A Project Report On The

Production Of Ethylene Dichloride By Direct Chlorination Method

Session 2018-2022

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A Dissertation Submitted to the Department of Chemical Engineering at Khawaja Fareed University of Engineering and Information Technology, Rahim Yar Khan in partial fulfillment of requirements for the degree of BSc in Engineering

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Preface

Ethylene dichloride (EDC) or 1,2dichloroethane is used in industry as a raw material for vinyl chloride monomers (VCM) and intermediates in polyvinyl chloride (PVC) production. Besides, the EDC is also used in TEL components, which are mixed in an anti-knock mixture; solvents for oils, waxes, and coating removers (coat cleaners); and raw materials for diamine ethylene, perchlorate ethylene, carbon tetrachloride, and trichloroethylene. The EDC needs in the world have increased since 1985 with the increasing demand for vinyl chloride and polyvinyl chloride. Therefore, to meet the lack of domestic EDC requirements, the establishment of the EDC plant was considered. Ethylene dichloride can be produced from ethylene and chlorine. It is the design of this EDC plant with a size of 50,000 tons/year. Based on a review of low operating conditions (temperature and pressure) and the factory presence previously made, the Ethylene dichloride (EDC) plant is classified as low risk. Furthermore, the Ethylene dichloride (EDC) plant of ethylene and chlorine with a 50,000 ton/year production capacity is feasible.

This report includes the introduction of process, which highlights importance of this process. Detailed description of "EDC by direct chlorination" is also presented in chapter 2. Afterwards material and energy balance for each equipment is presented.

In later chapter introduction to different equipment of plant along with their designing procedure and specification sheets are presented. Plant Safety, Instrumentation & Process Control, and Estimation for this plant are also include in this report.

Acknowledgement

The research project titled "Production of Ethylene Dichloride By Direct Chlorination Method" was successfully completed in the Institute of Chemical and Environmental Engineering of the Khwaja Fareed University of Engineering and Information Technology under the Pakistan Engineering Council (PEC) Annual Award of Final Year Design Projects (FYDP) for the year 2022-2023. The Project was supervised by Engr. Dr Rana Mujahid and Engr. Muhammad Kashif Ashraf.

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Chapter 1: Introduction

Ethylene dichloride (EDC) is largely used to make vinyl chloride monomer (VCM), which is primarily utilized in the polymerization of polyvinyl chloride (PVC). Pipes, fittings, profiles, tubes, windows, doors, sidings, wire, cable, film, sheet, and flooring are all made of PVC. Construction and infrastructure, agriculture, electrical items, and healthcare are all areas that use vinyl. EDC is also utilized as a solvent in the textile, metal cleaning, and adhesive industries, as well as an intermediary in the synthesis of chlorinated solvents and ethylene amines.

Northeast Asia, driven mostly by mainland China, is the world's largest producer and consumer of EDCs. Although North America is currently the world's second-biggest producer and consumer of EDC, the United States remains the world's greatest producer and consumer. The United States of America.

Given the disparities in cost positioning among the various areas, EDC trade flows will continue to be large (trade accounted for around 6% of world production/consumption in 2020). The United States and the Middle East, which have cheaper ethane-based manufacturing costs, are the key providers of EDC, whereas the Indian Subcontinent, Southeast Asia, and mainland China are the primary users' manufacture accounted for almost 98 percent of global EDC use in 2020. The most substantial EDC consumption into non-VCM uses is in Western Europe, mainland China, and the United States, primarily for chlorinated solvents, ethylene amines, and vinylidene chloride.

1.1) History and Background:

1.1.1) History:

Under the name of the Society of Dutch Chemists (Dutch: Gezelschap der Hollandsche Scheikundigen), physician Jan Rudolph Deiman, merchant Adrian Paetz van Troostwijk, chemist Anthoni Lauwerenburg, and botanist Nicolaas Bondt were the first to produce 1,2-dichloroethane from olefin gas (oil-making gas, ethylene) and chlorine gas in 1794.

Despite the fact that the Gezelschap did not conduct any in-depth scientific study in practice, they and their publications were well recognized. One reason for this is that 1,2-dichloroethane was once known as "Dutch oil" in chemistry. This is also the origin of the term "olefin gas" (oil-making gas) for ethylene, as it is ethylene that produces Dutch oil in this reaction. And "olefin gas" is the etymological root of "olefins," the hydrocarbon family in which ethylene belongs.

1.1.2) Background:

Ethylene Dichloride is an important hydrocarbon. It belongs to the class of organochlorides that is produced in large amounts. The raw materials used for the production of Ethylene Dichloride are Chlorine and Ethylene. It is mainly used for the production of PVC, a very important material used in both industries as well as daily life. Chlorine used for the production of Ethylene Dichloride is obtained from Rock Salt using electrochemical Cells. It is imported from India. The Ethylene is imported from the Saudi Arabia and China.

Chlorine is an inorganic compound. It is greenish yellow in color. It has an irritating smell and it becomes liquid at 34 ^{0}C. it is heavier than air two and half times. Ethylene is a hydrocarbon having double bond in its structure. Chlorine and Ethylene react via Direct Chlorination method and produce Ethylene Dichloride.

The reactor used for the reaction is Plug Flow Reactor. The reaction takes place in Gas phase at high temperature and relatively low pressures. The temperature ranges from 40 °C to 150 °C and pressure ranges from 1.4 to 1.3 atm. The conversion of reactants is 98%. Catalyst used for the production of EDC is Ethylene Dibromide. It is not consumed in the reactor. It simply aids the conversion of reactants to products. No any side product is produced in the reactor. Catalyst is used in very low amounts. It is present the reactor in vapor phase. Steady-state condition is used in all the equipment’s. There are no leakages in pipes and reactors. Ethane is also present in feed in small amounts.it has nothing to do with reaction. It simply passes from reactor without reacting.

The Degree of Freedom analysis showed that there is total 12 variables. Among these 5 are given variables, 6 given equations and 1 relation. In this way the degree of freedom of reactor is zero. The reaction taking place in reactor is highly exothermic. The heat of reaction is -88.53 MJ/mol. Temperature varies along the length of PFR to 150 °C.

Most common industrially practical processes for the production of EDC are

1) Direct Chlorination Method
2) Oxy-chlorination Method

Usage of these two methods depend upon the available raw materials. Direct chlorination method involves the direct addition of Ethylene and Chlorine. Different types of catalysts can be used for the production of EDC in Direct Chlorination method. Mechanism of reaction depends upon catalyst used. In this project, Ethylene Dibromide has been used. It is recovered in the distillation columns and recycled back. The reaction is given as:

Chlorinated solvents and ethylene-amines are also made by Ethylene dichloride and these products are used as solvents in textile, metal coating and in the adhesive industry. The largest and consuming worldwide region of EDC is Northeast Asia. Now the second largest producer and consumer of the EDC is North America. But the single largest producer and consumer of the EDC is the United State and also the largest exporter of the EDC.

In case the Iron dichloride is used as a catalyst, the reaction is exothermic, with a heat of reaction of 52 kcal/mol. The reaction takes place in the liquid phase with ferric chloride acting as the catalyst. The reaction temperature is approximately 50 °C at atmospheric pressure. The mechanism for the above reaction is also given by Morrison and Boyd, 1973 that is shown in next sections.

$$\mathbf{C_2H_4 + C_2H_4 \longrightarrow C_2H_4Cl_2}$$

Second process that is common industrial practice is Oxy-chlorination method. EDC is also produced in the balanced ethylene feedstock process by oxy-chlorination of ethylene with HCL.

$$\mathbf{C_2H_4 + 4HCl + O_2 \longrightarrow C_2H_4Cl_2 + H_2O}$$

The reaction is highly exothermic with a heat of reaction greater than 55 kcal/mole of EDC produced. Air is normally used as the source of oxygen, although pure oxygen may also be used. The ethylene oxy-chlorination is carried out at temperature of 225-325 °C and at pressures of 1-15 atm. Catalysts for the reaction almost always contain copper chloride and sodium or potassium chloride deposited on alumina or other suitable support media.

1.1.3) Physical and chemical properties of raw materials:

These physical properties are:

Chlorine:

1. It is a greenish yellow gas at room conditions
2. Heavier than air almost 2.5 times.
3. It is changed into liquid at -34 °C

4. Density of chlorine 3.214 g/l
5. It directly combines with almost all other elements and belongs to the family of halogens

Ethylene:

1. It is highly flammable gas having sweet smell
2. A colorless gas at room temperature having -169 °C and 104 °C melting and boiling points respectively.
3. It is non polar in nature and dissolves in organic liquids only
4. Reactivity of Ethylene is very high due to the presence of double bond

Ethylene Dichloride:

1. It appears colorless having odor similar to chloroform.
2. Density is 10.4 lb/gal and its vapors are heavier than air.
3. Insoluble in water having the flash point of 56 °F
4. Exposure to higher amounts of EDC can adversely affect human nervous system

1.1.4) Ethylene Dichloride Production Significance:

Ethylene dichloride is least difficult individual from the arrangement of conjugated hydrocarbon chlorides. Ethylene dichloride is very versatile compound used for the production of different types of compounds. It is mainly used in the production of compounds like vinyl chloride monomer (VCM) Which is further used in the production of polyvinyl chloride (PVC). PVC has a lot of worth and used for various purposes like pipes, fittings, windows, doors, tubes, wires, cable, film and sheet.

Chlorinated solvents and ethylene-amines are also made by Ethylene dichloride and these products are used as solvents in textile, metal coating and in the adhesive industry. The largest and consuming worldwide region of EDC is Northeast Asia. Now the second largest producer and consumer of the EDC is North America. But the single largest producer and consumer of the EDC is the United State and also the largest exporter of the EDC.

1.2) Product Applications:

Ethylene dichloride is very versatile compound used for the production of different types of compounds. It is mainly used in the production of compounds like vinyl chloride monomer

(VCM) which is further used in the production of polyvinyl chloride (PVC). PVC has a lot of worth and used for various purposes like pipes, fittings, windows, doors, tubes, wires, cable, film and sheet.

1.2.1) Vinyl Chloride Monomer:

Vinyl chloride is an organochloride with the formula $H_2C{=}CHCl$ that is also called vinyl chloride monomer (VCM) or chloromethane. It is a colorless, flammable chemical that is primarily used in the production of the polyvinyl chloride (PVC) resins This Ethylene dichloride, PVC, and VCM are the key components for the petrochemical and thermoplastic sectors.

By product hydrogen chloride is produced from the manufacture of ethylene dichloride but in ox chlorination method this hydrogen chloride is recycled and with additional ethylene it produced EDC. Further VCM is polymerized to produce PVC. In acetylene process no EDC is involved, and production of VCM directly from acetylene. Mainland China is the major consumer of the VCM/ PVC.

In 2020 almost 99% of the global consumption of VCM was used in the production of PVC. VCM consumption is highly depend upon the PVC market because major portion of VCM used in the production of PVC. Demand of PVC is increasing day by day and it plays a vital in the growth of the economy for any country. In construction site PVC are highly demanded because PVC pipes, fittings, and sheets are used. Northeast Asia is the largest VCM consumer, with mainland China consuming 80% of VCM in the entire region while globally consumption was 44% in 2020. The second largest consumer of VCM in 2020 was North America and its consumption was 17%. Western Europe was the third consumer of VCM about 11% consumption of VCM in 2020.

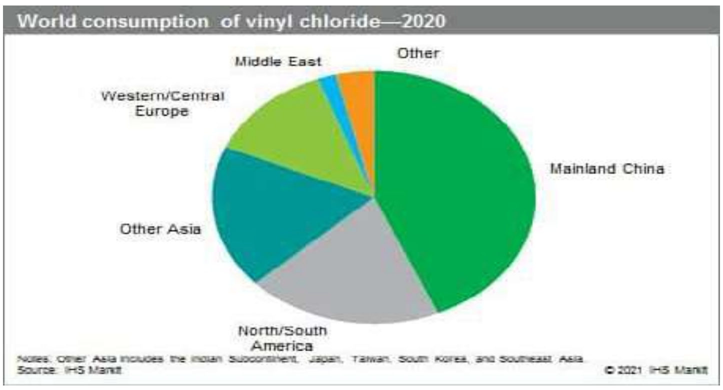

Figure 1: Vinyl consumption

1.2.2) Polyvinyl Chloride

PVC is a thermoplastic material. The material that can melted again and again. The basic raw material for the production of PVC derived from salt and oil. By the electrolysis of the salt water, chlorine is produced. Further chlorine is combined with ethylene which are produced from oil to form ethylene chloride. At high temperature EDC is converted into VCM. VCM is polymerized into PVC resins.

It is a good insulating material. It is resistant to weathering, chemical rotting, corrosion, shock, and abrasion. It is abrasion resistant, lightweight, and tough.

PVC is mostly used in the construction site which is about 50% and replacing other materials like wood, glass. It is also used for flooring, windows, and door frames and shutters, water and waste pipes. It has been used widely used for surgery, pharmaceutical, drug delivery, and medical packing. Other applications included toys, packing, electric equipment, household goods, coating, plastic parts in motor vehicles, office supplies, insulation, and adhesives tapes.

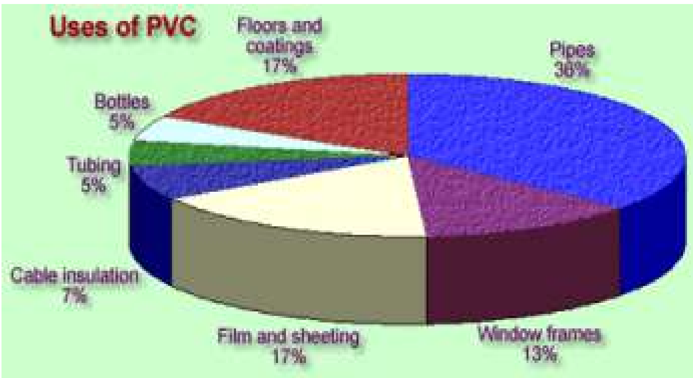

Figure 2: Uses of PV

1.3) Problem Statement:

Ethylene dichloride is one of the most important of greatest demand in the world. Because it is used in the production of many objects. For a few past years, its demand has increased day by day. The production capacity of United states of America in 2018 was around 10 million metric tons. Similarly, Europe is also producing a very large amounts of ethylene dichloride. The demand of ethylene dichloride is also increasing in Pakistan. Pakistan is importing most of the EDC to full its needs. There to strengthen the GDP in terms of exports and meet Pakistan's' needs as well and fill the demand and supply gap it is very necessary to accommodate a plant in Pakistan that will not only fulfil the Pakistan's requirement but we can also export it to make money. Other reasons to install the plant are to become a competitor in global market and high rising demands of EDC in various end use applications. The capacity of EDC production of our plant is 50,000 ton/year. It will be sufficient to meet the Pakistan's needs.

1.4) Objective And Scope:

- To produce Ethylene Dichloride (EDC) using ethylene and chlorine via direct chlorination process.
- Increasing uses of Ethylene Dichloride for the production of Polyvinyl Chloride and Vinyl Chloride monomer.

1.5) Market Analysis:

Ethylene Dichloride market, global by Application (Agricultural chemicals, chemical intermediates, chemical solvents, VCM/PVC raw materials production, Ethylene Amines, Trichloroethylene (TCE), Perchloroethylene (Tetrachloroethylene), Hexachlorophene, others), end-user industry (Automotive, Medical, Construction, Furniture, Packaging, others), country (United States, Canada, Mexico, Brazil, Argentina, Rest of South America, Germany, France, Italy.

1.5.1) Market Analysis And Insights:

In the projection period of 2021 to 2028, the ethylene dichloride market is predicted to increase at a rate of 5.24 percent. The ethylene dichloride market report from Data Bridge Market Research provides analysis and insights into the numerous aspects that are likely to be present during the forecast period, as well as their implications on the market's growth. The global increase in research activities is accelerating the expansion of the ethylene dichloride market.

The chemical compound 1, 2-dichloroethane, often known as ethylene dichloride, is a colorless liquid with a sweet odor produced by the reaction of ethylene with chloride. EDC is a chlorinated hydrocarbon liquid that is widely utilized in industries such as textiles, adhesives, construction, medical, and automotive, among others. One of the primary factors driving the expansion of the ethylene dichloride market is the increase in demand for the product from the building sector around the world. The market is expected to grow due to the growth of the PVC industry and its use in construction and electrical industries due to its lightweight and versatile nature, as well as an increase in the use of ethylene dichloride in industries such as transportation, packaging, healthcare, and apparel due to its high melting point and vapor pressure. Due to its high solubility and increased concerns about maintaining household products and industrial uses such as degreasing machines and other industrial uses, the product is being used as a solvent for cleaning and various extraction in the metal, textile, and adhesive industries, as well as the organic synthesis industry.

1.5.2) Global Ethylene Dichloride Market Country Level Analysis:

As mentioned above, the ethylene dichloride market is analyzed, and market size and volume data are supplied by nation, application, and end user industry. The United States, Canada, and Mexico in North America; Germany, France, United Kingdom, Netherlands, Switzerland, Belgium, Russia, Italy, Spain, Turkey, Rest of Europe in Europe; China, Japan, India, South Korea, Singapore, Malaysia, Australia, Thailand, Indonesia, Philippines, Rest of Asia-Pacific (APAC) in Asia-Pacific (APAC); Saudi Arabia, United Arab Emirates, Israel, Egypt, South Africa, Rest of Middle East and Africa (MEA) as a whole; Saudi Arabia, United Arab Emirates. Because of the rising usage of PVC in the execution of "smart city" projects in the region, North America dominates the ethylene dichloride market. Due to the region's fast industrialization, Asia-Pacific is predicted to grow rapidly throughout the forecast period of 2021 to 2028.

Figure 3: Global Analysis

Chapter 2: Process Selection

2.1) Introduction, Process Selection And Comparison:

The reactor used for the reaction is Plug Flow Reactor. The reaction takes place in Gas phase at high temperature and relatively low pressures. The temperature ranges from 40 °C to 150 °C and pressure ranges from 1.4 to 1.3 atm. The conversion of reactants is 98%. Catalyst used for the production of EDC is Ethylene Dibromide. It is not consumed in the reactor. It simply aids the conversion of reactants to products. No any side product is product is produced in the reactor. Catalyst is used in very low amounts. It is present the reactor in vapor phase. Steady-state condition is used in all the equipment's. There are no leakages in pipes and reactors. Ethane is also present in feed in small amounts.it has nothing to do with reaction. It simply passes from reactor without reacting.

The Degree of Freedom analysis showed that there is total 12 variables. Among these 5 are given variables, 6 given equations and 1 relation. In this way the degree of freedom of reactor is zero. The reaction taking place in reactor is highly exothermic. The heat of reaction is -88.53 MJ/mol. Temperature varies along the length of PFR to 150 °C.

2.1.1) Synthesis Of Product:

In this chlorination method, chlorine and ethylene are fed to a liquid-phase reaction vessel provided with heat exchange capabilities to remove the exothermic heat of reaction. Both liquid and vapor streams leave the reactor. The vapor pass through a water cooled and, in some cases, refrigerated, heat exchanger to condense the EDC and then to separator for removal of the condensate. Vapors from the separator are then scrubbed with water or dilute caustic to remove remaining EDC and small quantities of HCL and Cl_2. The condensed EDC from separator is combined with the liquid stream of EDC from the reactor and sent to the EDC purification section.

There are two methods used commercially for the production of Ethylene Dichloride (EDC).

- Direct Chlorination method
- Oxy-chlorination (basically it involving air)

2.1.2) Direct Chlorination Method:

Most important and widely used method for the production of EDC is by direct chlorination. Worlds 60 to 70 % EDC is produced by this method. Although this method uses pure reactants but it also produces 99% pure ethylene dichloride. This method for the production of EDC is also an efficient and cost effective and it requires low separation and transportation costs. The key reactants involved are chlorine and ethylene and the catalyst used is ethylene dibromide. Very low amounts of catalyst are enough. Catalyst used is also in the vapor phase.

Reactants (chlorine and ethylene) are stored in gas phases in separate tanks at room temperature. Reactor used is PFR. Inlet pressure is 1.5 atm and outlet temperature is almost same. The inlet temperature of reactor is 40 °C and outlet temperature is 150 °C. In the start of reactor, a catalyst is placed. Ethylene is passed through the catalyst mixer and it carries with it a very little amount of catalyst that is sufficient for the reaction to take place. Reaction is exothermic and takes place adiabatically in the reactor.

The temperature of reactor increases with the length of reactor. Products of reactor include chlorine, ethane, ethylene, water and ethylene dichloride. Mixture is then passed through a waste heat reboiler which basically removes the latent heat of reaction. Heat removed is basically used for the production of steam. Which is later used in reboilers of distillation columns. After reactor a condenser is installed which is basically a heat exchanger. Heavy products like EDC, water and ethylene are removed as liquid phase in the condenser. The liquid is further separated and purified in the distillation column. (OxyChem, 2014)

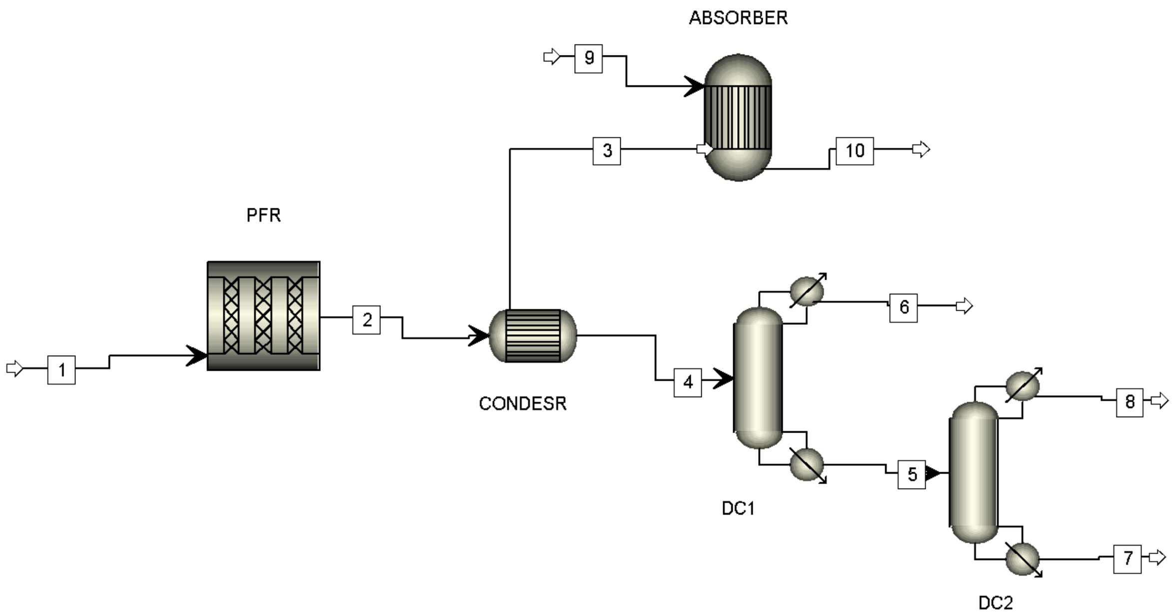

Figure 4: Flow Diagram (Method-1)

2.1.3) Direct Chlorination (Method 2):

In this chlorination method, chlorine and ethylene are fed to a liquid-phase reaction vessel provided with heat exchange capabilities to remove the exothermic heat of reaction. Both liquid and vapor streams leave the reactor. The vapor pass through a water cooled and, in some cases, refrigerated, heat exchanger to condense the EDC and then to separator for removal of the condensate. Vapors from the separator are then scrubbed with water or dilute caustic to remove remaining EDC and small quantities of HCL and Cl_2. The condensed EDC from separator is combined with the liquid stream of EDC from the reactor and sent to the EDC purification section. Part of the EDC intermediate for the balanced ethylene feedstock process is produced by direct chlorination of ethylene:

The reaction is exothermic, with a heat of reaction of 52 Kcal/mole. The reaction takes place in the liquid phase with ferric chloride acting as a catalyst. The reaction temperature is approximately at atmospheric pressure. The mechanism for the above reaction is (Morrison and Boyd,1973):

Formation of trace compound may occur by means of a chain reaction with substitution of additional chlorine atoms, as shown above (Morrison and Boyd, 1973).

This chain method yields all possible chloroethanes and to a much smaller extent, chlorobactenes and other chlorinated hydrocarbons. The ethylene and chlorine react almost quantitatively to give greater than 99% yield of ethylene dichloride product. EDC, as it comes from direct chlorination reactor, is of sufficient purity for pyrolysis. However, it may contain ferric chloride, which may lead to rapid fouling of the pyrolysis reactor. Other impurities are methane and ethane, which are present in the ethylene feed.

2.1.4) Oxy-Chlorination Method:

Other method for the production of EDC is oxy-chlorination which also involves the production of HCL.

This reaction also produces very large amounts of heat of reaction approximately more than 55 kcal/mole of ethylene dichloride produced.

Air is normally used as the source of oxygen, although pure oxygen may also be used. The ethylene oxychlorination is carried out at temperatures of 225-325 °C and at pressures of 1-15 atm. Catalysts for this reaction almost always contain copper chloride and sodium or potassium chloride deposited on alumina or other suitable support media.

Copper chloride ($CuCl_2$) is the active chlorinating agent. The cuprous chloride ($CuCl_2$) is produced is rapidly reconverted to ($CuCl_2$) under the reaction conditions, but the presence of some of cuprous chloride is thought to be advantageous because it complexes with ethylene, bringing the ethylene into contact with ($CuCl_2$) for a sufficient time for chlorination to occur. The purpose of sodium or potassium chloride is to increase EDC yield, mostly by inhibiting formation of ethyl chloride (Rothon, 1972).

Other catalysts components, such as rare metal chlorides, sulfate salts, ferric chloride and numerous other additives, have been described in the patent literature (McPherson, 1979).

Temperature control of the reaction is a key element in the successful production of EDC. Temperature higher than 325 °C lead to increase by-product formation, mostly through increased dehydrochlorination of EDC to vinyl chloride followed by additional oxychlorination to give products having high levels of chlorine substitution. Examples of these reactions and by-products are given later in this section. High temperatures also increase the amount of ethylene oxidized to carbon monoxide and carbon dioxide and are deleterious to catalyst life and activity.

Temperature control in fluidized bed reactors is maintained by the mixing of the catalyst particles and by the use of internal cooling surfaces. Temperature control in fixed bed reactors is more difficult. It is common practice in fixed bed reactors to pack the tubes with progressively more active catalyst mixtures so that there will be low catalyst activity at the inlet with steadily increasing activity to a maximum at the outlet. This grading of the catalyst activity allows good temperature control with high EDC production rate.

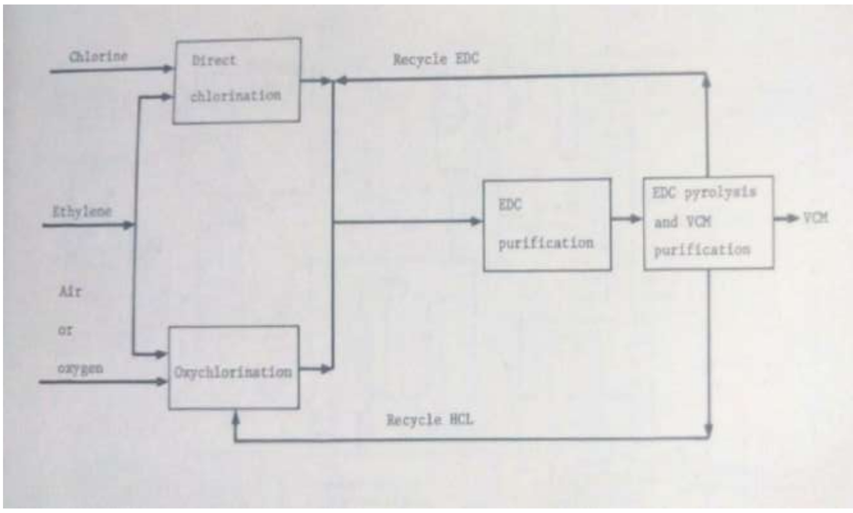

Figure 5: Main flow diagram

Chlorination of ethylene, operated good control, results in 94-97 % HCL conversion and 93-95 % yield of EDC. Excess ethylene in vent gases from oxychlorination is usually converted to EDC by direct chlorination with chlorine (Severin, 1977; Stauffer, 1971). If oxygen is used rather than air, the excess ethylene may be recycled to the oxychlorination reactor.

By-products of ethylene oxy-chlorination are vinyl chloride, ethyl chloride, 1,1-dichloroethylene, vinylidene chloride, cis and trans 1,2-dichloroethylene, trichloroethylene, chloroform, carbon tetrachloride, methyl chloride, chloral and high-boiling compounds such as trichloroethane and tetrachloroethane (McPherson, 1979).

The quantities of by-products need to be minimized to lower raw material costs, lessen the difficulties of purifying the crude EDC and prevent fouling in the pyrolysis reactor. Chloral, in particular, to be removed since it polymerizes readily in strong acids to give solids that clog and foul operating lines and controls. The ethylene and HCL feed to the oxychlorination reactor must be pure. Selective hydrogenation of this acetylene and ethane is practiced by many companies.

2.2) The Process (Introduction To Selected Process):

Most important and widely used method for the production of EDC is by direct chlorination. Worlds 60 to 70 % EDC is produced by this method. Although this method uses pure reactants but it also produces 99% pure ethylene dichloride. This method for the production of EDC is also an efficient and cost effective and it requires low separation and transportation costs. The key reactants involved are chlorine and ethylene and the catalyst used is ethylene dibromide. Very low amounts of catalyst are enough. Catalyst used is also in the vapor phase.

Reactants (chlorine and ethylene) are stored in gas phases in separate tanks at room temperature. Reactor used is PFR. Inlet pressure is 1.5 atm and outlet temperature is almost same. The inlet temperature of reactor is 40 °C and outlet temperature is 150 °C. In the start of reactor, a catalyst is placed. Ethylene is passed through the catalyst mixer and it carries with it a very little amount of catalyst that is sufficient for the reaction to take place. Reaction is exothermic and takes place adiabatically in the reactor.

The temperature of reactor increases with the length of reactor. Products of reactor include chlorine, ethane, ethylene, water and ethylene dichloride. Mixture is then passed through a waste heat reboiler which basically removes the latent heat of reaction. Heat removed is basically used for the production of steam. Which is later used in reboilers of distillation columns. After reactor a condenser is installed which is basically a heat exchanger. Heavy products like EDC, water and ethylene are removed as liquid phase in the condenser. The liquid is further separated and purified in the distillation column. (Francisco Jose Freire, 2012)

2.2.1) Pyrolysis:

Purified EDC is vaporized and passed through a cracking (pyrolysis) furnace to produce crude VCM. The pyrolysis furnace is heated by the burning of fuel. The hot flue gas from the burning of the fuel is discharged to the atmosphere. The hot effluent gases from the pyrolysis furnace are quenched and partially condensed by direct contact with cold EDC in a quenched tower. The cooled mixture is then sent to the HCL removal tower. The HCL overhead is returned to the oxychlorination process. The bottom from the HCL removal column is sent to distillation for purification and recovery of vinyl chloride and EDC. In the light of ends column, low boiling

2.3) Site Selection:

Proposed Site Location is Gwadar Industrial Estate. Here are the factors that we have considered in Site Selection:

2.3.1) Raw Materials Availability:

As mentioned earlier that we are importing Nitric acid from India and Liquefied propane Saudi Arabia through shipment, and Gwadar Industrial Estate is just 49.2 km from Gwadar Port.

2.3.2) Water Supply:

Zoodni dam is about 2.7km away from Gwadar Industrial Estate and hence cooling water utility is abundantly available.

2.3.3) Transportation Facilities:

All three means of transport are available near to the Gwadar Industrial Estate as it is about 37.1km away from Gwadar International Airport, 49.2 km from Gwadar Port and about 170 km away from Makran. Costal high way. Hence, availability of Nitroparaffins in domestic and international market can be assured easily.

2.3.4) Energy Availability:

China Communications Construction Company (CCCC) is working on Gwadar coal-based power plant under the supervision of Gwadar Port Authority (GPA) / Gwadar Development Authority (GDA) and this plant is proposed to produce 300-megawatt (MW) energy and will be in service by 2022. So, energy availability will not be an issue.

2.3.5) Market:

Nitroparaffins can be exported through Gwadar Port across the world. Gwadar will become an international trade center in coming 5-10 years. (Buys, 2017)

2.4) Process Flow Diagram:

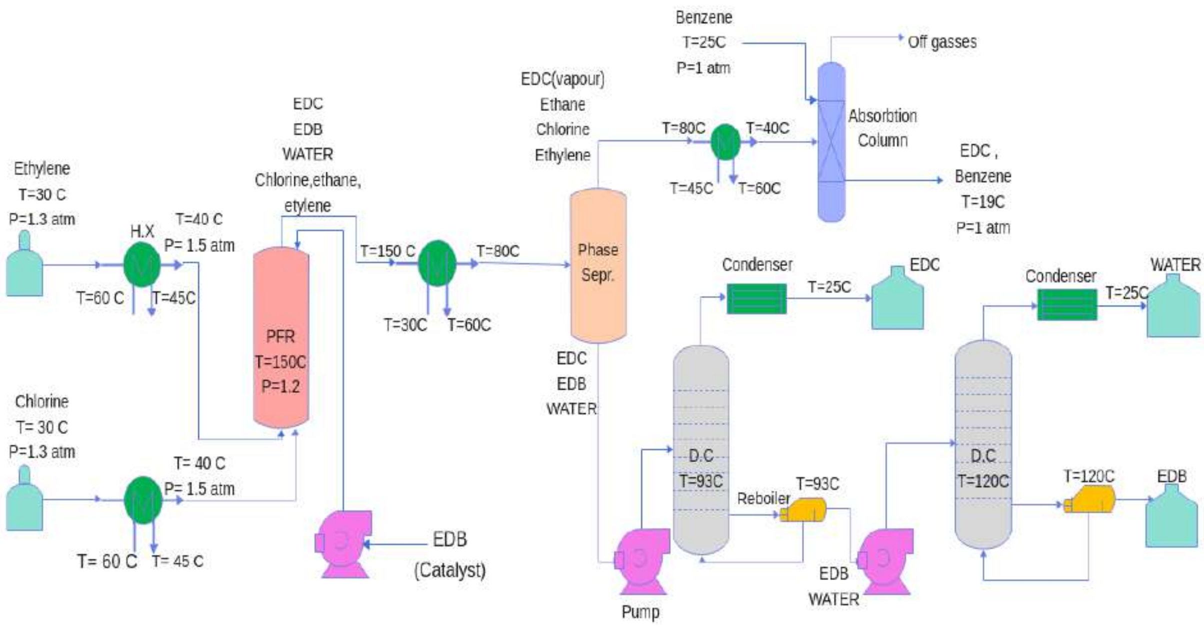

Figure 6: Process flow diagram

Chapter 3: Material And Energy Balance

3.1) Capacity Selection:

Depending on the requirements in various companies of Pakistan, we have decided our capacity to be 50,000 tons/year.

50,000 tons/year = 5952.38 kg/hr

3.2) Assumptions:

1. Mass out = Mass in + Generation – Consumption – Accumulation
2. All calculations performed at steady state conditions.
3. Pure raw material (reactant) is used.
4. There are no leakages in pipes and vessels in the system.
5. Catalyst used in the reactor does not affect the material balance.

Components	Formula	Molar masses
Ethylene	C_2H_4	28
Ethane	CH_4	30
Chlorine	Cl_2	71
EDB	$C_2H_4Br_2$	187
Water	H_2O	18
EDC	$C_2H_4CL_2$	99

Table 3.1 Components involve

3.3) Reactor (R-101):

Reactions involved in this reactor are as follows:

$$\mathbf{C_2H_4 + Cl_2 \rightarrow C_2H_4Cl_2}$$

Operating Conditions:

Conversion: 98%

Components	Stream 1 Inlet	Stream 2 Inlet	Outlet Stream
	Masses (Kg)	Masses (Kg)	Masses(kg)
Ethylene	1995.49	0	217.69
Ethane	105.03	0	105.03
Chlorine	0	4600	92
EDB	0	370.31	370.31
Water	0	93.87	93.87
EDC	0	0	6285.80
Total	2100.52	5064.18	7164.71
Inlet total	7164.71		Outlet total:7164.71

Table 3.2: Reactor material balance

EDB = Ethylene dibromide

EDC = Ethylene dichloride

Reactor Energy Balance:

Basis: 1 hr operation

Energy Balance Equations:

$$+((H+0.5u\ 2 + zg)n) = Q + w$$

$$\Delta H = \Delta H_R + \Delta H_{298} + \Delta H_P = 0$$

$$= 11414.35 \text{ J}$$

$\Delta H_{298} = conv. * moles\ of\ limiting\ reac. * Cp\ form./mole$

Heat Capacity Equation:

$$C_p = A + BT + CT^2 + DT^3 + ET^4$$

Assumptions:

- Adiabatic and no shaft work
- Neglect kinetic potential terms and assuming steady state
- Conversion is 98%

Operating Conditions:

- T_{ref}=25 °C (298K)
- T_{in}=40 °C (313K)
- Tout=150 °C
- Pressure (1.2 atm)
- ΔH_f^0= -182000 J/mol.K

Component	Input (MJ)		Output (MJ)
ΔH	ΔH_R	ΔH_{298}	ΔH_P
Total	- 88532.14	-11555.71	11414.35

Table 3.3: Reactor energy balance

2.5) Material Balance Of Partial Condenser:

Operating Conditions:

Inlet temperature = 150 °C

Outlet temperature = 80 °C

Cooling water inlet temperature = 30 °C

Cooling water outlet temperature 60 °C

Pressure = 1.4 atm

Feed moles		83.25	
Total Vapor moles	15.94	Liquid Moles	67.31

Components	Input (Kg)	Output (Kg)	
	Stream 7 (Gas)	Stream 8 (vap.)	Stream 8 (liq.)
Ethylene	217.69	217.69	0
Chlorine	92	91.99	0
Ethane	105.03	105.02	0
EDB	370.31	1.95	368.35
EDC	6285.80	364.73	5921.06
Water	93.87	4.84	89.03
Total:	7164.70	786.24	6378.45
		7164.70	

Table 3.4: Material balance of partial condenser

Components	Heat of condensation	Heat released for vap. (j/mol)	Heat released of liq till cond.. (j/mol)	heat released of liq. (j/mol)	Q (j/hr)
Ethylene	-4150.05	-3103.79	0	0	-24130911.12
Chlorine	-12501.08	-2094.93	0	0	-2714562.76
Ethane	-6406.47	-3850.61	0	0	-13480478.61
EDB	-36039.58	-5942.52	-511.33	-7952.82	-87726675.93
EDC	-31554.27	-5474.38	-5062.47	-655.23	-2249359342
Water	-38862.85	-2046.84	-1240.09	-1794.64	-207791933.2
Total	-129512.58	-22509.38	-6813.74	-10401.35	-2.59E+09

Table 3.5: Energy balance of partial condenser

Energy balance of partial condenser:

Cooling water energy balance:

T (inlet) °C	T (out) °C	C_p water (j/Kg.K)	M (Kg/hr)	Q (J/hr)
30	60	4200	41034.98	-2.59E+09

Operating conditions:

Inlet temperature = 30 °C

Outlet temperature = 60 °C

Mass flow rate = 42859.78 Kg/hr

Component	heat released (j/mol)	Q (j/hr)
Ethylene	-51450.38	-400008651.9
Chlorine	-23844.05	-83474796.79
Ethane	-65536.96	-84921132.45
EDB	-85375.50	-169066322.7
EDC	-80378.64	-419208378.4
H2O	-24309.57	-1543486961
Total		-2700166243

Table 3.6: Cooler energy balance

2.6) Distillation Unit 1:

Material Balance:

Assumptions:

Light key: EDC 98% in Distillate

Heavy key: Water 5% in bottom

Conversion:

Basis: 1 hr operation

Overall Balance:

F = D + W

66.7249 = D + W

W = Water

D = Distillate

F = Flow

EDC Balance: 0.98D+0.05W= 0.89634(66.7249)

Distillate:

Components	Mass flow (kg/hr)
EDC	5921.06
Water	89.03
EDB	368.35
Total	6378.45

Table 3.7: Distillation material balance

Bottom:

Water 3.9777	Components	Kg Moles	Masses (Kg)
	EDC	0.19	19.68
	Water	1.80	32.56
	EDB	1.96	368.35
	Total	3.97	420.60

Distillate	Components	Kg Moles	Masses (Kg)
	EDC	59.60	5901.37
62.7472	Water	3.13	56.47
	Total	62.74	5957.89

Energy Balance:

$$Q - W_s = \Delta H + \Delta E_k + \Delta E$$

Assumptions:

- No moving parts $W_s = 0$
- Negligible velocity change $E_k = 0$
- Negligible height change $E_P = 0$

$$Q = \Delta H$$

$$Q_{net} = (\sum n_i H_i)_{out} -(\sum n_i H_i)_{in}$$

Operating Conditions:

$T_{ref} = 25$ °C

$T_{ini} = 93$ °C

Component	C_p (J/mole.k)	N	ΔH (J)	
EDC	8681.86	59808.74	519251223	
Water	4888.72	4946.37	24181478.62	
EDB	8844.33	1969.82	17421800.28	
Total	22413.58	66742.93	560854501.9	
Θ				
Components	Feed k values	relative volatility	Underwood	R_m
EDC	1.04E+00	1.71E+00	0.0008	2
Water	0.60	1	0.0005	4
EDB	0.24	0.40	0.0003	5

Table 3.8: Distillation energy balance

To Find Dew Temperature:

Operating Conditions:

- Temp : 93 °C
- Pressure: 1.3 atm

Component	Yd	Psat	K-Values	∑Xi=Yi/K
EDC	0.95	1.02E+03	1.035	9.18E-01
Water	0.05	5.99E+02	0.606	8.25E-02
Total	1	7.01E+05	1.64	1.00E+00

Table 3.9: Dew temperature

To Find Bubble Temperature:

Operating Conditions:

- Temperature = 93 °C
- Pressure = 1.3 atm

Component	Xd	Psat	k-values	∑yi=xiK
EDC	0.04	1652.13	1.67	0.10
Water	0.45	1428.83	1.44	0.65
EDB	0.49	517.70	0.52	0.25
Total				1.00

Table 3.10: Bubble temperature

Condenser Duty:

Operating Conditions:

- T_{dew} = 93 °C
- λ=A(1-T/Tc)^n
- Qc=λ*n

To Find Mass Of Water:

Tin °C	Tout °C	C_p (J/kg.k)	m=Qc/ C_p dT (Kg/hr
30	60	4200	159474.89

Reboiler duty:

Component	A	Tc	N	λ (kj/mol)	n (Bottom flow rate)mol	Qr (J/hr)
EDC	45.42	561	0.342	30.25	15686.80	474655347
Water	52.05	647.13	0.321	38.70	142682.81	5522658550
EDB	42.93	476	0.36	23.18	155366.48	3602879594
Total						9.93E+09

Table 3.11: Reboiler Duty

Distillate Enthalpy:

Operating Conditions:

- T_{ref} = 25 °C
- T_f = 93 °C

Component	N	C_p dT (J/mol)	ΔH=n C_p dT
EDC	59609.86	6598.74	393350535.2
Water	3137.36	3163.69	9925651.88
Total			403276187.1

Table 3.12: Distillate top enthalpy

Bottom Enthalpy:

Operating Conditions:

- T_{ref} = 25 °C
- T_f = 83 °C

Component	N	C_p dt	ΔH=nC_pdT
EDC	198.88	1.25E+04	2487339.36
Water	1809.01	6935.39	12546226.03
EDB	1969.82	12685.92	24989066.63
Total			40022632.03

Table 3.13: Distillate bottom enthalpy

2.7) Distillation Unit. 02:

Material Balance:

Assumptioms:

- Product purity: 95 %
- Light key: Water
- Heavy key: EDB

Basis: 1hr operation

Overall Material Balance:

F = D + W

3.97 = D + W

EDB Balance:

0.005D+0.999W= 0.4952(3.977)

F	D
3.978	1
1.970	0.005
D	2.01
W	1.96

Distillate:

D	Components	Kg Moles	Masses (Kg)
2.016019288	EDC	0.19	19.68
	Water	1.80	32.52
	EDB	0.01	1.88
	Total	2.01	54.10

F = Flow

D = Distillate

W = Water

Bottom:

W	Components	Kg Moles	Masses (Kg)
1.961707005	Water	0.001	0.03
	EDB	1.95	366.47
	Total	1.96	366.50

Table 3.14: Distillate overall material balance

Energy Balance:

Energy Balance Equation:

$Q - W_s = \Delta H + \Delta E_k + \Delta E_p$

$Q_{net} = (\sum n_iH_i)_{out} -(\sum n_iH_i)_{in}$

$Q = \Delta H$

Assumptions:

- No moving parts : Ws= 0
- Negligible velocity changes : Ek= 0
- Negligible height change : Ep = 0
- T_i = 93 °C
- T_{ref} = 25 °C

Component	C_p (J/mole)	n	$\Delta H=n(C_p\, dT)$(J)
EDC	1.25E+04	198.88	2483502.67
Water	6920.24	1809.01	12518828.85
EDB	12666.18	1969.82	24950175.14
Total	19587.67	3976.88	39952506.66

Table 3.15: D-2 material balance

To Find Dew Temperature:

Operating Conditions:

- Tdew : 120
- Pressure : 1.3 atm

Component	Yd	Psat	K-Values	∑Xi=Yi/K
EDC	0.09	1.47E+03	1.49E+00	6.65E-02
Water	0.89	9.49E+02	9.60E-01	9.34E-01
EDB	0.005	6.85E+07	6.93E+04	7.21E-08
Total	1.00			1.00E+00

To Find Bubble Temperature:

Operating Conditions:

- T_{bubble} : 120 °C
- Pressure : 1.3 atm

Component	Xd	Psat	k-values	∑yi=xiK
Water	0.0009	2886.67	2.92	0.002
EDB	0.99	986.11	0.99	0.997
Total	1	3872.67	3.90	1.00

		Ɵ	1.457038					
Component		Feed k values	Relative volatility	Rm	R	Ln	Vn	Vm
EDC	0.05	2.00E+00	3.82	1.12	2.254	4.54	6.56	6.56
Water	0.45	1.39589	2.66	1.39	2.39	5.64	7.93	7.80
EDB	0.49	0.523995	1.0	1.45	2.87	6.78	8.10	8.32

Table 3.16: Bubble temperature

Condenser Duty:

Operating Conditions:

- Tdew : 93 °C
- $\lambda = A(1-T/T_c)^n$
- $Q_c = n*\lambda$

Condenser Duty At Top:

Component	A	Tc	n	λ (kj/mol)	Qc (Kjoule)	Qc (joule)
EDC	45.42	561	0.342	31.31	20266.49	20266497.73
Water	52.05	647.13	0.321	39.55	232607.56	232607556.1
EDB	42.93	650.15	0.187	36.63	1201.57	1201574.04

To Find Mass Of Water:

Tin °C	Tout °C	C_p (j/kg.k)	m=Qc/Cp dT
30	45	4200	4032.94

Boiler Duty:

Operating Conditions:

- T_{bubble}: 120 °C

Component	A	Tc	n	λ (kj/mol)	Qr (Kjoule)	Qr (J/hr)
Water	52.05	647.13	0.32	38.70	253.90	253908.41
EDB	42.93	650.15	0.18	36.17	237077.78	237077781.9
Total	94.35	1297.56	0.50	75.01	237330.30	254568253.4

Distillate Enthalpy:

Operating Conditions:

- T_{ref}: 25 °C
- T_f : 93 °C

Component	N (moles)	C_p	ΔH=n C_p dT
EDC	198.88	7.99E+03	1589881.65
Water	1807.05	3.85E+03	6956333.78
EDB	10.08	8.66E+03	87267.22
Total	2016.89	401.65E+09	8633482.66

Table 3.17: Enthalpy Balance

Bottom Enthalpy:

Operating Conditions:

- T_{ref}: 25 °C
- T_f : 93 °C
- DHD + WHW + Qc
- FHF+Qr

Component	N	C_p dT	ΔH=n C_p dT
Water	1.96	8792.22	17247.76
EDB	1959.74	16223.74	31794401.84

Condenser Material Balance:

Efficiency	80%
Feed moles	15.94
Vapor mole out	13.30
liquid mole out	2.64

Condenser Inlet:

Components	vapor masses(kg)
Ethylene	217.69
Chlorine	91.99
Ethane	105.02
EDB	1.95
EDC	364.73
Water	4.84
Total	786.24

Condenser Outlet:

Components	vapor mols	masses	liquid mols	masses
Ethylene	7.77	217.69	0	0
Chlorine	1.29	91.99	0	0
Ethane	3.50	105.02	0	0
EDB	0	0	0.01	1.95
EDC	0.73	72.94	2.94	291.78
Water	0	0	0.26	4.84
Total	13.30	487.66	3.21	298.58

Condenser Energy Balance:

Components	Condensation (kj/mol)	For vapor (j/mol)	For Condensation (j/mol)	For liquid (j/mol)	Qc (j/hr)	Qc (cal/hr)
Ethylene	-4.15	-2354.90	0	-6706.66	-2354.90	-563.37
Chlorine	-12.50	-1713.09	0	-3569.17	-1713.09	-409.81
Ethane	-6.40	-2890.52	0	-6044.23	-2890.52	-691.51
EDB	-36.03	-4620.71	-665.33	-5878.87	-444659	-106377
EDC	-31.55	-4217.35	-609.64	-5775.76	-114929743	-27495154
Water	-38.86	-1688.19	-237.22	-3231.00	-11388917	-2724621

Cooling Water Energy Balance:

Tin °C	Tout °C	Qc (j/mol)	C_p (j/Kg.K)	m=Qc/ C_p *(Tout-Tin) (Kg/hr)
30	60	126770279.6	4200	815.76

Absorption Column Material Balance:

Feed				
Components	Vapor moles (k moles)	Masses (kg)	Molecular Masses	Fraction Composition
Ethylene	7.77	217.69	28	0.58
Chlorine	1.29	91.99	71	0.09
Ethane	3.50	105.02	30	0.26
EDC	0.73	72.94	99	0.05
Total	13.30	486.30	228	1

F= D+ W

13.32= D+W

EDC Balance:

0.055367855*(13.30812172) =0.05(D)+.95(W)

Components	Molar Masses (kg/kmol)	Molar flow (kmol/hr)	Masses (kg/hr)	Fraction Component	Molar flow rate (kmol/hr)	Masses (kg/hr)
Ethylene	28	7.77	217.69	0.61	0	0
Chlorine	71	1.29	91.99	0.10	0	0
Ethane	30	3.50	105.02	0.27	0	0
EDC	99	0.03	3.64	0.002	0.70	69.3

2.8) Absorption Column Energy Balance:

Enthalpy of inlet stream			Enthalpy of top product		Enthalpy of bottom stream	
Components	heat capacity flow rate (j/mol)	ΔH (j/hr)	heat capacity flow rate (j/mol)	ΔH (j/hr)	heat capacity flow rate (j/mol)	ΔH (j/hr)
Ethylene	667.40	5188818.4	667.40	5188818.4	667.40	0
Chlorine	507.37	657447.26	507.37	657447.22	507.37	0
Ethane	811.89	2842327.9	811.89	2842321.6	811.89	0
EDC	1202.06	885729.99	1202.06	44286.49	1202.07	841449.80

Chapter 4: Detailed Equipment Design

4.1) Reactor R (101):

Feed Inlet

Product Outlet

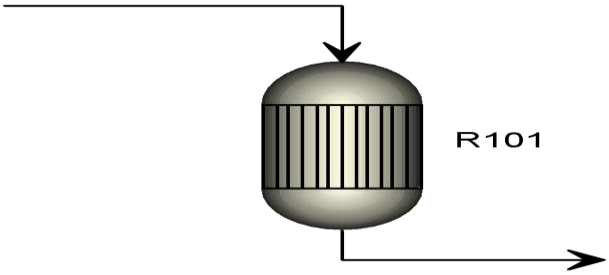

Figure 7: Plug flow reactor 1

Operating Conditions:

Phase	: Gaseous
Operating Temperature	: 40-150 °C
Operating Pressure	: 1.4 atm
Catalyst	: Ethylene Dibromide
Conversion	: 98 %

Reaction Kinetics:

$-r_A = k\ C_A^{*}\ C_B$

$k = 0.011\ m^3/gmol.s$

Volume Of Reactor:

$$\frac{\tau}{C_{A0}} = \frac{V}{F_{A0}} = \int_{X_0}^{X} \frac{dx}{-r_A}$$

V=32.55 m^3

Length To Diameter Ratio Of Reactor:

$\frac{L}{D} = 5$

V = L*A = L*$\frac{\pi}{4} D^2$ = 32.54 m^3

L = 10.37 m , D = 2.073 m

Cross Sectional Area Of Reactor:

A = $\frac{\pi}{4} D^2$ = 5.35 m^2

Wall Thickness Of Shell:

t = $\frac{P*D}{2S*E-1.2P} + C$

t = 0.011 m

Design of Domed ends:

$t_S = \frac{P*D}{2S*E-0.2P} + C$

t_S = 0.011043 m

Outer diameter of shell:

$D_o = D_i + t$ = 2.084 m

Weight Of Shell:

This is given by the formula:

$$W_v = C_v \pi \rho_m D_m g(H_v + 0.8D_m)t \times 10^{-3}$$

D_m = 2.073 m

H_v = 10.37 m

ρ_m = 7980 kg/m^3 (material)

Weight of Shell W_v = 73454.8 N

Weight of insulation:

Vol. of Insulation = $\pi D_m H_v t$

P = 200 kg/m^3 , g = 9.8 m.s^{-2}

D_m = 2.073 m

H_v = 10.37 m

t = 0.011 m

V_i = 0.7463 m^3

W_i = 1462.7 N

Total weight of Reactor:

Total weight = $W_i + W_v$ = 74917.56 N

Pressure Drop Across Reactor:

This is calculated using general gas flow equation:

$$Q = 1.1494 \times 10^{-3} \left(\frac{T_b}{P_b} \right) \left[\frac{\left(P_1^2 - P_2^2 \right)}{G T_f L Z f} \right]^{0.5} D^{2.5}$$

D = 2073 mm

P_1 = 141.65 KPa

ΔP = 30.2 kPa

Specification Sheet:

No. of reactors	1
Operation	Continuous
Type	Catalytic, plug flow reactor
Volume	32.54 m^3
Length of shell	10.36 m
Diameter of shell	2.073 m
Reactant conversion	0.98
Density of material	7980 $\frac{kg}{m^3}$
Weight of shell	73454.8 N
Insulation weight	73454.8 N
Total weight	74917.56 N
Thickness of Shell	0.011 m
Pressure Drop	0.3 atm
Space time	5 s
Space velocity	0.2 sec^{-1}

(Richardson's, 2011)

4.2) Shell And Tube Heat Exchanger Design:

Heat Exchanger Energy Balance:

Operating conditions:

Pressure: 1.4 atm

Temperature: 150-80 °C

Hot stream:

Components	**Heat of condensation (J/mol)**	**Heat released for vapor (J/mol)**	**Heat released of liquid (J/mol)**	**Q_h (J/hr)**
Ethylene	-4150.056	-3103.795	0	-24130911.12
Chlorine	-12501.088	-2094.934	0	-2714562.769
Ethane	-6406.479	-3850.614	0	-13480478.61
EDB	-36039.589	-5942.523	-7952.82	-87726675.93
EDC	-31554.273	-5474.383	-655.23	-2249359342
Water	-38862.859	-2046.841	-1794.64	-207791933.2

Table 4.1: EB of HX

Cold Stream:

Mass flow Rate (Kg/s) = 1.99

Q_h (Watt)	7.181E+05
Q_c (Watt)	7.181E+05
Difference	0.0001

Equipment Selection:

Why shell and tube Heat exchanger:

Shell and tube exchanger is by far the most commonly used type of heat exchanger and the advantages of shell and tube exchanger are:

- The configuration gives a large surface area in a smaller volume.
- Good mechanical layout and a good shape for pressure
- Uses well established fabrication techniques
- Can be constructed from wide range of materials
- Maintenance is easy
- Well established design procedures.
- The construction is simple and economical.
- The inside of the tubes can be cleaned mechanically or chemically

Figure 8: Heat exchanger

Physical Properties:

Fluid Properties Hot stream					
Components	Composition	C_p (J/kg-K)	k (Watt/m-K)	Viscosity (N*s/m2)	Density (kg/m3)
Ethylene	0.09	690.15	136.82	0.00013	730.01
Ethane	0.04	9.65	92.63	0.00012	789.96
Chlorine	0.02	563.04	24.81	0.00017	851.29
EDB	0.02	334.63	0.02	0.00014	1206.19
Water	0.06	361.24	0.23	0.00013	1302.10

EDC	0.76	68.65	0.26	0.00011	1205.72
Weighted mean	1	156.48	17.26	0.00012	1144.38

Cold stream properties					
Component	C_p water (KJ/Kg. K)	Density (Kg/m3)	K value	viscosity N*s/m2	Composition
water	4.2	994.94	0.61	0.00079	1

Table 4.2: Physical properties

Fluid Placement:

Shell Side Fluid Will Be Water:

- Water will be in shell side as it is non- corrosive
- It has less fouling and scaling
- it has less temperature
- high pressure drop
- low flow rate

Tube Side Fluid:

- Process stream will be in Tube side as it is corrosive
- It has high fouling and scaling
- it has high temperature
- Less pressure drop
- High flow rate

Log Mean Temperature Difference (LMTD) :

Hot stream inlet: 150°C

Hot stream outlet: 80 °C

Cold stream inlet: 30 °C

Cold stream outlet: 60 °C

ΔT_{lm} = 68.05

LMTD Correction Factor:

F_t	0.92
ΔT_m	62.60
R	2.33
S	0.33

Length of Tubes L_T (ft.)	20
Diameter of tubes D_0 (in.)	1
Tube wall Thickness (BWG)	14
Length of Tubes L_T (m)	6.098
Diameter of tubes D_0 (m)	0.025
Inner dia of tubes (inch)	0.834
Inner dia of tubes (m)	0.0212

Estimation Of Overall Heat Transfer Co-Efficient:

For the initial estimate for the size of heat exchanger we have to assume U_D

U_D (Wat/m^2-K)	200

Heat Transfer Area And Number Of Tubes:

As, water stream is at really high pressure and temperature so, recommended tubes for highly fouling fluids will be used.

Area (m2)	50.55
Nt	103.92

Number Of Tubes Passes:

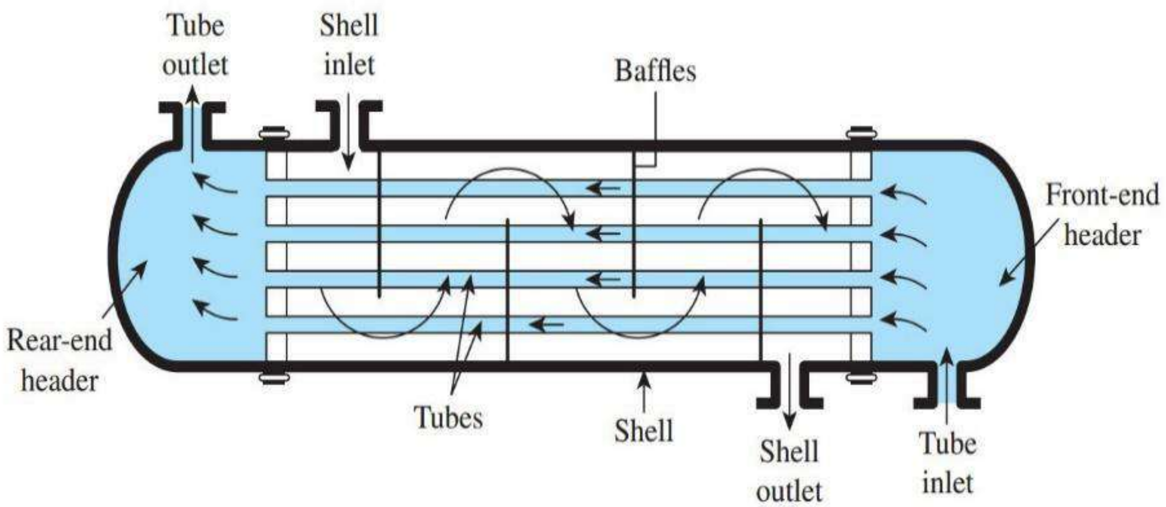

Figure 9: Internal Design 1

For BWG 14 pipe	
Di (in.)	0.834
Di (m)	0.021
Di (mm)	21.18
Np	2

Table 4.3: Design of heat exchanger

Calculation Of Required Overall Coefficient (Ur):

Ur (Watt/m^2-K) =	196.079

Tube Side Heat Transfer Coefficient (hi) Calculations:

Surface area of one tube (m2)	0.48
Nt	103.92
Cross sectional area A (mm2)	352.44
Cross sectional area A (m2)	0.00035
Tube per pass	51.5
Total flow area A (m2)	0.0091

Mass velocity Gs (kg/s.m2)	217.35
Density of Process stream (Kg/m3)	1144.38
Linear velocity u (m/s)	0.18

Tube Side Heat Transfer Coefficient (hi) Calculations:

Re	7998.9
Pr	11.11
L/di	287.76
Jh	5.00E-03
hi (Watt/m2.k)	338462.17

Tube Pitch:

- As shell side fluid is clean water so we will be using triangular pitch

Pt (m)	0.031

Shell Side Heat Transfer Coefficient calculations (ho):

Bundle Diameter:

- Assume 1 shell passes and 2 tube passes
- From Table 12.4 Coulson and Richardson, k1 and n1

K1	0.175
n1	2.285
Db (m) =	0.415

Shell Diameter And Baffle Spacing:

- Using a fixed tube head type because we have normal temperature ranges and no thermal expansion
- From Figure 12.10 Coulson And Richardson,

Bundle diametrical clearance = 0.012m

- $Shell\ diameter\ Ds = Clearnce + Db$
- Baffle spacing is 45% of Ds

Ds (m)	0.43
Baffle Spacing l_B (m)	0.19

Cross Flow Area:

As (m^2)	0.0165

Shell Side Mass Velocity Gs And Linear Velocity U_s:

- Where Ws is fluid flow rate on shell side, Kg/s
- ρ is shell side fluid density

Gs (kg/m2-s)	346.141
u_s (m/s)	0.35

Shell Side Equivalent Diameter:

De	0.0180

Shell Side Reynold's Number :

Re	37532.20
Pr	5.34

Heat Transfer Co-Efficient Ho :

From graph in Coulson and Richardson fig 12.29 jh value is obtained

Jh	0.01
hs (watt/m2.k)	4695.82

Over All Heat Transfer Coefficient:

- Material of tubes is carbon steel
- From Table 12.6 of Coulson and Richardson

kw (W/m-oC) = 45

From Table 12.2 of Coulson and Richardson

Fouling factor on tube side = h_{id}(W/m^2-°C) = 5000

Fouling factor on shell side = h_{od} (W/m^2-ºC) = 3000

Actual Area	
A (m^2) =	45.9
$1/U_o$ =	0.0045
U_o (W/m^2-^oC) =	220.16

Table 4.4: Design specifications

Pressure Drop Calculations:

Tube Side Pressure Drop:

As we have tube side Re use that and fig. 12.24 friction factor j_f value obtained

Assume viscosity change is negligible so take viscosity factor is = 1

Re =	3.75E+04
j_f (Friction factor)	2.30E-01
ΔP_t (N/m2)	43921.681
ΔP_t (psi)	6.36 < 10 psi

Shell Side Pressure Drop:

Assume viscosity change is negligible so take viscosity factor is = 1

(Richardson's, 2011)

Re =	7.83E+03
j_f (friction factor)	1.60E-01
DP_s (N/m2)	57889.38
DP_s (psi)	8.39 < 10 psi

4.3) Mechanical Design Of Heat Exchanger:

Wall Thickness Of Material:

Design Of Domed Ends:

Ellipsoidal heads are cheaper and provide less internal volume, they are the same thickness as the shell, and are most common for systems with greater than 15 bar.

Corrosion allowance margin is usually between 1/16" and 3/16"

Weld/Joint Efficiency for Double butt E = 0.80

S = 1625000 Psi for 316-stainless steel

Calculation Of Stress:

Longitudinal Stress: $\sigma_L = \frac{PD_i}{4t}$ Hoop Stress: $\sigma_h = \frac{PD_i}{2t}$

Parameters	Symbol	Values	Units
Corrosion allowance	C	0.125	in
Inside Diameter	D	4.027	m
Welded joint efficiency	E	0.80	
Internal pressure	P	507.77	Psi
Max allowable stress	S	162500	Psi
Wall thickness of material	t_s	0.011	m
Thickness of ends	T	0.011043	m

Parameters	Symbol	Values	Units
Internal Pressure	P	507.77	Psi
Inner Diameter of shell	Di	4.027	m
Wall thickness of shell	T	0.011	M
Hoop Stress	σ_h	92458	Psi
Longitudinal Stress	σ_L	46229	Psi
Dead Weight stress	σ_W	98.93	Psi
Radial Stress	σ_R	254	Psi

(Richardson’s, 2011)

4.4) Design Of Distillation Column:

Working Principle:

Separation of a mixture based on the difference in the boiling point (or volatility) of its components.

Distillation:

- Oldest separation process and the most widely used unit operation in industry
- Well-established technology and supply of equipment
- Almost gives the pure product
- Has the potential for high mass transfer rates
- No solvent involvement in conventional distillation
- Thermodynamic efficiency for distillation is higher than all available processes

Tray Column	Packed Column
• Trayed columns can handle wide range of gas and liquid flow rates	• Packed columns are more suitable for low-capacity operations
• Tray efficiency can be predicted more accurately	• Efficiency of these types of columns are difficult to observe
• These types of columns are better for non-foaming systems	• Packed columns are suitable for handling foaming system
• Cleaning due to fouling deposition is easily to perform	• Cleaning due to fouling deposition is easily to perform

Conclusion

We have

- High gas and liquid flowrates
- Non foaming system

Hence, Tray Column will be the better choice.

As a rule of thumb, plates are always used in columns of large diameters and towers that have more than 20 to 30 stages (in our case stages were 51).

Selection Of Plate Type:

Factors	Sieve Plate	Valve	Bubble-Cap
Relative Cost	1	1.2	2.0
Capacity	Relatively high	High	Low
Pressure Drop	Lowest	Intermediate	Highest
Vapor Capacity	Highest	Highest	Lowest
Efficiency	Low	High	Highest
Maintenance	Easy	Hard	Hardest

Table 4.5: Selection of plate type

Conclusion:

We have to require:

- Low cost & Pressure drop
- High Capacity & easy maintenance

Hence, Sieve Plate will be the better choice.

Physical Property Estimations:

Components	M wt.	P^{sat} (mm of Hg)	Density (kg/m^3)	Surface Tension (dynes/cm)	Viscosity (Ns/m^2)
EDC	98.96	1027.98	519.81	0.41	0.09
Water	187.86	783.08	938.21	76.44	0.37
EDB	18.01	299.00	826.77	0.60	0.11

Design Calculations:

Minimum Number Of Stages:

Fenske's equation.

N_{min} +1= $\frac{log[\left(\frac{x_{lk}}{x_{hk}}\right)_D * \left(\frac{x_{hk}}{x_{lk}}\right)_B]}{loglog\,(\frac{\alpha_{lk}}{\alpha_{hk}})avg}$

N_{min} = 23

Minimum Reflux Ratio:

Reflux ratio can be found by using Underwood equation

$$\sum \frac{\alpha_i \ * \ x_{i,f}}{\alpha_i - \ \theta} = 1 - q$$

$$\sum \frac{\alpha_i \ * \ x_{i,D}}{\alpha_i - \ \theta} = R_m + 1$$

Θ = 1.0149

R_m = 0.943

Actual Reflux Ratio:

As a rule of thumb R = (1.2-1.5)*R_m

Actual Reflux Ratio = 1.5*0.943

Actual Reflux Ratio = 1.415

Theoretical No. Of Stages:

Using relation

$$\frac{N - N_{min}}{N + 1} = 1 - exp[\left(\frac{1 + 54.4\Psi}{11 + 117.2\Psi}\right)\left(\frac{\Psi - 1}{\sqrt{\Psi}}\right)]$$

In this equation

$$\Psi = \left(\frac{R - R_{min}}{R+1}\right)$$

R_{min} = 0.943

R = 1.415

Theoretical number of stages = 40

Actual No. Of Stages:

Efficiency is calculated by O Connel's correlation.

$$Eo = 51 - 32.5 log * \mu_F, avg$$

Efficiency of column = 60-90%

Actual number of stages = N (theoretical)/ 79.2

Actual number of stages = 51

Excluding the reboiler stage= 51-1= 50

Location Of Feed Plate:

The Kirkbride method is used to determine the number of trays above and below the feed point.

$$log(\frac{N_r}{N_s}) = 0.206 log[\left(\frac{B}{D}\right)\left(\frac{xf_{,lk}}{xf_{,Hk}}\right)\left(\frac{(x,lk)_B}{(x,Hk)_D}\right)^2]$$

Nr/Ns = 0.9466

NS = 26

Nr = 24

Feed plate = 26

Quantity	Top Section	Bottom Section
mass flowrate (kg/s)	3.996	4.470
Vol rate (m_3/s)	0.965	1.061
D = $\sqrt{\frac{4A}{\pi}}$	D = 1.288m	D = 1.268m

Column Diameter		
Top Section	Bottom Section	Formulas
F_{LV} = 0.051	F_{LV} = 0.072	
Assume Plate spacing=0.45m		
K_1 = 0.080	K_1 = 0.076	From Graph
K_1 = 0.0912	K_1 = 0.087	Correction factor for K_1 = $\left[\frac{\sigma}{0.02}\right]^{0.2}$
u_f = 1.052m/s	u_f = 1.235m/s	$u_f = K_1 \times \sqrt{\frac{\rho L - \rho V}{\rho V}}$
Actual u_f = 0.842	Actual u_f = 0.988	Assume u_f as 80%
1.146m^2	1.073m^2	Vol rate/u_f = A_n
Assuming 12% Down comer area		
A_{total} = 1.302m^2	A_{total} = 1.263m^2	A_{total} = A_n/0.88

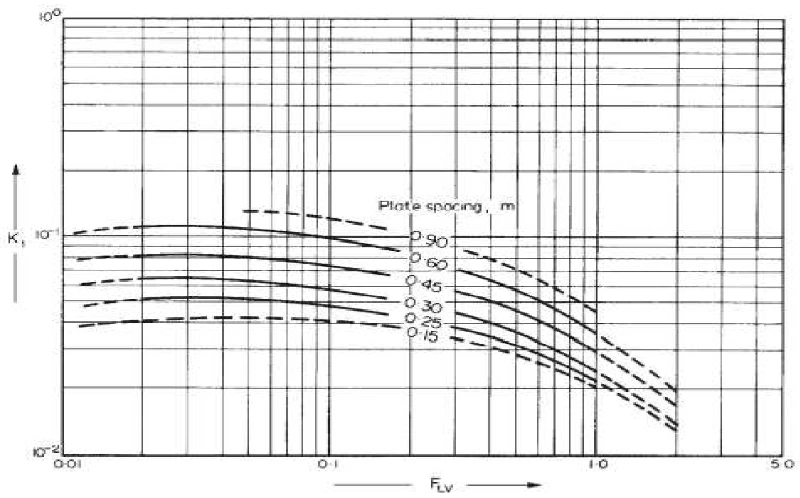

Figure 11.27. Flooding velocity, sieve plates

Figure 10: Graph for flow rate

Height Of Column:

No. of plates = 41-1 = 50

Spacing of tray = 0.45m

Functional height = 50*0.45= 22.398 m

Actual height = 1.05*22.398 = 23.518 m

Weir Length And Number Of Holes:

Length of weir = L_w =0.75*Dt =0.97m

Hole diameter = d_h = 5 mm

Plate thickness = 5 mm

Area of the one hole= 0.000019625 m^2

No. of the holes/Plate = 5044

Area By Coulson Richardson Formulae:

Net Area = A_n = 1.146 m^2

Area of column A_c = A_n/0.88 = 1.302 m^2

Down comer area A_d = 0.12Ac = 0.156 m^2

Active area A_a = Ac – 2A_d = 0.990 m^2

Hole area =A_h= 10% A_a = 0.099 m^2

Column Pressure Drop:

The total plate drop is calculated as

$$h_t = h_d + (h_w + h_{ow}) + h_r$$

Dry plate drop (h_d) is calculated by using orifice expression

$$h_d = 51\left(\frac{\hat{\upsilon}}{C_o}\right)^2 \frac{\rho_v}{\rho_L}$$

Here $C_o$is orifice constant and come from graph

Orifice constant C_o = 0.84

H_r = 14.499 mm of liquid

H_d= 40.556 mm of liquid

Total plate drop = h_t= 128.45 mm of Liquid

Total column pressure Drop is calculated as

$$\Delta P_t = (9.81 * 10^{-3}) * h_t \rho_L$$

Pressure drop of one plate = ΔP= 1086.299 Pa

=0.01068 atm

Total pressure drop= 0.011*50 =0.534 atm

Liquid Flow Pattern			
Top Volumetric Flowrate	0.004 m^3/s	Top Mass Flowrate	2.342 kg/s
Bottom Volumetric Flowrate	0.0053 m^3/s	Bottom Mass Flowrate	4.588 kg/s
Max Flowrate occur at bottom			

From graph:

It lies in cross flow (single pass) regime.

Downcomer Liquid		
h_{ap}	h_w-10	40 mm
Area under apron		0.039 m^2
h_{dc}		3.147 mm
Backup in downcomer		
h_b	$(h_w + h_{ow}) + h_t + h_{dc}$	0.200 m
1/2 (plate spacing + weir height) = 0.25		

As 1/2 (plate spacing + weir height) > h_b so plate spacing is acceptable.

Weeping:

The minimum design vapor velocity is calculated by using Eduljee correlation

$$\mathring{\upsilon} = \frac{K_2 - 0.90(25.4 - d_h)}{(\rho_v)^{0.5}}$$

K2 is a constant calculated by Hw + How**.**

K2 = 30.5

$\mathring{\upsilon}$ = 5.913 m/s

Actual vapor velocity through holes = vap flow rate/ area of hole

= 7.499 m/s

As actual V is greater so no weeping will occur.

Entrainment:

The fractional entrainment factor Ψ is calculated by using 74.8% flooding and 0.072 F_{lv}

Ψ comes to be 0.035

Residence Time:

5.876 s > 3 s is satisfactory .

2.5) Mechanical Design:

Thickness of Shell			
Design Pressure 10% above operating		0.13169	N/mm^2
At Designed Temperature; Typical Design Factor f = 150 N/mm^2			
Thickness of shell	t = e + C		
E	$\frac{P_I * D_i}{2f - P_i}$	0.566	Mm
Add Corrosion Allowance = C =2 mm			
Thickness of shell	t= e + C	2.566	Mm

Weight of Vessel			
$W_V = C_V \pi \rho_m D_m g(H_v + 0.8D_m)t * 10^{-3}$			
C_V	factor for the weight of nozzles	1.15	-
ρ_m	density of vessel material	7980	Kg/m^3
D_m	Mean Diameter of Vessel (D_i + t)	1290	Mm
H_v	Height of Cylindrical section	23.51	M

Total Weight of Vessel =Weight of Vessel + Weight of Insulation + Weight of Plates			
Weight of Insulation	Density of Insulation * Volume of Insulation* g		
Volume of Insulation	$\pi D_m H_v t$	5.719	m^3
Weight of Insulation	$V\rho g$	7.290	KN
Allow for Fittings	2*$V\rho g$	14.587	KN
Weight of Plates	61*Wp	95.356	KN
Total Weight of Vessel	$W_V + W_I + Wps$	132.93	KN

Wind Load Analysis			
Wind speed	U	160	Km/hr.
Wind Pressure	$P_w = 0.05u^2$	1280	N/m^2
Mean Diameter Including Insulation	D_m	1.413	m
Wind loading	$F_W=P_W*D_m$	1808.7	N/m
Bending Moment	$Mx = \frac{FwHv2}{2}$	500189	Nm

-	$Iv = \frac{\pi}{64}[Dm4 - Di4]$	6.6*10^10	mm^4
The Bending Stress	$\sigma b = \pm \frac{Mx}{Iv}\left[\frac{Di}{2} + e\right]$	5.32	N/mm^2

The Resultant Stresses are therefore,

$$\sigma z(upwind) = \sigma L - \sigma w + \sigma b = 19.64\frac{N}{mm2} \quad ; \sigma z(downwind) = \sigma L - \sigma w - \sigma b = 9.0\frac{N}{\text{mm2}}$$

Elastic Stability Check:

The Critical Bulking Stress $\sigma\text{C} = 2 * 104\left(\frac{\text{e}}{\text{Dm}}\right) = 8.766\ \text{N/mm2}$

The maximum compressive stress $\sigma\text{max} = \sigma\text{w} + \sigma\text{b} = 7.53\ \text{N/mm2}$

As $\sigma\ c\ > \sigma\ max$, so mechanical design is safe and satisfactory.

4.5) Specification Sheet:

Distillation Column Specification Sheet			
Item	Distillation Column	Date	
Code	D-101	By	
Number of Units	01	Cost	$441866.78
Type		Tray type Distillation Column	
Operation	Continuous	Orientation	Vertical
Design Data			
Operating and Design Temperature	80 ^oC / 93 ^oC	Material of Construction	Stainless Steel

Operating and Design Pressure	1.3/ 1.56 atm	Safety Factor	20 %
Minimum Reflux Ratio	0.943	Actual reflux ratio	1.425
Minimum No. of stages	23	Theoretical No. of stages	40
Actual No. of stages	50	Feed Location	26th plate from bottom
Diameter of column	1.288 m	Area	1.302 m^2
Weir Length	0.97 m	Plate Thickness	5mm
Number of Holes	5044	Hole Diameter	5mm
Height of Column	23.51 m	Column Pressure Drop	0.534 atm

4.6) Design of Absorber (S-101):

Absorption:

Absorption is the transfer of one or more materials from the gas phase to a liquid solvent. The phenomena in which there is removal of one or more components from gas stream by adding a suitable solvent which comes in contact with the gas mixture and selectively absorbs components through mass transfer from gas to liquid.

Types Of Absorption:

1) Physical Absorption
2) Chemical Absorption

Physical Absorption:

In it mass transfer takes place purely by diffusion and is governed by the physical equilibrium.

Chemical Absorption:

In this type of absorption a chemical reaction occurs as soon as a certain component comes in contact with the absorbing liquid.

Types Of Absorber:

There are two major types of absorbers which are mainly used for absorption purposes:

- Packed column
- Plate column

Tray Column:

A tray tower is a vertical, cylindrical pressure vessel in which vapor and liquid, flowing counter-currently, are contacted on trays or plates that provide intimate contact of liquid with vapor to promote rapid mass transfer.

Packed Column:

A packed column is a vessel containing one or more sections of packing over whose surface the liquid flows downward as a film or as droplets between packing elements.

Comparison Between Packed And Plate Column:

- The packed column provides continuous contact between vapors and liquid phases while the plate column brings the two phases into contact on stage wise basis.
- Pressure drop in packed column is less than the plate column. In plate column there is additional friction generated as the vapor passes through the liquid on each tray. If there are large number of Plates in the tower, this pressure drop may be quite high and the use of packed column could affect considerable saving.
- For diameters of less than 3 ft. packed tower require lower fabrication and material costs than plate tower with regard to height, a packed column is usually shorter than the equivalent plate column
- Tray column can't handle toxic and flammable liquid while packed column can handle these type of liquids.
- Tray columns can handle wide range of gas and liquid flow rates while packed columns are more suitable for low capacity operations.

Selection Of Column:

We select packed column due to following reasons

- Have an open structure: low resistance to gas flow.
- Packed columns are more suitable for low capacity operations.
- Packing should always be considered for small diameter columns where plates are difficult to install
- It can easily handle toxic and flammable liquid
- Packed towers are better for corrosive liquids**.**
- Low Pressure Drop

Selection Of packing:

The packing is the most important component of the system. The packing provides sufficient area for intimate contact between phases. The efficiency of the packing with respect to both HTU and flow capacity determines to a significance extent the overall size of the tower. The economics of the installation is therefore tied up with packing choice.

The packing's are divided into those types which are dumped at random into the tower and these which must be stacked by hand. Dumped packing consists of unit 1/4 lo 2 inches in major dimension and is used roost in the smaller columns. The units in stacked packing are 2 to about 8 inches in size; they are used only in the larger towers.

The Principal Requirement of a Tower packing are:

1) It must be chemically inert to the fluids in the tower.
2) It must be strong without excessive weight.
3) It must contain adequate passages for both streams without excessive liquid hold up or pressure drop.
4) It must provide good contact between liquid and gas.
5) It must be reasonable in cost.

Thus most packing is made of cheap, inert, fairly light materials such as clay, porcelain, or graphite. Thin-walled metal rings of steel or aluminum are some limes used.

Common packing's are given below.

- Rashing Rings
- Berl Saddles
- Intalox Saddles
- Pall Rings

We select Ceramic Intallox saddle due to following reasons.

- Ceramic intalox saddle has superior performance.
- It has good gas-liquid separation efficiency
- Low operating cost
- Effective for corrosive liquid
- Lower pressure drop.

Designing Steps For Absorption Column:

- Selection of Column
- Selection of packing and material
- Calculating the size of packing
- Calculate Flow Factor
- Calculate K4& Mass Velocity
- Calculate the Area of Column
- Calculating the diameter of column
- Determining the height of transfer unit (HOG)
- Determining the number of transfer units (NOG)
- Determining the height of packing
- Determining the height of the column
- Determining the pressure drop

Design Calculations:

L = liquid flow rate=2550.50 kg/hr

T = 25 ^oC

P = 1 atm

ρL = 876 kg/m3

μL = 0.000607 N.s/m^2

G = gas flow rate = 4876.45 kg/hr

T = 40 ^oC

P = 1 atm

ρG = 1.483 kg/m^3

μG = 0.0008 N.s/m^2

Flow Factor FLV:

FLv = 0.03

Design for pressure drop of 42 mmH2O/m of packing

K4 = 1.5

K4 at flooding = 4.5

%Flooding = 57.77%

Calculation Of Mass Velocity:

K_4 = 1.5

ρ_v = 1.438 kg/m^3

ρ_L = 876 kg/m^3

F_P = Packing factor=170/m

μL = 0.000607 N.s/m^2

V*w = 1.107 kg/m^2.s

Calculation Of Area:

Vw = 1.352 kg/s

V*w = 1.107 kg/m^2.s

Area of column required = Vw/V*w = 1.22 m^2

Area = 1.22 m^2

D = $\sqrt{\frac{4A}{\pi}}$ = 1.24 m

Column area = 1.20 m^2

Packing size = 2 in.

Height Of Packing:

$Z = H_{OG} x\ N_{OG}$

HOG = Height of overall transfer units

HOG = HG+mGm/Lm+HL

ONDAS Method:

a_w = Effective interfacial area of packing per unit volume $m^2\ /m^3$

L_w = Liquid mass velocity=0.580 kg/ m^2.s

σ_L = surface tension of benzene=0.0262 N/m

σc = critical surface tension for the particular packing material

μ_L = 0.000607 N.s/m^2

a = actual area of packing per unit volume = 108 $m^2\ /m^3$

g = 9.81 m/s^2

ρ_L = 876 kg/m^3

Aw = 17.1 $m^2\ /m^3$

Calculation Of Coefficients:

K_L = Liquid mass coefficient m/s

Dp = packing size = 51 mm = 0.051 m

D_L = 2.8*10.9 m^2/s

a_w = 17.1 $m^2\ /m^3$

L^*_W = 0.58 kg/m^2.s

A = 108 m^2/m^3

ρ_L = 876 kg/m^3

μ_L = 0.000607 N.s/m^2

KL = 0.0002 m/s

K_G = gas film coefficient

K_5 = 5.23 for packing size above than 15 mm

T_G = 313.15 k

D_v = 0.00052 m^2/s

R = 0.08314 bar.m3/kmol.k

V*w = 1.10 kg/m^2.s

μ_v = 0.0008 N.s/m^2

KG = 0.0024 kmol/m^2.s.bar

HG = Height of gas transfer unit

Gm = 0.033 kmol/m^2.s

K_G = 0.0024 kmol/m^2.s.bar

P = 1.033 kg/Cm^2

a_w = 17.24 m^2/m^3

HG = 0.77 m

HL = Height of liquid transfer unit

HL = $\frac{Lm}{KLawCt}$

L_m = 0.0074 kmol/m^2.s

HL = 0.19 m

k_L = 0.0002 m/s

Ct =11.23 kmol/m^3

HOG = Height of overall transfer units

HG = 0.77 m

HL = 0.19 m

mGm/Lm = 0.8

HoG = 0.99 m

NOG = number of transfer unit

Y1 = mole fraction of EDC at entrance = 0.055

Y2 = mole fraction of EDC at outlet = 0.0007

Y1/Y2 = 78.5

mGm/Lm = 0.8

NOG = 14

Z = Height of packing

Z = HoGxNoG = 14x0.9 = 12.6 m

Total Height Of Column = 14.6 m

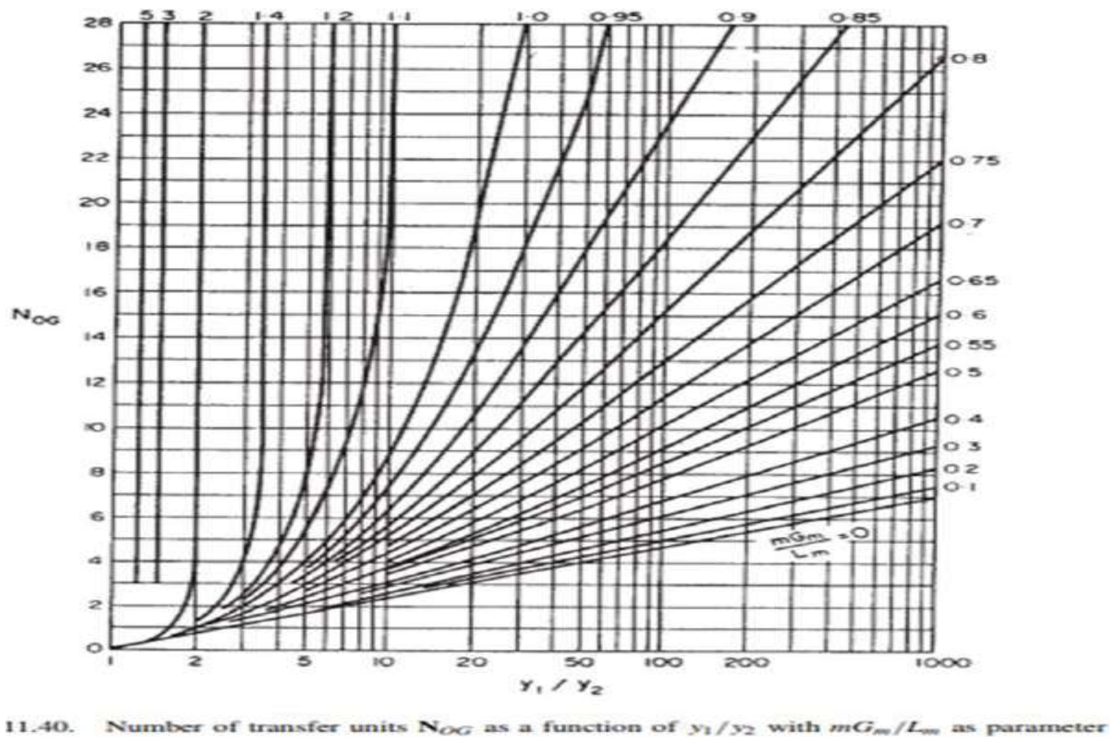

Figure 11: Number of transfer unit

Pressure Drop:

Pressure Drop at flooding

F_p = 130 m

ΔP = 0.1 atm

Total Pressure Drop:

So we have used the Strigle chart to find out the pressure drop through generalized pressure drop correlation.

G_x = Liquid mass velocity = 0.5807 kg/m^2.s

G_y = Gas mass velocity = 1.107 kg/m^2.s

ρ_G = 1.438 kg/m^3

ρ_L = 876 kg/m^3

G = gas flow rate = 1.32 kg/sec

Fp = 130 m

μ_L = 0.000607 N.s/m^2

ρ_G = 1.438 kg/m^3

ρ_L = 876 kg/m^3

g_c = 1 kg.m/N.s^2

By using correlations with the help of graph we get pressure drop

ΔP = 1.5 in H20/Ft of packing

Height of packing = 54.7 ft

Total pressure drop = ΔPx height of packing

ΔP = 72.46 atm

ΔP = 0.2 atm

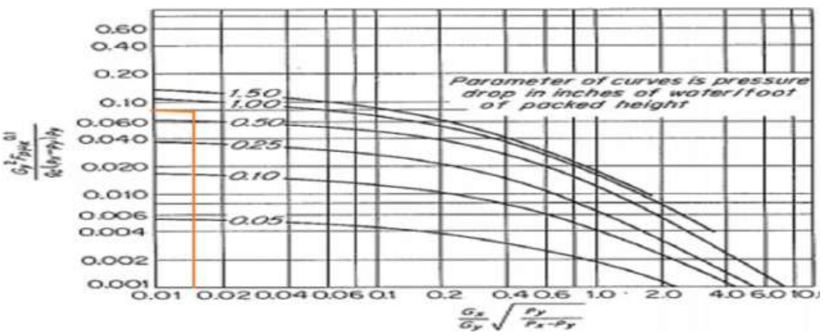

Figure 12: Graph for pressure drop

4.7) Mechanical Design:

Thickness Of Shell:

Material of construction = Stainless steel

Di = internal diameter = 1240 m

Pi = Design Pressure 10% above operation = 0.1 N/mm^2

J = 1(if joints are welded)

Typical design factor f = 175 N/mm^2

e = $\frac{P_I*D_i}{2jf-P_i}$ = 0.4 mm

Add Corrosion Allowance = C =2 mm

t = e+C =2.4 mm

Weight Of Vessel:

$W_V = C_V\pi\rho_m D_m g(H_v + 0.8D_m)t * 10^{-3}$

Cv = factor to account for the weight of nozzles = 1.15

ρm = density of material = 8000kg/ m^3

Dm = Mean Diameter of Vessel (D_i + t) = 1244.44mm

Hv = Height of vessel= 14.6 m

Wv = weight of vessel = 22.469 KN

Weight of insulation = Density of insulation*Volume of insulation*g

Volume of insulation = $\pi D_m H_v t$ = 4.8 m^3

Density of Insulation (Calcium silicate) = 200 kg/ m^3

Weight of Insulation = V*ρ*g = 9.4 KN

Allow for fittings = 2*V*ρ*g = 18.816 KN

Weight of packing= 10 KN

Total weight = Wv + Wins + Wpacking = 51.285 KN

Stress Analysis:

Longitudinal Stress:

$$\sigma_L = \frac{P_i*D_i}{4t} = 12.65 \text{ N/mm}^2$$

Circumferential Stress:

$\sigma_h = \frac{P_i * D_i}{2t}$ = 28.67 N/mm^2

Dead Weight Stress:

$\sigma_w = \frac{W_v}{\pi(D_i+t)*t}$ = 0.002 N/mm^2

Radial Stress:

$\sigma_R = \frac{P_i}{2}$ = 0.055 N/mm^2

Wind Load Analysis:

Wind speed = u = 160 km/hr

Wind pressure = P_w = 0.05 u^2

Pw = 1280N/m2

Mean diameter including insulation = Dm = 1.264 m

Wind Loading:

$F_W = P_W * D_m$

Fw = 1617.92 N/m

Bending Moment:

$Mx = \frac{FwHv2}{2}$ = 172437.9 Nm

Bending Stress:

$\sigma b = \pm \frac{Mx}{Iv}\left[\frac{Di}{2} + e\right]$ = 0.0122 N/mm^2

$Iv = \frac{\pi}{64}[Dm4 - Di4]$ = 8.8*10^9 mm^4

The resultant stress are follows:

$\sigma z(upwind) = \sigma L - \sigma w + \sigma b = 12.649 \frac{N}{mm2}$

$\sigma z(downwind) = \sigma L - \sigma w - \sigma b = 12.5 \frac{N}{mm2}$

Elasticity Stability Check:

The Critical Bulking Stress $\sigma C = 2 * 104 \left(\frac{e}{Dm}\right) = 38.7\ N/mm2$

The maximum compressive stress $\sigma max = \sigma w + \sigma b = 0.0252 N/mm2$

As $\sigma C > \sigma max$, so Mechanical Design is safe and Satisfactory

4.8) Specification Sheet:

Name of Equipment	**Gas absorber**
Function	Absorption of Ethylene Di chloride
Type	Packed Column
Temperature	25 ^{o}C
Pressure	1atm
Type of packing	Ceramic intalox saddle
Material of Construction	316-Stainless steel
%Flooding	57.77%
Column diameter	1.24 m
Area of column	1.22 m^2
Height of packing	12.6 m
Height of column	14.6 m
Pressure Drop	0.2 atm

Table 4.6: Specification sheet

Chapter 5: Instrumentation and Control

This plant has four major equipment. There include two reactors as well as two distillation columns. Each of the equipment has their own associated hazards. Equipment process control for each equipment is given below. Instrumentation and control primary objectives are:

5.1) Safety Of Plant Operation:

i. Production Rate:

To meet the desired product rate.

ii. Product Quality:

Maintaining the product quality standards**.**

iii. Minimize the product cost by carefully and effectively controlling the conditions.

Control On Reactor:

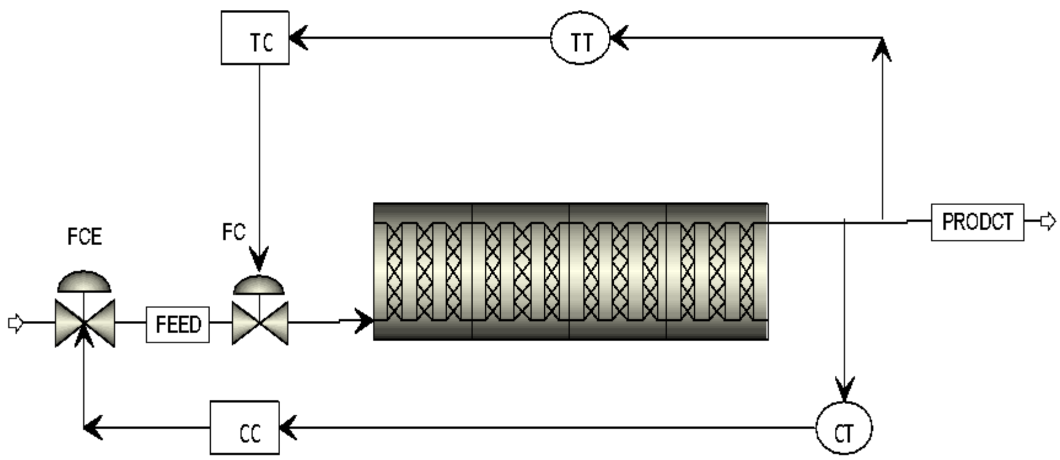

Figure 13: Reactor Control Diagram

Variable	Variable to control	Variable to manipulate	Control type	Set point
Maintain inlet flow rate	Inlet valve	Flow rate of inlet	Cascade (master)	5664 Kg/hr
To maintain reactor pressure	Inlet valve	Flow rate of inlet	Cascade (slave)	1.4 atm
Maintain reactor temp.	Inlet feed temp.	Feed input	Feedback Controller	150 ^{0}C

Table 5.1: Control on reactor

5.2) Distillation Column Control System:

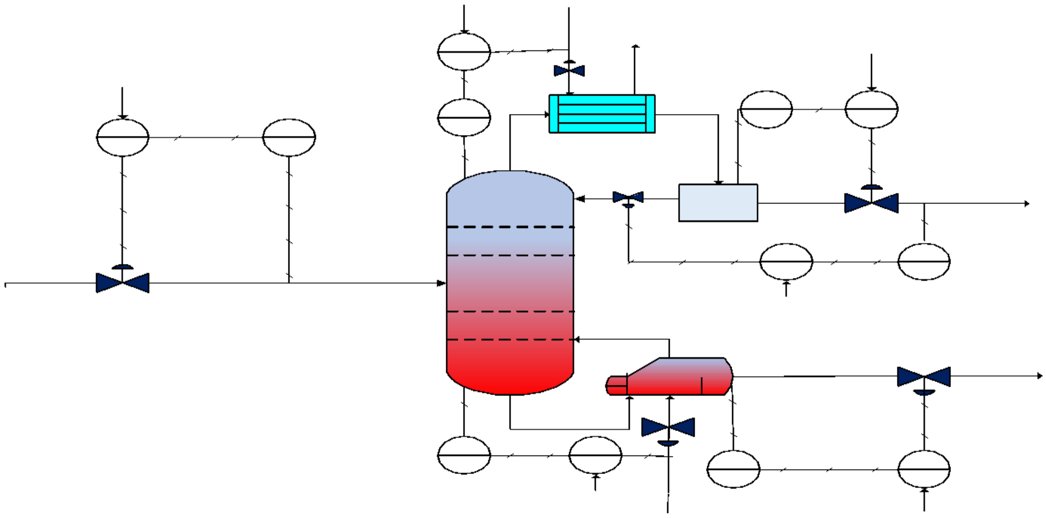

Figure 14: Distillation Control

The control is based on three factors:

i. Control of Material balance.
ii. Control of Product quality.
iii. Constraints Satisfaction.

Control of Material Balance:

Sum of mass flow rates of top product and bottom must be equal to the sum of feed streams mass flow rates. With the passage of time the production rate may vary depending on demand. So, control system must ensure the smooth transition of production rate.

Control of Product Quality:

This control mechanism makes sure that the product of desired purity is obtained.

Constrains Satisfaction:

Constraints necessary for the safe operation of column must be satisfied. For example, flooding, weeping and dumping must be avoided.

Objective	Variable to control	Manipulated variable	Control type	Disturbance
Temperature	Top Temperature	Cooling Water inlet to Condenser	Feedback	Temperature change
Temperature	Bottom Temperature	Steam flow to boiler	Feedback	Temperature change
Liquid level	Reflux drum liquid level	Reflux Stream into the Column	Feedback	Liquid level change in Reflux Drum
Flowrate	Flowrate to the Distillation Column	Feed stream into the Distillation Column	Feedback	Change in stream flow rates
Liquid level	Liquid level in Reboiler	Bottom Flow rate	Feedback	Liquid level change in Reboiler
Composition of the product.	Composition of Product stream	Reflux to Distillation Column	Feedback	Change in composition of product stream

5.3) Control On Absorber:

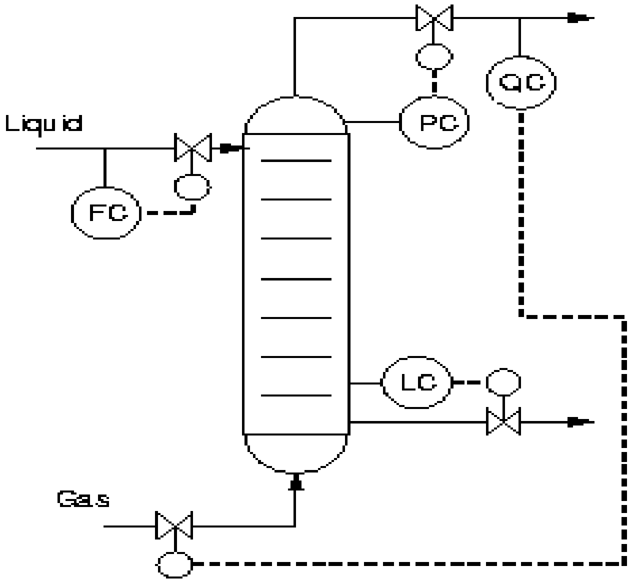

Figure 15: Absorber Control

5.4) Control On Heat Exchanger:

Variable	Variable to control	Variable to manipulate	Control type
Maintain inlet flow rate	Inlet valve	Flow rate of inlet	Cascade (master)
To maintain pressure	Inlet valve	Flow rate of inlet	Cascade (slave)
Maintain temperature	Inlet feed temp.	Feed input	Feedback Controller

Table 5.2: Heat exchanger control

Chapter 6: Cost Estimation

6.1) Introduction:

The economic evaluation that incorporates the calculations of the monetary investment that should be put into the plant should come before, as it's one of the most important requirements of the entire process design. It likewise the assurance of the relationship of salary and cost to the welfare of the organization. The figuring includes the financial potential for the chose plant was only a harsh estimation in which the computation does not include in including in different factors, for example, devaluation, plant lifetime, etc.

Economic analysis of this project is done by calculating the FCI, TCI, TPC and revenue from sales. Equipment costing have been determined in Chapter V with the evaluated Chemical Engineering Plant Index in 2021, which are 597.1. The vast majority of the hardware citations are gotten by utilizing the exposed module technique. Finally, the profitability analysis is performed by analyze the discounted cash flow. Payback period (PBP), discounted break-even period, net present value (NPV) and discounted cash flow rate of return (DCFRR) will be determined.

6.2) Grass-Root Capital:

Equipment sizing has been carried out before and the cost for each of the equipment used in the plant is being estimated and because the gross root capital cost is the major portion of total fixed capital cost, it's has been done first. Cost of equipment, cost of installation, contingency and fees are all includes in the gross root capital cost part.

6.2.1) Equipment Costs and Grass Root Capital:

Equipment	Cost ($)
Heat exchanger (HX-101)	10500
Heat exchanger (HX-102)	10500
Catalyst Mixer (MIX-101)	25000
Plug flow reactor (R-101)	459391.45
Partial Condenser (C-103)	16700
Flash column (C-104)	17662.8
Heat exchanger (HX-105)	10500

Absorber (A-106)	322423.92
Distillation column 1 (DC-101)	446878.78
Distillation column 2 (DC-102)	427055.9
Pump (101)	2000
Total Bare Module Cost, C_{tbm}	1748612.85 $
Total Bare Module Cost, C_{tbm}	323493377.25 Pkr

Table 6.1: Equipment cost and grass root capital

Type of cost	Formula	Price (RS)
Contingency and Fees	CC + CF = 0.08CTBM	25879470.18
Total Module Cost	CC+CF+CTBM=CBM	349372847.3
Auxiliary Facilities	0.10CTBM	23349337.7
Gross-roof Capital (GRC)		398601655.18

Table 6.2: Grass root capital

6.3) Total and Fixed Capital Investment Cost:

Fixed Capital is the total cost for the installation of the process equipment with some auxiliaries that complete the operation of the process. It includes the cost of direct and indirect cost for the setup of the plant. General formula is,

Total Capital = Fixed Capital Investment + Working Capital + Start Up Cost

Onsite	Specification	Cost (RS)
Purchased equipment Installation	15% GRC	59790248.277
Instrumentation and control (installed)	10% GRC	39860165.518
Piping (installed)	10% GRC	39860165.518
Electrical and material (installed)	5% GRC	19930082.79
Offsite		
Building	12% GRC	47832198.612
Yard improvement	3% GRC	11958049.653

Service facilities	8% GRC	31888132.408
Land	1% GRC	3986016.5
Total 1		255105058.143

Table 6.3: Fixed and total capital investment cost

Indirect cost		
Engineering & supervision	8% GRC	31888132.41
Legal expenses	1% GRC	3986016.55
Construction expenses	8% GRC	31888132.41
Contractor’s fee	1.5% GRC	5979024.827
Contingency	5% GRC	19930082.75
Total 2		93671388.936
Total = total 1+ total 2		348776447.076
Gross root capital (GRC)		398601655.18
Fixed capital investment (FCI)		747378102.256
Working capital	10% FCI	37368905.112
Startup cost	5% FCI	74737810.2
Total capital investment (TCI)		859484817.5

Table 6.4: Fixed and total capital investment cost

So, total capital investment (TCI) calculated is 859484817.5 rupees. It includes all equipment cost, waste treatment cost, the direct cost in setting up the plant, indirect cost and also cost for working and startup cost.

7.4) Raw Materials Costing and Annual Profit:

Raw material	Price($/ton)	Amount(ton/yr)	Annual cost($/yr)
Ethylene	607.6	50635.77	30766297.21
Chlorine	434.6	4063.34	407662.21
Ethylene Dibromide	344.6	5065	207662.21
Total Annual Cost	1386.59	59764.11	4346970132 Rupees/yr

Annual product credit	Cost	Amount	Annual cost($/yr)
Ethylene Dichloride (EDC)	943.58	20000	18871600
HCl	607.6	24862.16	15106250.98
Total product Cost	1551.18	44862.16	4800730565 Rupees/yr

Table 6.5: Raw materials costing and annual profit

Total Annual profit = 453760433 Rupees/yr.

Conclusion

The detailed analysis for the production of Ethylene Dichloride (EDC) has been explained in previous sections. The production of Ethylene Dichloride through direct chlorination method is more beneficial, economical and environment friendly than oxy-chlorination method. Reason is that the oxy-chlorination method produces harmful gases that pollute the environment. The production of ethylene dichloride will help in strengthen the GDP in terms of export and will meet Pakistan's need as well. It will help to fill the demand and supply gap. We can use this product in synthesis of many other materials like household things, plastic and manufacturing of other chemicals. Other uses of Ethylene Dichloride are the production of polyvinyl chloride (PVC), in production of Solvents, cleaners and Soaps, paints, production of chemicals like ethylene diamine, ethylene glycol, nylon and fumigation of grains (cereals).

Economic analysis of this project is done by calculating the FCI, TCI, TPC and revenue from sales. Equipment costing have been determined in Chapter V with the evaluated Chemical Engineering Plant Index in 2021, which are 597.1. The vast majority of the hardware citations are gotten by utilizing the exposed module technique. Equipment sizing has been carried out before and the cost for each of the equipment used in the plant is being estimated and because the gross root capital cost is the major portion of total fixed capital cost, it's has been done first. Cost of equipment, cost of installation, contingency and fees are all includes in the gross root capital cost part.

Finally, the profitability analysis is performed by analyze the discounted cash flow. Payback period (PBP), discounted break-even period, net present value (NPV) and discounted cash flow rate of return (DCFRR) will be determined. The fixed capital investment for this plant is 747378102.256 RS and the total capital investment is 859484817.5 Rs. The total annual profit is estimated to be 453760433 Rupees which is very good and handsome account.

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