum reflux ratio, We assume  $q=1$  because of thermal condition at feed is saturated liquid.

Where,

$\alpha_i$  = the relative volatility of the component  $i$  with respect to some reference component, usually the heavy key,

$R_m$  = the minimum reflux ratio,

$X_{i,d}$  = concentration of component  $i$  in the top at minimum reflux and  $\Theta$  is the root of the equation.

#### 4.6 COLUMN DIAMETER:

Vapour flowrate is the principal factor that determines the column diameter. Souder and Brown Equation, Lowenstein (1961) is used to estimate the allowable superficial vapor velocity and hence the column area and diameter.

Where

$u$  = maximum allowable vapour velocity, based on the gross(total) column cross sectional area, m/s

$l_t$  = plate spacing, m (range 0.5 – 1.5)

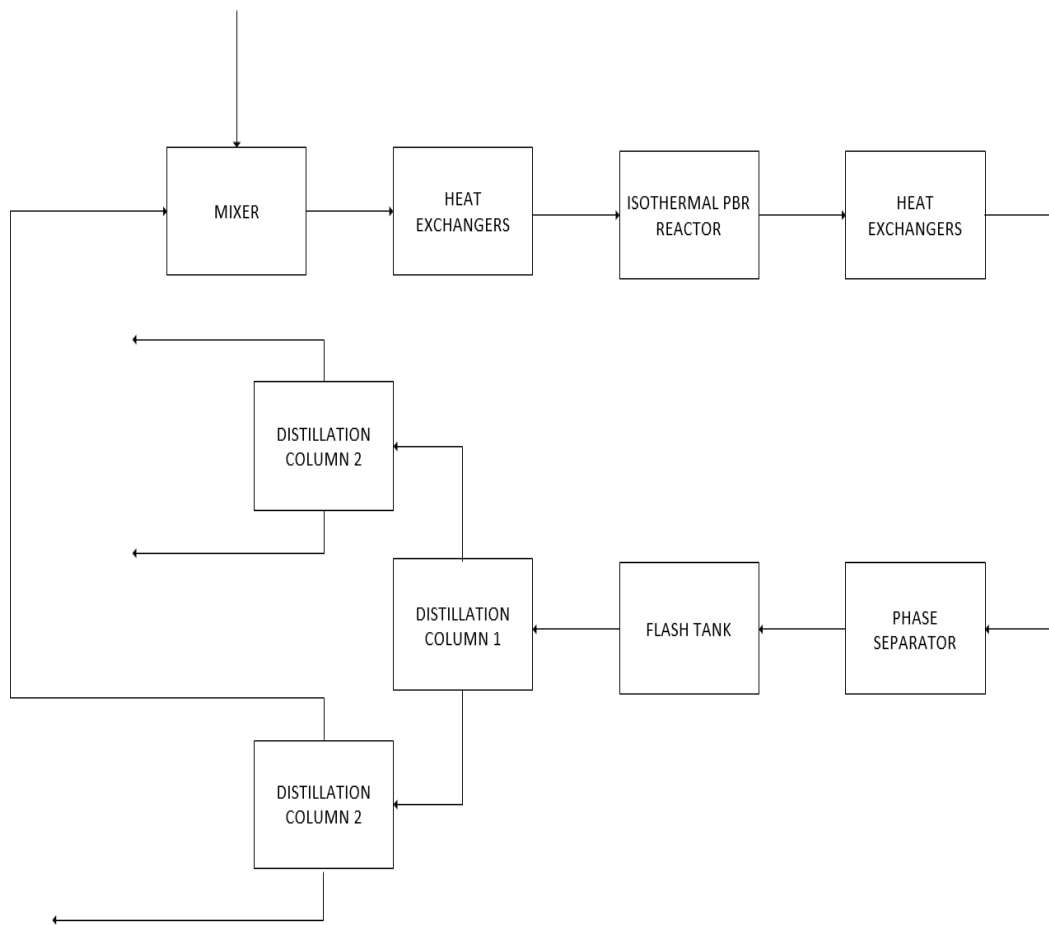
Assumption,

1) Plate spacing,  $l_t = 0.45\text{m}$

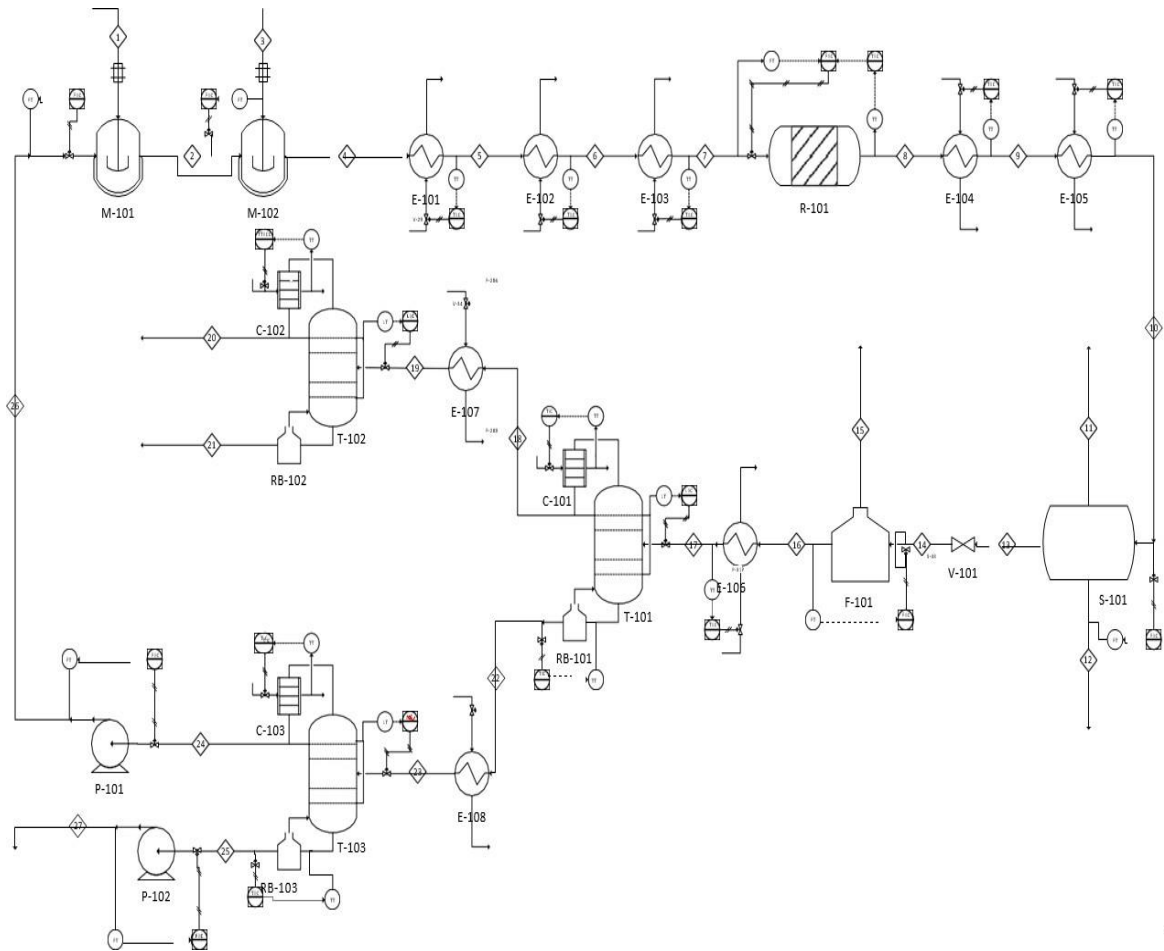
2) Liquid density,  $\rho_l = 909 \text{ kg/mL}$  at  $25^\circ\text{C}$

3) Vapor density,  $\rho_v = 1.45 \text{ kg/mL}$

Therefore, substitute the assumption value ,  $uv = 0.9975$







**Figure 4.6.2: P & ID Styrene Production Plant**

**Table 4.6.3 – Process Equipment Symbols and Numbering**

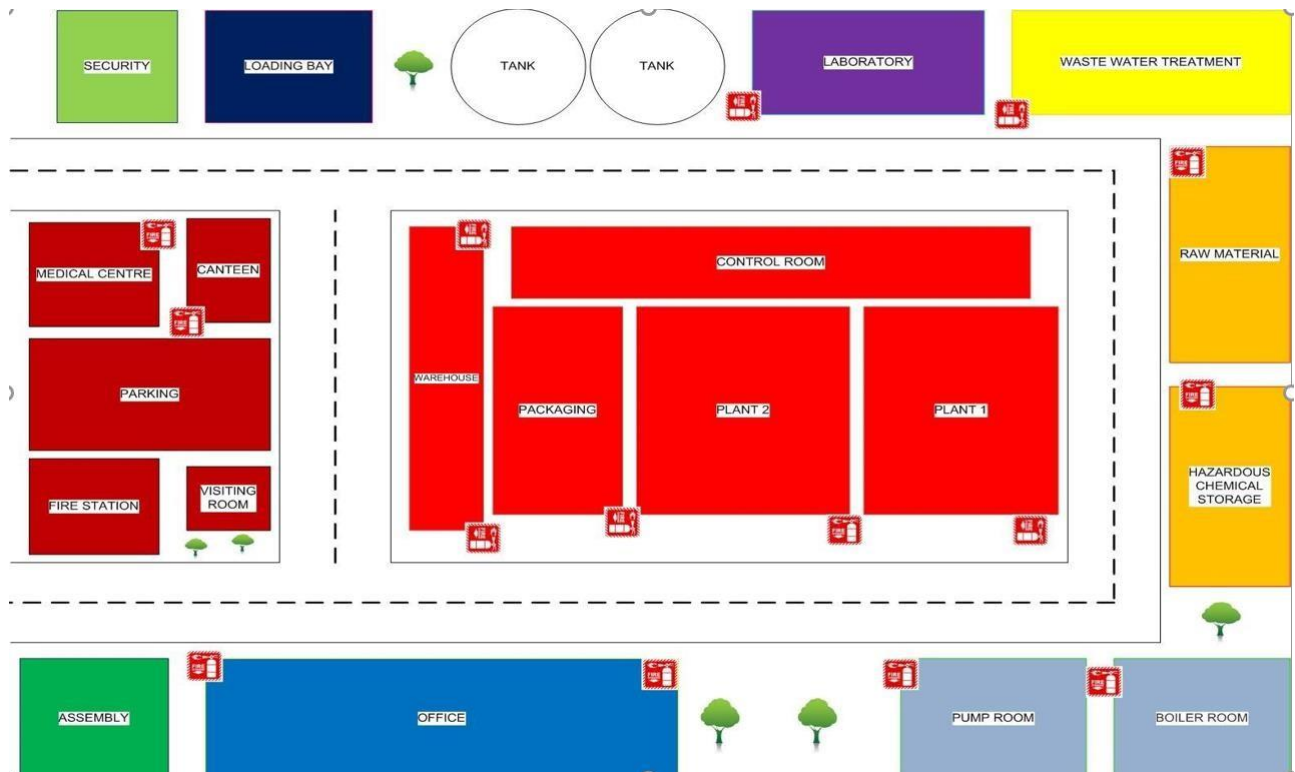
| <b>Numbering</b> | <b>Process Equipment</b> | <b>Numbering</b> | <b>Process Equipment</b> |
|------------------|--------------------------|------------------|--------------------------|
| C-101            | Condenser 1              | E-105            | Dowtherm Cooler          |
| C-102            | Condenser 2              | E-106            | Column 1 Feed Heater     |
| C-103            | Condenser 3              | E-107            | Column 2 Feed Cooler     |
| R-101            | Reboiler 1               | E-108            | Column 3 Feed Cooler     |
| R-102            | Reboiler 2               | R-101            | Isothermal PBR Reactor   |
| R-103            | Reboiler 3               | S-101            | Phase Separator          |
| M-101            | Mixer 1                  | V-101            | Flash Tank               |
| M-102            | Mixer 2                  | T-101            | Distillation Column 1    |
| E-101            | Furnace Heater           | T-102            | Distillation Column 2    |
| E-102            | Dowtherm Heater          | T-103            | Distillation Column 3    |
| E-103            | Molten Salt Heater       | P-101            | Recycle Pump             |
| E-104            | Molten Salt Cooler       | P-102            | Styrene Pump             |

**Table 4.6.4 – No of Stream, Temperature, Pressure and Mass Flow Rate For Styrene Production Plant**

| <b>No of Stream</b>           | <b>1</b> | <b>2</b> | <b>3</b> | <b>4</b> | <b>5</b> | <b>6</b> | <b>7</b> | <b>8</b> |
|-------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|
| <b>Temperature (°C)</b>       | -        | -        | -        | 116.5    | 250      | 415      | 600      | 600      |
| <b>Pressure (atm)</b>         | -        | -        | -        | 2        | 2        | 2        | 2        | 2        |
| <b>Mass Flow Rate (MT/hr)</b> | 15.2     | 23.3     | 31.6     | 55       | 55       | 55       | 160      | 160      |

## CHAPTER 5

### PERFORMANCE ANALYSIS



**FIGURE 5.1 PLANT LAYOUT**

## 5.2 SITE SELECTION

Based on the market survey and preliminary feasibility study, there are few places have been considered for the site selection. Four sites within Peninsular Malaysia were selected for further consideration : Pasir Gudang, Pengerang, Kerteh and Butterworth. It is proposed to develop a 80MT/yr styrene plant in Pasir Gudang, Johor, Malaysia. The location was chosen for the existing infrastructure, close proximity to road, rail and sea transport and thus minimizing the overall transportation costs. Government assistance is anticipated in order to encourage the development of the state. The plant layout is design based on specified safety considerations, costs and ease of access and flexibility.

**Table 5.2 – Characterization Of The Site Suggestion**

| No    | Factors                         | Site Suggestion |           |                        |                         |
|-------|---------------------------------|-----------------|-----------|------------------------|-------------------------|
|       |                                 | Pasir Gudang    | Pengerang | Kerteh<br>(Terengganu) | Butterworth<br>(Penang) |
| 1     | Raw materials Availability      | 5               | 4         | 3                      | 3                       |
| 2     | Markets                         | 5               | 4         | 3                      | 3                       |
| 3     | Energy Availability             | 4               | 4         | 4                      | 4                       |
| 4     | Climate Conditions              | 3               | 3         | 3                      | 3                       |
| 5     | Transportation facilities       | 5               | 4         | 3                      | 3                       |
| 6     | Water Supply                    | 3               | 3         | 4                      | -                       |
| 7     | Waste Disposal                  | 5               | 5         | 5                      | 5                       |
| 8     | Labor Supply                    | 3               | 3         | 3                      | 3                       |
| 9     | Taxation and legal Restrictions | 3               | 3         | 3                      | 3                       |
| 10    | Site characteristics            | 3               | 3         | 3                      | 3                       |
| 11    | Flood and Fire Protection       | 3               | 3         | 3                      | 3                       |
| 12    | Community factors               | 4               | 4         | 4                      | 4                       |
| Total |                                 | 46              | 43        | 41                     | 37                      |

### **5.2.1 Raw Material Availability**

The source of raw material is one of the most important factor in selection of a plant site. If large volume of raw material is consumed, it is the best to choose the place for the plant site near the raw materials sources. This is because it will reduce the transportation cost and storage sites facilities.

### **5.2.2 MARKET**

Pasir Gudang, Johor and Butterworth, Penang were choose as the best from the best for marketing factor. There is few companies that highly demand for styrene. Based on statistics in 2013, Idemitsu that operate at Pasir Gudang have 120 KMts demand of styrene for production of Polystyrene and Toray that operate at Butterworth, Penang have 107 KMts demand of styrene for production of Acrylonitrile Butadiene Styrene (ABS). Thus, we decided to choose Pasir Gudang due to the fact that the market is bigger around the plant site area.

### **5.2.3 Energy Availability**

All the state has equivalent price for electricity. It is due to standard price provided by the Tenaga National Berhad (TNB) for the industrial sector. However, for the company that generate their own electricity by using turbine concepts or other means of generation electricity allowing the reducing of the utilities cost.

### **5.2.4 Climate Conditions**

Adverse climatic conditions at a site will increase costs. Abnormally low temperatures will require the provision of additional insulation and special heating for equipment and pipe runs. Stronger structures will be needed at locations subject to high winds (cyclone/hurricane) or earthquakes.

### **5.2.5 Transportation Facilities**

Transportation is another factor that must be considered for site selection because with transportation is the way for connection. The plant should have better transportation facilities to ease the transportation of the product to the customer and for the utilities. Based on the table, we decided to choose Pasir Gudang as the 1<sup>st</sup> place for transportation facilities, it is because Pasir Gudang have three main terminal port compared to Kerteh which only have two and Butterworth only have one. Thus, Pasir Gudang provide a greater choice for transportation and thus allowing to reduce the cost for the transportation

### **5.2.6 Water Supply**

Based on the data from the table below, the minimum charge for water supply in Johor is lower compared to Terengganu. However, the rate per cubic metre for large consumption, Terengganu offers lower price for the water supply. Therefore, Kerteh, Terengganu is the best option since the price of the water is the lowest among the other states. However, we still choose Johor due to the fact that the other factors for site selection prefer more towards the state.

### **5.2.7 Waste Disposal**

All industrial processes produce waste products, and full consideration must be given to the difficulties and cost of their disposal. The disposal of toxic and harmful effluents will be covered by local regulations, and the appropriate authorities must be consulted during the initial site survey to determine the standards that must be met. An environmental impact assessment should be made for each new project or major modification or addition or an existing process.

The production of styrene using catalytic dehydrogenation process produces almost none waste that needs to be dispose. The steam is used for power to keep the reaction going, whereas water used for the reaction is reusable since it literally inert and not involved directly in the conversion of ethyl benzene to styrene. The catalyst used is non toxic and not considered as a hazardous chemical. Thus, requiring no special handling problems with the chemical. The toluene and benzene is considered as useful by-product and could be sales for profit other than styrene whereas ethyl benzene left at the end of the process can be recycled back to the feed stream. Therefore, it is decided that no additional waste-treatment facilities is required for the plant

### **5.2.8 Labour Supply**

Labour will be needed for construction of the plant and its operation. Skilled construction workers will usually be brought in from outside the site area, but there should be an adequate pool of unskilled labour availability locally and labour suitable for training to operate the plant. Skilled tradesmen will be needed for plant maintenance. Local trade union customs and restrictive practices will have to be considered when assessing the availability and suitability of the local labour for recruitment and training.

### **5.2.9 Taxation and Legal Restrictions**

Capital grants, tax concessions, and other inducements are often given by governments to direct new investment to preferred locations such as areas of high unemployment. The overriding of such grants can be the overriding considerations in site selection.

In addition to the main plant, we also have to consider the associated services which have to be amalgamated within a particular plant site. Canteens, parks, general utilities, emergency medical services and places for storage must also be taken into consideration while deciding on a particular site.

## **5.3 Site Characteristics**

Sufficient suitable land must be available for the proposed plant and for future expansion. The land should ideally be flat, well drained and have suitable load-bearing characteristics. A full site evaluation would be made to determine the need for piling or other special foundations

### **5.3.1 Flood and Fire Protection**

The location should be located nearer the port location. However, the protection such as flood protection should be considered. The plant must build at the place that has low chances to be flooding. It can be measure by studies the topography of the site location. For the fire protection, the plant should have many protection for the fire such as fire extinguisher, and etc. The location of the fire extinguisher must be easy for the people to see. It is because the fire extinguisher can be used easily whenever getting emergency situation.

### **5.3.2 Community Factors**

The proposed plant must be fit in with and be acceptable to the local community. Full consideration must be given to the safe location of the plant so that it does not impose a significant additional risk to the community. On a new site, the local community must be able to provide adequate facilities for the plant personnel: schools, banks, housing, and recreational and cultural facilities. All of the state or site chosen for the potential site.

## **CHAPTER 6**

### **SUMMARY AND CONCLUSION**

Styrene who is also known as ethylbenzene, vinylbenzene and phenylethene is an organic compound with the chemical formula  $C_6H_5CH=CH_2$ . Although styrene was discovered way back in 1839, its commercial production and applications were developed in the 1930s. Post world war period witnessed a boom in styrene demand due to its application in the manufacture of synthetic rubber. This led to a dramatic increase in styrene capacity. Styrene has wide application in producing plastic and synthetic rubber industry. It is mostly used in side-chain chlorination of ethylbenzene followed by dechlorination, side-chain of chlorination of ethylbenzene hydrolysis to the corresponding alcohols followed by dehydration and pyrolysis of petroleum recovery. In an effort to find a sustainable method of manufacturing of styrene from ethylbenzene, several design objectives were chosen as a necessity for the proposed system such as identifying suitable catalyst, the economic factor, environmental factor, strategic location to build for styrene plant, the design specifications on the reactors and distillation column used in the plant, the market price and also not to forget the safety issue relating to the plant. Obtaining this data was very crucial before scaling up the design of a complete industrial plant.

### **CONCLUSION**

Styrene is the precursor for polystyrene, which is used in plastics, protective coatings, polyesters, resins, and chemical intermediates. . The demands for styrene is indeed very high. The most common method for styrene production is catalytic dehydrogenation, thus the team proceed with the method. The team believed Pasir Gudang , Johor is the best location for the plant. Since the raw material availability and the demands for styrene is high in the area. Besides, the transportation facilities and community factors also contribute in the decision making for choosing Pasir Gudang. The team successfully construct Block Flow Diagram (BFD), Process Flow Diagram (PFD) and Piping and Instrumentation Diagram (P&ID) for the production of styrene. Therefore, the team believed styrene would provide a good platform for high profit interest and low capital cost. Besides, the construction of the plant provides job opportunities and increase the economy for Malaysia.

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