
بسم الله الرحمن الرحيم

PRODUCTION OF 530 TONNES PER YEAR BIODIESEL FROM ALGAE

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Dedicated To

Our Beloved Parents

Respected Teachers

&

All Those Who Devoted Their Yesterday for Our Bright Today

ACKNOWLEDGEMENT

All praises to **ALMIGHTY ALLAH**, who provided us with the strength to accomplish the final year project. All respects are for His **HOLY PROPHET (PBUH),** whose teachings are true source of knowledge and guidance for whole mankind.

We are also thankful to our Parents who have always been a source of moral support and driving force behind whatever we do. We are indebted to our project supervisors **Engr. M. Umar Mushtaq** and project Coordinator **Engr. Fazeel Ahmed** for their worthy discussions, encouragement, inspiring guidance, remarkable suggestions, keen interest, constructive criticism and friendly discussions which enabled us to complete this report. They spared a lot of their precious time in advising and helping us in writing this report. Without their pains taking tuition, kind patronization, sincere coaching and continuous consultation, we would not have been able to complete this arduous task successfully.

ABSTRACT

The production of biodiesel represents one of the largest industries with a growth estimate of a near 4% per year. There are several alternatives for such process to be considered, however, the acidic transesterification is selected as the manufacture route. In addition, advantages and disadvantages of each possible solution will be discussed and the most reliable traditional method was selected. The main aim of the project is to develop a chemical engineering approach to a real industrial challenge taking into consideration economic and marketing situation in the country and in global scale, safety issues and risks evaluation. In this project, rate of production and product purity need to be specified. The reaction is conducted in a continuous stirred tank reactor with required reaction conditions followed and necessary calculations performed. In order to obtain pure, the purification section for the process will be designed. In preceding chapters introduction to different equipment's of plant along with their designing procedure and specification sheets is presented. Instrumentation and process control, HAZOP study, and cost estimation for this plant is also included in this project. The purpose of this project is to design the plant of 530 ton/yr production of biodiesel from algae. The project includes equipment design, cost estimation, environmental impact assessment, material and energy balance. Calculated data in tabulated form with brief description is given in the chapters while necessary tables and figures are placed in appendix. MS Word, MS Excel, MS Visio and Aspen Tech are the software used in design and calculations of project. This report includes all important topics which should be considered necessary for designing a plant for production of biodiesel. This report is divided in different sections, first of all the introduction of biodiesel and algae is given which highlights its importance. Next are the detailed description of manufacturing processes for biodiesel and selection of process and capacity. Afterwards material and energy balance is presented in preceding chapters. Design of different equipment of plant along with their specification sheet is also presented. Next are cost estimation, Instrumentation and Control, HAZOP study and Environmental Impact Assessment of biodiesel.

Keywords: Algae; Biodiesel; Energy Crises; Renewable Source.

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1.1 Introduction:

One of these biggest issues, the energy crisis, makes the world unsafe and violent. Every day there is more demand. Resources are being used up quickly, and all indications point to their eventual disappearance. More consideration must be given to renewable energy sources in such circumstances. Fossil fuels are widely used worldwide, but they are unsustainable since they raise CO_2 levels and build up greenhouse gases that harm the ecosystem [1]. Renewable and environmentally friendly fuels must be developed in order to ensure sustainability and a clean environment. Biofuels are described as liquid fuels made from biomass from various agricultural and forestry products as well as a percentage of industrial waste that can decompose. Algae are aquatic organisms that produce biomass by utilizing light and carbon dioxide (CO_2). Algae are divided into two groups: macroalgae and microalgae. The enormous, multicellular algae that are frequently seen growing in ponds are known as macroalgae, and they are measured in inches. These bigger algae have many different ways they can grow. Seaweed refers to the biggest multicellular algae; an illustration is the enormous kelp plant,which may grow to a length of more than 100 feet. The microscopic, unicellular algae known as microalgae, on the other hand, are measured in micrometres and often grow in suspension within a body of water. Because of their relatively high oil content and quick biomass synthesis, microalgae have long been recognized as possible viable sources for biofuel generation [1]. When compared to terrestrial crops, microalgae develop much more quickly. Algal mass culture can be carried out on nonarable fields utilizing non-potable saline water and waste water. As a result, interest in using microalgae as a substitute for biodiesel biofuel feedstock is growing among academics, business people, and the general public. Algae can also be employed to cut down on CO_2 emissions from power plants. The largest fossil energy source in the world is coal, by a wide margin. The United States holds about one-fourth of the world's coal reserves. Over the ensuing decades, coal use will increase globally and in the United States. Microalgae use their photosynthetic metabolism to take in CO_2 and expel oxygen. By recycling waste CO_2 from power plants into clean-burning biodiesel, CO_2 produced by the power plant might be used as a carbon source for algal growth if an algae farm is developed next to one. This would minimize carbon emissions. The world's primary source of biofuel generation is increasingly coming from algae [1].

They are regarded as the preferable source of biodiesel production while other sources can result in food issues as they mostly comprise plants that are used for food. They have the capacity to thrive without much concern on waste nutrients [2]. Additionally, compared to algae, the biodiesel content of crops is less abundant and more short-term. Compared to petroleum, algae have an energy level that is around 80% higher [2]. Algal cells contain 30% more lipids than other sources, such as soybean and palm oils. Dry weight lipid concentrations for microalgae range from 30% to 40%, rising to 85%. Algae may effectively remove the hazardous elements from water, aiding in the cleanup of waste water [2]. They are appropriate sources to be developed on a wide scale because to their remediating effects in waste water treatment and their abundance in biodiesel. Both micro and macro algae may be grown on a huge scale quickly. Microalgae have the potential to be grown as energy crops since they are heterotrophic and photosynthetic [3]. They have the capacity to create a number of crucial substances for the economy, including fats and oils. Algal biofuel doesn't contain any dangerous compounds, therefore after combustion, the environment may be maintained clean [3]. The J. curcas plant has been successfully cultivated by Pakistan State Oil to create biodiesel, and production has begun. While drying crops and other food-producing plants requires energy, drying algae using sunlight is more cost-effective [3]. Algae are easier to dry using thermochemical methods than other plants. Biogas is created by anaerobic microbes using biomass and has a high methane content, making it a potential alternative energy source. Anaerobic digestion, which is the most popular method obtaining these components from the cells, is usually favored since algae cells have the biofuel contents inside of them and the cell wall preserves these components intact [4]. The algae that are easily cultivable and have a high biofuel content are selected. In order to efficiently or inexpensively create biodiesel from algae, this study aims to critically describe a variety of elements of algae as a suitable target for biofuel operations [4].

1.2 Project Motivation:

A domestically generated, clean-burning, and renewable alternative to petroleum diesel is biodiesel. The use of biodiesel as a vehicle fuel boosts energy security, enhances the environment and air quality, and offers safety advantages. Because the carbon dioxide emitted during biodiesel burning is balanced by the carbon dioxide absorbed during the growth of the soybeans or other feedstocks used to make the fuel, using it minimizes life.

The fact that agricultural area used for growing food supplies should not be relocated makes employing algae for biofuels a considerable advantage. Algae have the potential to provide at least

30 times more energy than the land-based crops now used to make biofuels, according to the Department of Energy.Algae are a renewable source of biofuels that can be cultivated in salt water or brackish water on non-arable ground. The fact that agricultural area used for growing food supplies should not be relocated makes employing algae for biofuels a considerable advantage. Algae have the potential to provide atleast 30 times more energy than the land-based crops now used to make biofuels, according to the Department of Energy [5]. Algae effectively recycle carbon from the atmosphere. Although algae make up less than 2% of the world's plant carbon, they can fix up to 50% of atmospheric carbon dioxide (between 30 and 50 billion metric tonnes annually) and convert it to organic carbon. Up to 50% of the oxygen on the planet is produced by them through photosynthesis [5]. According to the Environmental Protection Agency, fatty acid methyl transesterification, the only method of producing algae based biodiesel that has been studied thus far, can cut greenhouse gas emissions by more than 60% when compared to petroleum diesel [6].

Table 1.1: Yield of Various Plants Oil [1]

Crop	Extracted Oil (L/A)
Algae	1,00,000
Castor	1413
Coconut	2689
Palm	5950
Safflower	779
Soy	446
Sunflower	952

1.3 Objectives and Aims:

Pakistan, due to biodiesel being environment friendly and its likelihood of manufacturing from the biomass of the solid waste of various origins, has additionally joined this hunt for biofuels and as it seems greater suitable to provide biodiesel domestically as opposed to uploading it from overseas. As the sector oil expenses are constantly rising, introducing biodiesel in Pakistan might certainly upload fee to the Pakistan Economy. Thus, the intention of the work said right here is to brought nice approach for the production of biodiesel and the opposite is to check out whether It is technically and economically feasible to produce biodiesel in Pakistan and replacement it as an alternative fuel beneath the import substitution coverage. The objectives are as follows:

- Production of biodiesel in an optimize way.
- Identification of scale of production.
- Planning and designing of a plant for production of biodiesel in Quetta (Pakistan).
- Evaluation to judge the project's technical soundness and economic viability.

1.4 Physical and Thermodynamic Properties:

Table 1.2: Physical and Thermodynamics Properties of Algae Oil [3]

Physical Properties	Chemical Properties
Light to dark green liquid.	Chemical name of green algae is "Chlorophyta".
Algae has light soapy texture.	Algae is composed of ~ 50% carbon,10% nitrogen, and 2% phosphorus.
Pungent odour.	Its chemical molecular formula is $C_{33}H_{38}N_4O_6$.
The density of algae oil is 0.932 g/cm^3.	Molecular weight is 586.7g/mol.
Specific gravity of algae oil is 0.934.	
Kinematic viscosity of algae oil is 70.44 mm^2/sec.	
Higher heating value for algae oil is 41.38 MJ/kg.	

Table 1.3: Physical and Chemical Properties of Methanol [4]

Physical Properties	Chemical Properties
Methanol is a colourless liquid that boils at 64.96 °C (148.93 °F) and solidifies at -93.9 °C (−137 °F).	Chemical name of methanol is methyl hydroxide.
It forms explosive mixtures with air and burns with a nonluminous flame.	Chemical formula is CH_3OH.
It is completely miscible in water.	Kinematic viscosity at 25°C is 0.545 mpa.s.
Density of methanol is 0.792 g/cm^3.	Molar mass is 32.04 g/mol.
Vapour pressure is 13.02 Kpa at 295 K.	

Table 1.4: Physical and Chemical Properties of Hexane [4]

Physical Properties	Chemical Properties
Hexane is a colourless liquid.	Chemical name of hexane is hexacarbonyl.
Hexane has petrolic odor.	Chemical formula is C_6H_{14}.
Boiling point of hexane is 341.6 K.	Kinematic viscosity is 294 µ.pa. s.
Density of hexane is 0.796 g/cm^3.	Molar mass is 86.16 g/mol.
Vapour pressure is 17.6 Kpa at 295 K.	
Flash point is 247.2 K.	

Table 1.5: Physical and Chemical Properties of Biodiesel [4]

Physical Properties	Chemical Properties
The color of biodiesel ranges from golden to dark brown, depending on the production method.	Chemical name of bio-diesel is fatty acid methyl ester.
It is slightly miscible with water.	Chemical formula is C_{14}-C_{24}.methyl ester.
It has a high boiling point.	Kinematic viscosity range between 25 to 50 mm^2/s.
Light soapy and oily odor.	Molar mass of biodiesel is 857g/mol.
Heating value for it is 41000 KJ/kg.	Moisture content ranges from 0.01 to 0.025 % w/w.
Density ranges from 860 to 950 kg/m^3.	Ash content in biodiesel is 0.04 % w/w.
Its boiling point is greater than 475 K.	The range of cloud point is -3 to 12^{o}C.
Heat of formation is -224309.895 KJ/mol.	

1.5 Worldwide Market Analysis of Biodiesel:

The present trend of increase in production and consumption of biofuel show the need for more production in the coming future. The genetically engineered microalgal cells and fundamental structural units of applied biomass act as the small transformation units for biofuel generation from the trapped solar energy. With technological applications for the processing of biomass, liquid biofuel such as biodiesel is produced. The key cause that drives the growth is the demand for algae biofuel as an important energy source. Due to the increase in prices of petrol and diesel, the requirement for algae biofuel has increased. Furthermore, increasing dependence towards eco-friendly lifestyles. There are around 72,500 algal species in the world and almost 33% of this algal specie have been marked for different purposes to this day. Pakistan had a special geographical, geological, and environmental position in this region which promotes biodiversity. Pakistan possesses sufficient algal flora due to rich saline habitats and diverse water. The international algae biofuel market is predicted growth from US$5.022 billion in 2022 to US$9.033 billion in 2027 at CAGR of 8.75%. A typical open pond in Pakistan can produce around 5 to 10 grams of biomass (dry basis) per m^2 of surface area per day, which is 7.4 to 14.8 tons (dry biomass) per acre per year. Someresearchers noted that biomass yield can be as high as 50 g/m^2 per day, i.e., 74-ton biomass/m^2 per year in an open pond. The world production and consumption data for biodiesel production from algae are shown in the below graph.

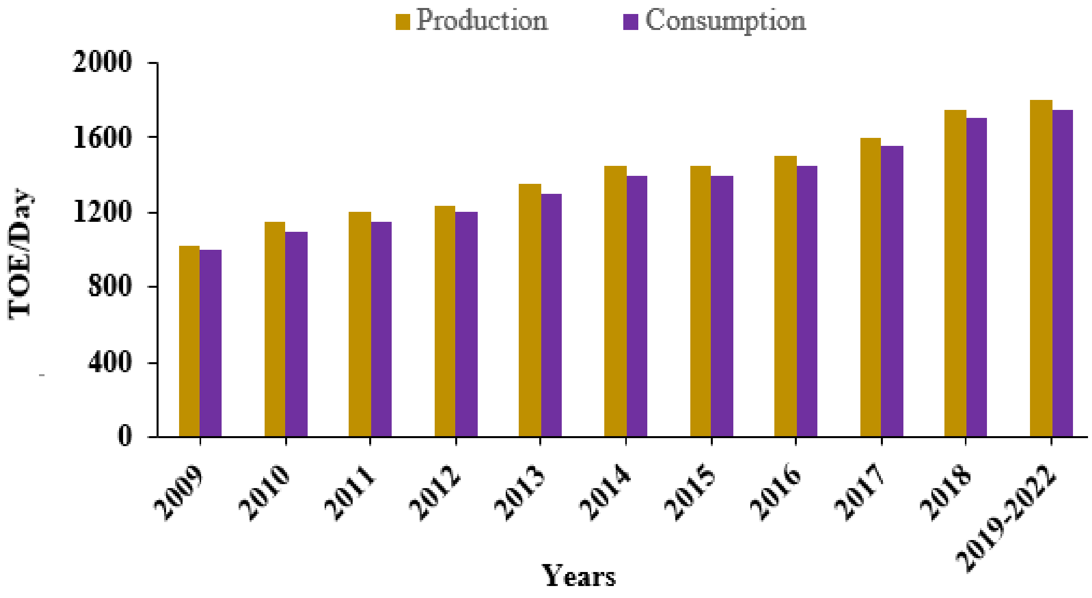

Figure 1.1: Global Production and Consumption of Biodiesel from Algae [6]

Global production of biodiesel in present and expectations in future are shown in the below graph:

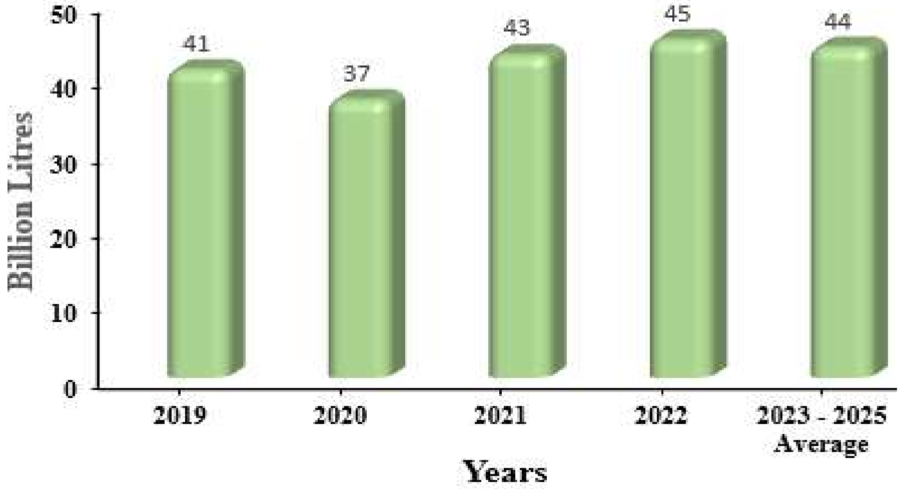

Figure 1.2: Global Biodiesel Production [6]

All biofuels are referred to as a replacement for oil or any other environmentally hazardous fuel. Algae biofuel has the potential to give around 20 times the output of other biofuels like corn, sorghum, beet, and corn Stover. Due to this feature of algae biofuel, there is a potential to open new pathways for industrial growth during the forecast period [7]. From 2021 to the mid of 2022, The epidemic of COVID-19 has brought serious social, medical, and economic challenges. It is seen that most of the companies working in the manufacturing sector (53%) expect COVID-19 to affect their operations.The expectations have become a reality in the sector due to the increase in oil prices and rising demand & supply bottlenecks which results in a decline in expenditures and rising uncertainty in credit markets.Companies across the world in the beverage & food industry have faced a decline in the consumption of their products [8]. Due to the reason of lockdown in several parts of the world and many restrictions on the transportation of commodities, companies are facing a disrupted supply chain. The reduction in agricultural production disturb the raw material supply, the lack of workers in manufacturing plants, and some disturbances in the distribution system have disrupted supply chains. Pakistan is ranked 34th for the consumption of refined petroleum products and its petroleum consumption per day is around 450,000 barrels. Most of the energy is consumed in automobiles. To bring an end to the energy crisis problem of the transport sector, there is a need to provide awareness for using alternative fuels for automobiles. Energy consumption in the transport sector is 34.2% of the total of 41.9 billion TOE (Tonnes of Oil Equivalent) of Pakistan's energy consumption. Pakistan is importing diesel fuel every year and even though local manufacturing of diesel decreases the volume of import in the year 2013 to 2014, the import of diesel has quite risen to 3.54 million tons for the year 2018 to 2020. Compared to other sources of biofuels, algae can produce much more oil per acre around 10 to 300 times more.So, the use of this method in Pakistan for biodiesel production is a good choice and it also boosts the economic condition of Pakistan. We are planning for our project to produce around 530 tons/year of Biodiesel from algae and in Pakistan algae production for 2020 to 2022 is predicted to be around 14,700 per acre and we use algae ¼ of this production.

1.6 Future Prospects of Biodiesel Production from Algae:

Quick expansion in human population, industrialization, vehicles and Gross domestic product drivesworld energy prerequisites and specifically petroleum derivatives with the improved site of is probably going to drain restricted normal assets over brief time frame while supported advancement needs dominancy energy can't be compromised. So, look for elective fuel is just the method for defeating this issue of impending energy emergency. In this view point biofuel is a maintainable choice [9]. Creation of biofuels from different biomasses turns into an extremely intriguing field of exploration. Biomasses utilized for biodiesel creation incorporate green growth, creature fats, vegetable oils like soybean, rapeseed, jatropha, mahua, mustard, flax, sunflower, palm, hemp, field pennycress, Pangamic pinnate and so on. Presently, the populace blast requiring enormous food requests, horticultural land can't be utilized for biofuel creation [9]. To moderate the issue involving green growth for biodiesel creation could assume a significant part. Certain types of green growth contain oil at an extremely huge level and furthermore are quickly developing [10]. This algal oil could be handled into biodiesel without any problem. Given specific circumstances are kept up with during the cycle. Biodiesel creation from green growth includes recognizable proof of appropriate algal species, cultivation of green growth by keeping up with specific boundaries (like temperature, pH, supplements, and air circulation), reaping, oil extraction, and cycle normalization [10]. Biodiesel creation from green growth in Pakistan is in an underlying stage which needs considerations of scientists for additional investigations [10].

1.7 Application of Algae Biodiesel:

Biodiesel dissolved in various proportions with petroleum based diesel is used largely as a heating oil.

1.7.1 Transportation:

The main reason for making biodiesel is to have a clean, renewable, and biodegradable alternative to conventional diesel. This means it will mainly be used in the transportation sector. The transportation sector is responsible for 24% of energy and over 60% of oil all over the world, with more than 30% of the energy consumed in only US alone. This means that over a third of the oil in the world is used to run vehicles. Biodiesel is therefore an improvement in the transportation sector as it is a renewable alternative to fossil diesel.

1.7.2 Providing Heat:

Over the past few years, the concept of bioheat has grown. It depends on using biofuel such as biodiesel as a source of heating. It replaces wood, which is the most useable heating method. A blend of biodiesel for heating can also decrease the emission of both nitrogen and sulfur dioxide. This heat can also be used in cooking by replacing kerosene which is usually used in stoves and non-wick lanterns.

1.7.3 Cleaning Oil Spills:

Biofuel is environmental friendly and can be used to clean oil spills and grease. It has been tested that biodiesel will work as a potential cleaning agent for those areas where crude oil contaminates the water. The results have also been found to increase the recovery areas and allow it to be removed from the water even if biodiesel is spilt or released into the environment, it causes less damage than fossil diesel, as it is too less combustible. It is safe to handle, transport, and store, making it good for cleaning oil spills.

1.7.4 Lubrication:

Biodiesel is necessary for vehicle engines as it decreases the sulfur concentration, where sulfur provides the most lubricity of the fuel. Biodiesel keeps the engine functioning properly and avoids premature infection failure.

CHAPTER # 02

MANUFACTURING PROCESS AND CAPACITY OF PLANT

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2.1 Introduction to Manufacturing Process:

Manufacturing is the process of turning raw materials or parts into finished goods through the use of tools, human labor, machinery, and chemical processing. Most products were handmade using human labor and basic tools before the industrial revolution. Manufacturing systems are important because they provide the means by which products are created. Without manufacturing systems, it would be difficult to produce the vast array of goods that we have come to rely on in our everyday lives.

2.2 Manufacturing Process for Biodiesel:

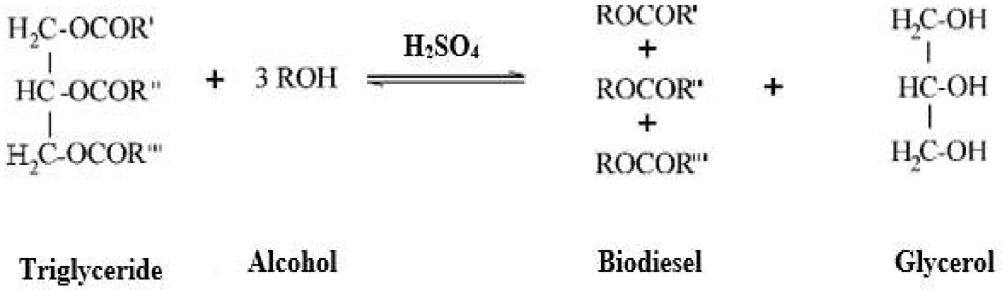
There are general two available manufacturing processes for biodiesel on commercial scale. Although biodiesel is produced from many raw materials like edible, non-edible oils, tobacco and algae etc but the main processes behind production of biodiesel from these raw materials are same. So, the two main manufacturing processes are mentioned below:

- Transesterification process.
- Biocatalytic process.

2.2.1 Transesterification Process:

Transesterification is the cycle where fat or oil responds with a liquor to frame esters and glycerol. An impetus is utilized to further develop the response rate and yield. Since the response is reversible, abundance alcohol is utilized to move the equilibrium to the product side [11]. This cycle has been broadly used to diminish the high consistency of fatty oils. Transesterification acquired a lot of acknowledgment lately for the change of vegetable oils into items with in fact more viable fuel properties. Transesterification is a basic interaction for biodiesel creation, as it can decrease the thickness of the feedstock/vegetable oils to a level nearer to the customary fossil based diesel oil. Transesterification addresses a significant gathering of natural responses during which exchange of the alkoxy moiety brings about the change of one ester into another [12]. Transesterification is a balance response depicting the alcoholics of carboxylic esters typically acted within the sight of ordinary impetus (e.g., NaOH and KOH) for important speed increase of the harmony to accomplish more significant returns of esters. Transesterification can be delegated reactant and noncatalytic processes [13]. The catalyzed transesterification cycle can be characterized into corrosive and base catalyzed processes.

Reaction:



$$\begin{matrix} H_2C\text{-}OCOR' \\ | \\ HC\text{-}OCOR'' \\ | \\ H_2C\text{-}OCOR''' \end{matrix} + 3\,ROH \xrightarrow{H_2SO_4} \begin{matrix} ROCOR' \\ + \\ ROCOR'' \\ + \\ ROCOR''' \end{matrix} + \begin{matrix} H_2C\text{-}OH \\ | \\ HC\text{-}OH \\ | \\ H_2C\text{-}OH \end{matrix}$$

………… (2.1)

Transesterification is an eco-friendly cycle done under gentle circumstances. This cycle can be utilized to deliver biodiesel from various feedstocks [13]. Vegetable or creature oils based fatty substances comprise of three unsaturated fats connected to one glycerol. In this response, fatty substances are responded with an alcohol and produce esters and glycerol. Transesterification of fats and oils is the most normally involved process for the production of methyl esters according to response at per reaction [14]. Fatty oils are transesterified group wise or consistently by multi step reactors at environmental tension and at temperature of around 60 to 70°C with an over abundance of methanol and within the sight of a soluble impetus like sodium methylate or potassium hydroxide [15]. The gentle response conditions, in any case, require the expulsion of free unsaturated fats from the oilby refining or pre-esterification before transesterification to stay away from the arrangement of cleanser advanced by the basic impetus. The blend toward the finish of the response is permitted to settle. The lower glycerin layer is drawn off, though the upper methyl ester layer is washed to eliminate entrained glycerin and is then handled further. The over abundance methanol is recuperated into a correcting segment for purging and reused. Methyl esters delivered can be refined or fractionated into smaller cuts or even individual parts with same refining arrangement previously portrayed for unsaturated fats [16]. A powerful transesterification reaction is suggested by the detachment of the glycerol layers and methyl ester (biodiesel) after the reaction time. The heavier co product settles out glycerol and may be sold with no guarantees or cleansed for use in various endeavors, forinstance, drug, excellence care items, and cleansers. After the transesterification response and the partition of the weighty glycerin stage, the minimizer is left with a rough light biodiesel stage [17]. This unrefined biodiesel requires a refinement before use. The principal issue is the cycles are moderatelytedious and need partition of the oil, alcohol, catalyst, and saponified debasements blend from the biodiesel [18]. Cleansing of biodiesel is a lot more straight forward as no impetus is expected during the supercritical transesterification process, in this way keeping cleanser development or saponification from happening. Nonetheless, the disadvantages of the supercritical liquor transesterification processare the high temperature and tension that outcome in the significant expense of the device.

The block flow diagram for transesterification process is on next page:

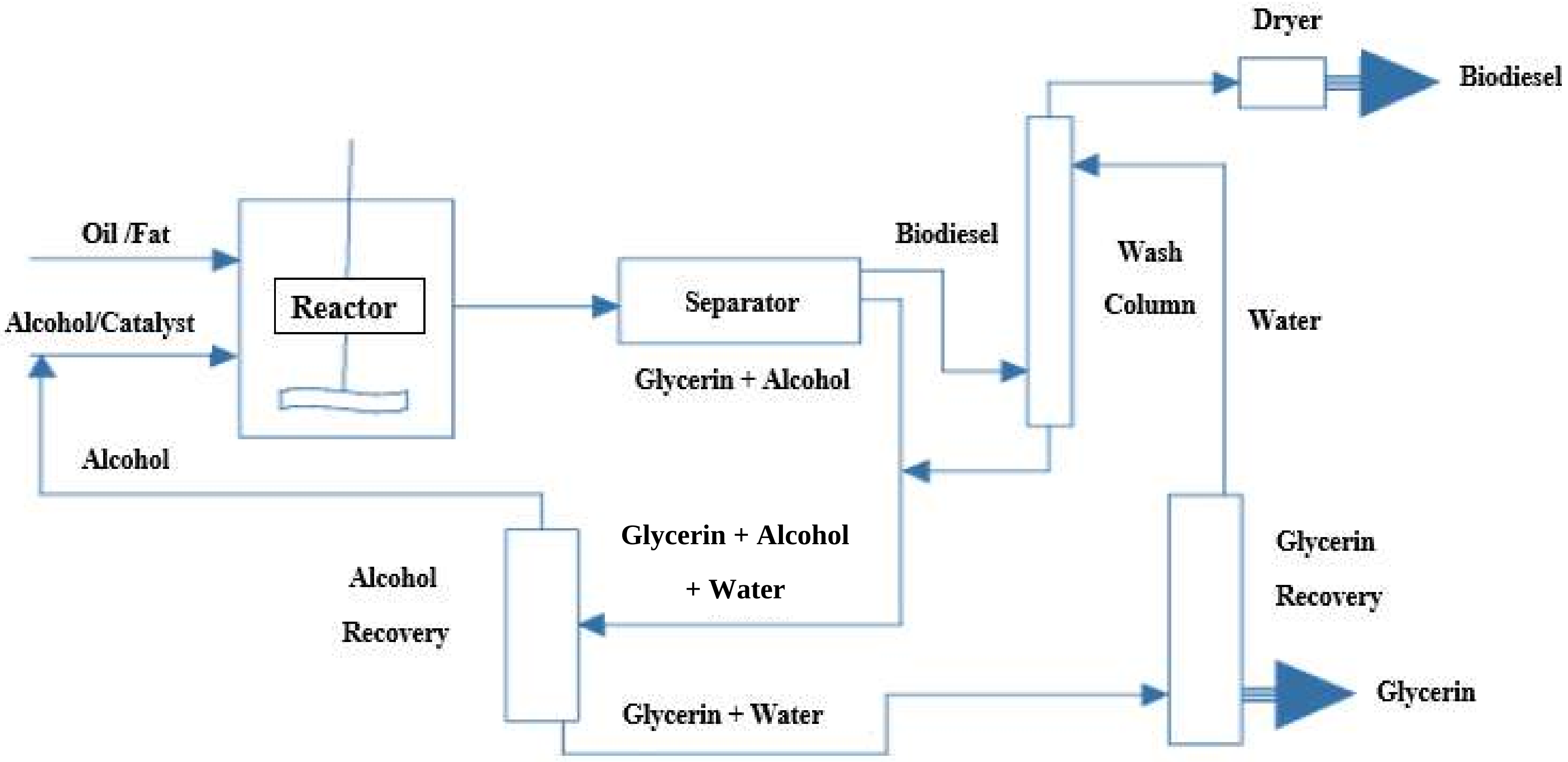
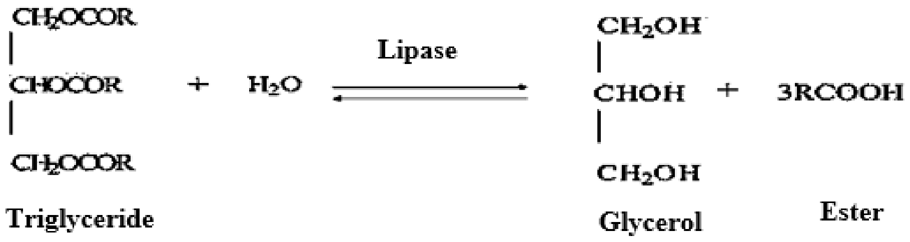


Figure 2.1: Block Flow Diagram for Transesterification Process [18]

2.2.2 Biocatalytic Process:

Biocatalytic cycles to deliver biodiesel or biofuel is the need of time to diminish the discharge of ozone depleting substances created from customary diesel or non-renewable energy sources. Lipases with phenomenal biochemical and physiological properties are most normally used to catalyze the transesterification cycle for biodiesel creation [19]. Lipases acquired from organisms, for example, microbes and parasites produce 70% - 95% ethanol and methanol. Biodiesel is normally made out of unsaturated fat alkyl esters which are mono-alkyl esters of either unsaturated fat methyl esters or unsaturated fat ethyl esters relying on the liquor (acyl acceptor) being utilized in the response [20]. Factors, for example, bioreactor type, acyl acceptor, temperature, and glycerol can influence the enzymatic transesterification response. Recombinant chemicals, for example, recombinant lipases can be utilized to get higher level of biodiesel because of their high explicitness and biocatalytic movement for various substrates utilized for biodiesel creation. Biocatalysts incorporate catalysts particularly lipases which are exceptionally famous in biodiesel creation [21]. Enzymatic biodiesel creation technique reduces issues related with salt and corrosive catalyzed strategies. Utilization of chemical impetuses has a few monetary and natural benefits over compound biodiesel creation processes. Benefits of catalyst catalysis incorporate creation of unadulterated and high market esteem glycerol, minor, or no waste water age to that end treatment of waste water isn't needed, gentle response conditions are required, no cleanser development since chemicals can esterify low quality feedstock having high centralization of FFA for that reason this technique is unfeeling toward feedstock focus. Enzymatic biodiesel creation is straight forward, so energy utilization is exceptionally low, catalysts can be reused in light of their simple partition from the response blend, and generally speaking possibility of defilement is lower than other transesterification strategies [22].

Reaction:



$$\begin{array}{l}CH_2OCOR\\ |\\ CHOCOR\\ |\\ CH_2OCOR\end{array} + H_2O \overset{\text{Lipase}}{\rightleftarrows} \begin{array}{l}CH_2OH\\ |\\ CHOH\\ |\\ CH_2OH\end{array} + 3RCOOH$$

………. (2.2)

The block flow diagram for biocatalytic process is on next page:

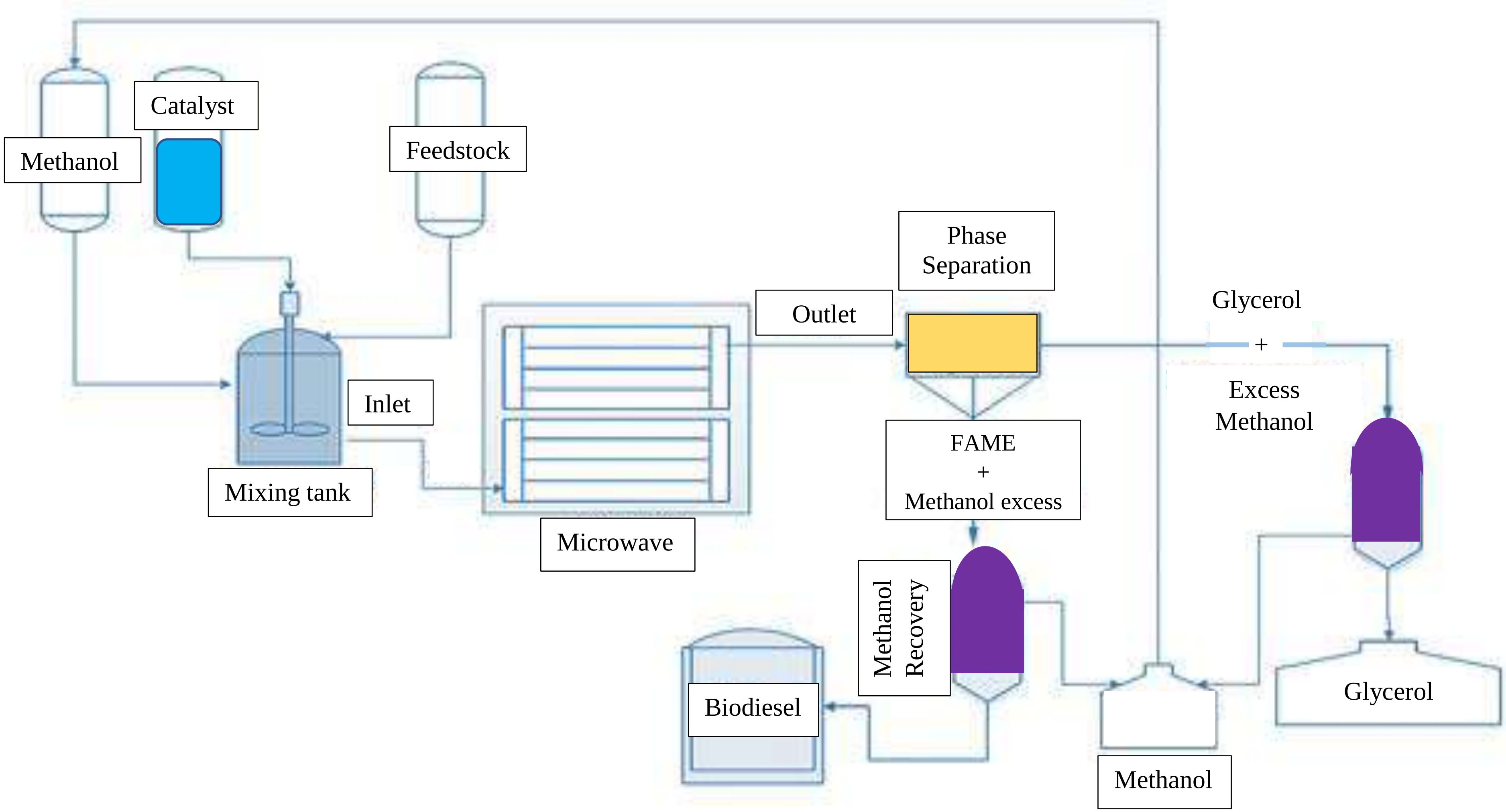


Figure 2.2: Block Flow Diagram for Biocatalytic Process [13]

2.3 Comparisons of Different Available Processes for Biodiesel:

Table 2.1: Comparisons of Different Processes for Biodiesel [22,23]

Factors	Biodiesel Production from Crops /Vegetable Oils	Biodiesel Produced from Tobacco	Production of Biodiesel from Algae	Production of Biodiesel from Biotechnologic Approach
Raw material	Palm oil, Soya bean, Sunflower oil	Tobacco	Algae oil	Ethanol
Oil content in raw material	Less than 20 % oil content obtained from seeds	30% oil content obtained from tobacco	More than 50 % of oil content in whole algae cell	Appro.68% of oil content.
Process used	Transesterification	Transesterification	Transesterification	Biocatalytic process
Reaction temperature	20 - 120°C	20 - 120°C	20 - 120°C	150 - 500°C
Pressure	60 – 150 bars	60 – 150 bars	60 – 150 bars	100 – 350 bars
Water requirement	More (approx.6500 Lto produced 1L of biodiesel)	More (approx.6500L to produced 1L of biodiesel)	Less (approx.4 L to produced 1L of biodiesel)	More (above 3500 L)
Greenhouse gas emission (kg of CO_2 created per MJ of energy produced)	30 – 50	30 - 50	-183	10 - 20
Yield	87 – 90 %	85%	89%	88%

2.4 Selection Criteria of Process:

We have selected transesterification process that use algae as raw material due to following reasons:

- This process is economical and efficient.
- Easily availability of raw material.
- Algae is a sustainable source.
- Lower emission of CO_2 and no SO_2 emission.
- High flexibility of the plant, wide range of load.
- Less costly equipments are required with respect to other processes.
- Less water required.

2.5 Process Description:

The raw material used in this process is as follow:

- Microalgae.

The catalyst used in this process are as follow:

- Methanol.
- Hexane.
- H_2SO_4.
- NaOH.

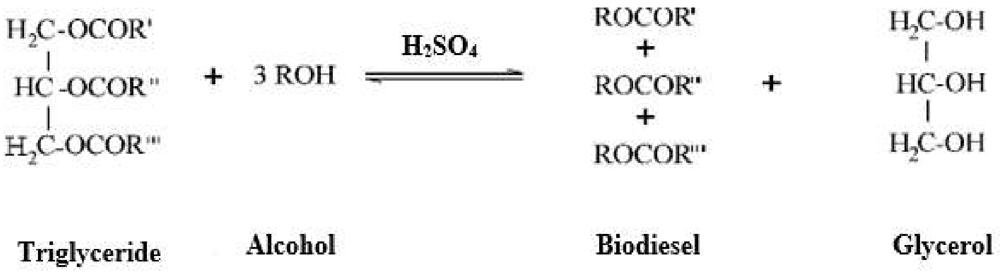
Other description is described below:

2.5.1 Extraction and Separation:

Firstly, we extract algal oil from algae. Approximately 0.5 to 1 wt% sodium hydroxide by weight is blended in with methanol prior it is warmed to 60 ^oC to be taken care of to the reactor. It ought to be noticed that a pump was utilized before the heat exchanger to represent the pressure drop in the heat exchanger.

2.5.2 Reactor (Transesterification Reaction Step):

The blend is then fed into the CSTR and the algal oil is added again at a similar temperature as the liquor/oil combination. This framework is completely shut from the environment to forest all the deficiency of alcohol. The response blend is kept just beneath the edge of boiling over of methanol (60^{o}C) so the response happens.



………. (2.3)

Besides, the prescribed response time fluctuates from 1 to 8 hours. The abundance methanol is typically used to guarantee that the algal oil is absolutely or profoundly changed over completely to the methyl esters (biodiesel). Essentially, around 76.5% change was achieved, which grants the utilization of a subsequent reactor. It is vital to follow how much free water and free unsaturated fats in the algal oil being taken care of. If not, cleanser development would block the partition of biodiesel from glycerin in any of the decanters.

2.5.3 Type of Reactor:

The stoichiometric reactor is decided to complete the transesterification process response for accompanying reasons:

- Response energy is obscure.
- Degree of response is known.

The overall stoichiometry of the response is for the most part known. Additionally, the degree of the response is known, which is measure of substance changes; it is an amount that depicts the advancement of the substance response or to which degree a response happens. Be that as it may, the energy of response is obscure as a result of the way that the creation of algal oil is obscure or is not entirely set in stone like for this situation.

2.5.4 Separation Unit:

Once more, biodiesel and glycerin are isolated from one another in view of their densities. And furthermore, the two of them contain methanol. After detachment, glycerin stage from the second decanter is taken care of along the glycerin from the main decanter.

2.5.5 Removal of Alcohol:

Presently, methanol is isolated from both the biodiesel and glycerin stage layers utilizing refining sections 1 and 2. The yield of methanol recuperated was 100 percent from glycerin and 99.3% from biodiesel. The biodiesel yield accomplished was 99.48%.

2.5.6 Refinement of Glycerin:

Further treating of glycerin that is the evacuation of salts (cleansers) and water, produces close to 100% or more unadulterated glycerin which could be offered to the restorative and drug markets. For the refinement of glycerin have a unit called neutralizer. It also acts as a reactor. The reaction occur in it,is mentioned below:

$$2NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O \quad \text{…………… (2.4)}$$

2.5.7 Purification of Biodiesel:

After partition from the methanol, the biodiesel is now and again sanitized by delicately washing with warm water to eliminate remaining cleansers or impetus, dried, and afterward shipped off be put away. At times this step is pointless; like in our process that is washing with water diminished the yield and virtue of biodiesel. So, this step was disposed of.

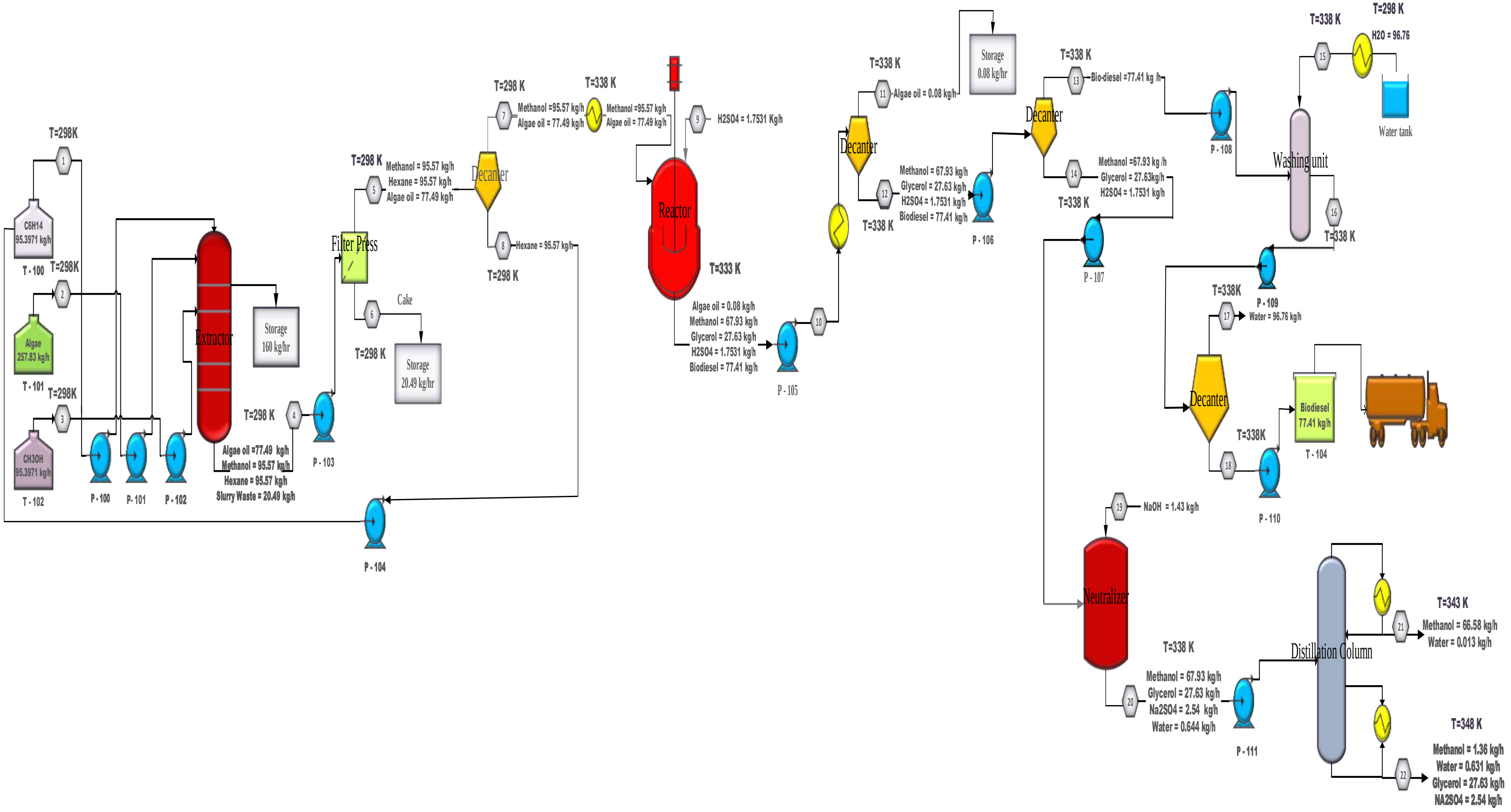


Figure 2.3: Process Flow Diagram for Biodiesel Production from Algae

2.6 Capacity Selection:

As we are on an initial stage of start up. So, in order to check product demand, we have target one application of biodiesel which is “transport”. As transport is one of the wide applications so we have to be more particular and target “Metro buses of Islamabad and Rawalpindi”. The estimated average monthly consumption in Rawalpindi-Islamabad Metrobus System is 40000 Litres [23]. Based upon the data taken from Punjab Metro bus Authority report, we have selected the production capacity of our project plant to be 530 tons/yr for meet the increasing demand of biodiesel. It is also decided that in the upcoming years if this biodiesel is suitable for transport application then we increase our production capacity according to demand at that time.

CHAPTER # 03

MATERIAL BALANCE

CHAPTER # 03

MATERIAL BALANCE

3.1 Introduction to Material Balance:

A mass equilibrium, also known as a content balance, is a physical system measurement extension to mass conservation. Stuff entering and leaving a system may be counted to measure mass movements, which would otherwise be uncertain or impossible to estimate without this technique. The exact conservation law used in the system's study is dependent on the context of the issue, but everything centers around mass conservation, which states that matter cannot randomly vanish or be generated. Content balances are critical in production management, especially in the control of products yields. A mass balance is defined as the mass that enter a system and must either exit or accumulate within the system due to mass conservation. We used the elemental material balance technique for our material balance [24].

The general formula for the material balance is:

Input to the system - Output from the system + Generation in the system - Consumption in the system = Accumulation in the system …………… (3.1)

3.1.1 Capacity of Plant:

The production of plant is 530 Tons/yr.

3.1.2 Operating Time of Plant:

Operating time is 300 days in 1 year.

3.1.3 Raw Material Used in Plant:

- Algae.
- Methanol.
- Hexane.

3.1.4 Basis Related to Material Balance:

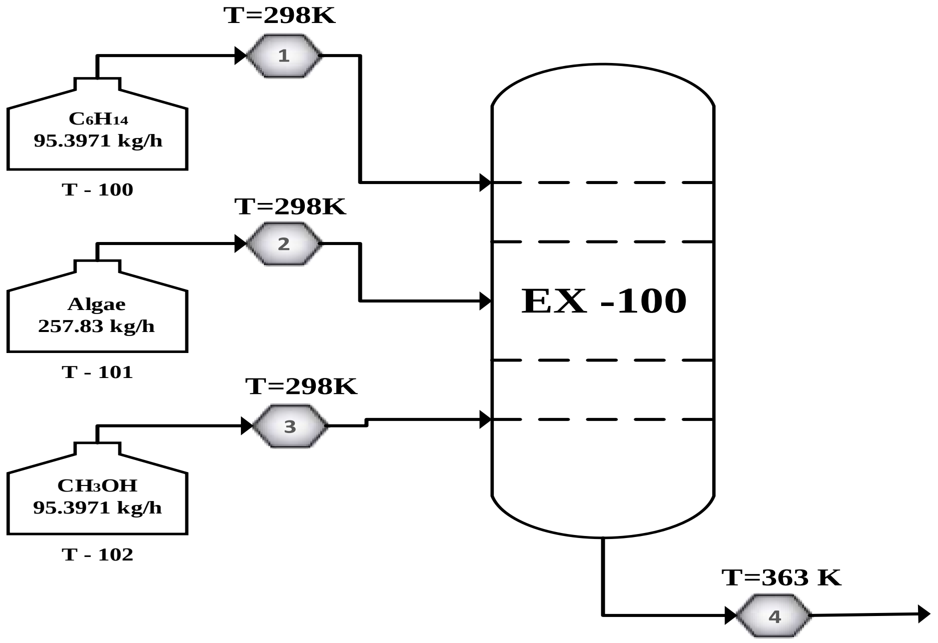
- 1 hours of operation.

3.1.5 Production Rate:

$$\frac{530\ \cancel{\text{Ton}}}{\cancel{\text{Year}}}\ \Big|\ \frac{1000\ \text{kg}}{1\ \cancel{\text{Ton}}}\ \Big|\ \frac{1\ \cancel{\text{Year}}}{300\ \cancel{\text{Days}}}\ \Big|\ \frac{1\ \cancel{\text{Day}}}{24\ \text{hr}}$$

The production rate of plant is 73.61 kg/hr.

3.2 Material Balance at Extractor (EX -100):



Components	Flowrate (kg/hr)
CH_3OH	95.57
C_6H_{14}	95.57
$C_{57}H_{104}O_6$	77.49
Slurry Waste	180.49

Figure 3.1: Extractor (EX-100)

Overall Material Balance:

Algae + Hexane + Methanol = Algae Oil + Methanol + Hexane + Slurry Waste ……….. (3.2)

Algae Balance:

$0.3 \times \text{Algae} = \text{Algae oil}$

$0.3 \times \text{Algae} = 77.49$

$\text{Algae} = \frac{77.49}{0.3}$

Algae = 258.28 kg/hr

Methanol Balance:

0.35 × Algae = Methanol

0.35 × 258.28 = Methanol

Methanol = 95.57 kg/hr

Hexane Balance:

0.35 × Algae = Hexane

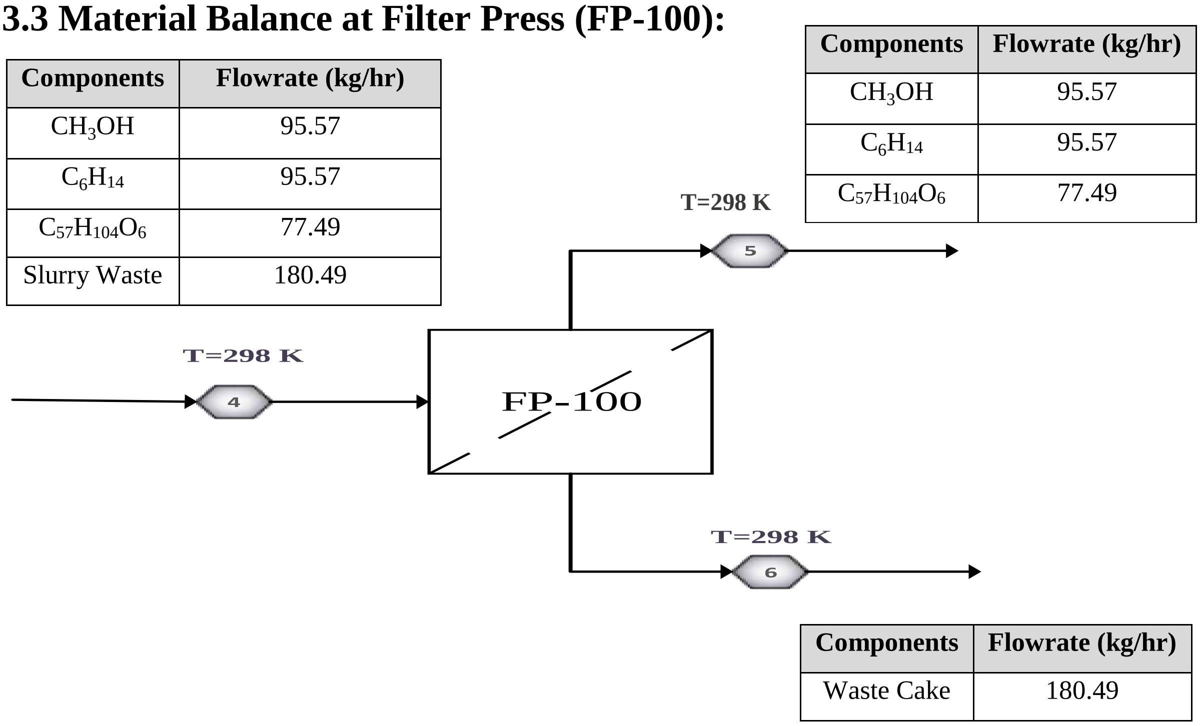
0.35 × 258.28 = Hexane

Hexane = 95.57 kg/hr

Table 3.1: Streamwise Material Balance on EX-100

Components	Inlet Stream kg/hr			Outlet Stream kg/hr
	1	2	3	4
Algae	258.28	-		-
CH_3OH	-	95.57		95.57
C_6H_{14}	-	-	95.57	95.57
$C_{57}H_{104}O_6$	-	-		77.49
Slurry Waste	-	-		180.49
Total	449.42			449.42

3.3 Material Balance at Filter Press (FP-100):



Components	Flowrate (kg/hr)
CH_3OH	95.57
C_6H_{14}	95.57
$C_{57}H_{104}O_6$	77.49
Slurry Waste	180.49

Components	Flowrate (kg/hr)
CH_3OH	95.57
C_6H_{14}	95.57
$C_{57}H_{104}O_6$	77.49

Components	Flowrate (kg/hr)
Waste Cake	180.49

Figure 3.2: Filter Press (FP-100)

Overall Material Balance:

Feed stream = Filter + Cake …………… (3.3)

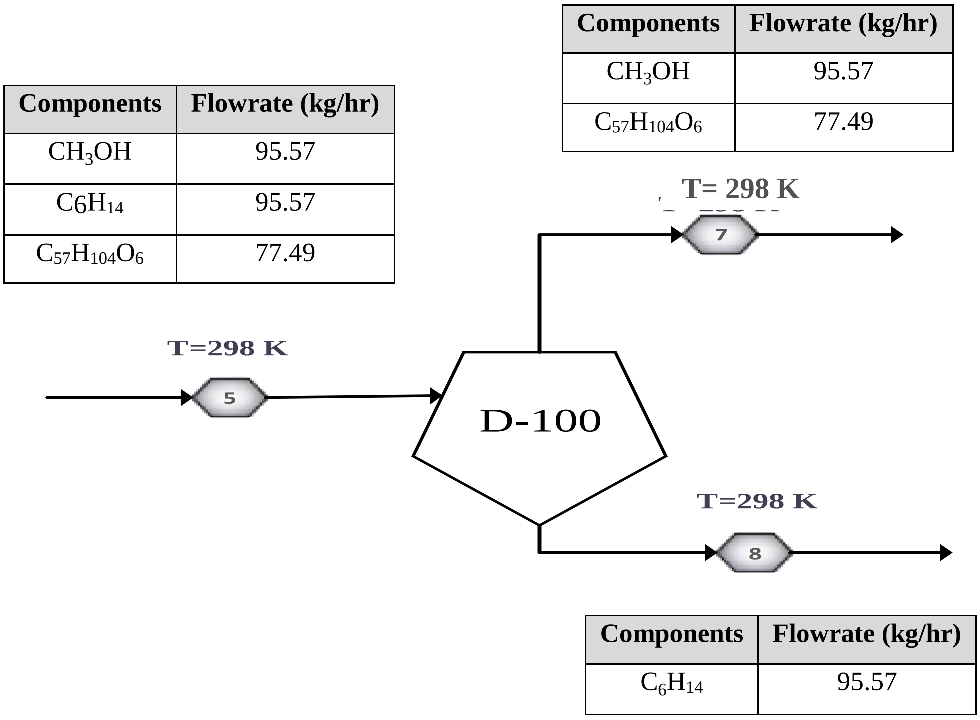
Cake:

Cake = 180.49 kg/hr

Table 3.2: Streamwise Material Balance on FP-100

Components	Inlet Stream kg/hr	Outlet Stream kg/hr	
	4	5	6
CH_3OH	95.57	95.57	-
C_6H_{14}	95.57	95.57	-
$C_{57}H_{104}O_6$	77.49	77.49	-
Slurry Waste	180.49	-	-
Cake	-	-	180.49
Total	449.42	449.42	

3.4 Material Balance at Decenter (D-100):



Components	Flowrate (kg/hr)
CH_3OH	95.57
$C_{57}H_{104}O_6$	77.49

Components	Flowrate (kg/hr)
CH_3OH	95.57
$C6H_{14}$	95.57
$C_{57}H_{104}O_6$	77.49

Components	Flowrate (kg/hr)
C_6H_{14}	95.57

Figure 3.3: Decanter (D-100)

Overall Material Balance:

Hexane + Methanol + Algae oil = Top (Algae oil + Methanol) + Bottom (Hexane) ……… (3.4)

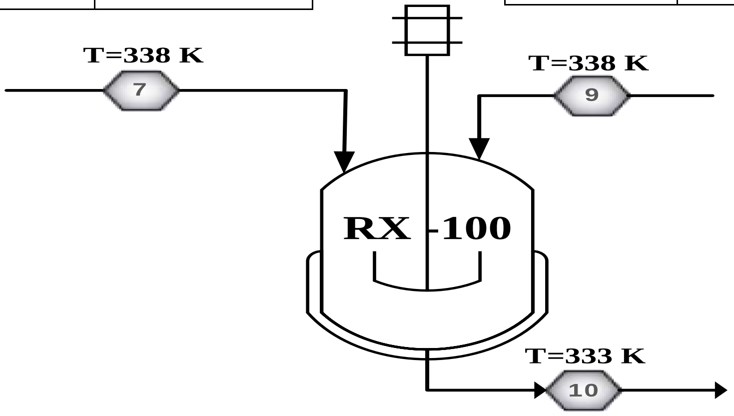
Table 3.3: Streamwise Material Balance On D-100

Components	Inlet Stream kg/hr	Outlet Stream kg/hr	
	5	7	8
CH_3OH	95.57	95.57	-
C_6H_{14}	95.57	-	95.57
$C_{57}H_{104}O_6$	77.49	77.49	-
Total	268.62	268.62	

3.5 Material Balance at Reactor (RX-100):

Components	Flowrate (kg/hr)
CH_3OH	95.57
$C_{57}H_{104}O_6$	77.49

Components	Flowrate (kg/hr)
H_2SO_4	1.7531



Components	Flowrate (kg/hr)
CH_3OH	67.93
$C_{57}H_{104}O_6$	0.08
H_2SO_4	1.7531
$C_{19}H_{36}O_2$	77.41
$C_3H_8O_3$	27.63

Figure 3.4: Reactor (RX-100)

Overall Material Balance:

$$C_{57}H_{104}O_6 + 3CH_3OH \longrightarrow 3C_{19}H_{36}O_2 + C_3H_8O_3 \quad \ldots\ldots\ldots\ldots (3.5)$$

Conversion = 99.9%

For catalyst of H_2SO_4 = 5%

For Methanol:

Ratios = Algae oil: Methanol

Methanol = 27.6315 kg/hr

For Glycerol:

Ratios = Algae oil: Glycerol

Glycerol = 27.628 kg/hr

Unreacted Methanol:

Unreacted methanol = Actual - Consumed

= 67.93 kg/hr

Biodiesel:

Biodiesel = 77.41

Unreacted Algae oil:

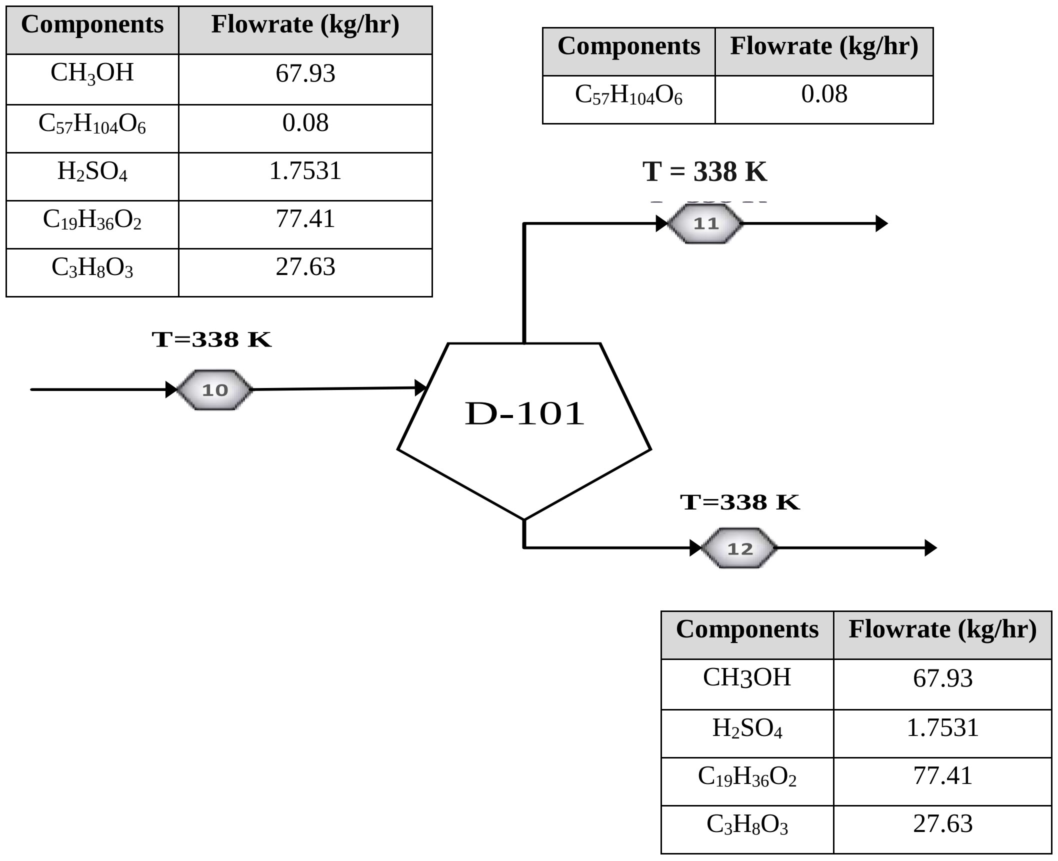
Unreacted algae oil = Actual – Consumed

= 0.08 kg/hr

Table 3.4: Streamwise Material Balance on RX-100

Components	Inlet Stream kg/hr		Outlet Stream kg/hr
	7	9	10
CH_3OH	95.57	-	67.93
$C_{57}H_{104}O_6$	77.49	-	0.08
H_2SO_4	-	1.7531	1.7531
$C_{19}H_{36}O_2$	-	-	77.41
$C_3H_8O_3$	-	-	27.63
Total	174.80		174.80

3.6 Material Balance at Decenter (D -101):



Components	Flowrate (kg/hr)
CH_3OH	67.93
$C_{57}H_{104}O_6$	0.08
H_2SO_4	1.7531
$C_{19}H_{36}O_2$	77.41
$C_3H_8O_3$	27.63

Components	Flowrate (kg/hr)
$C_{57}H_{104}O_6$	0.08

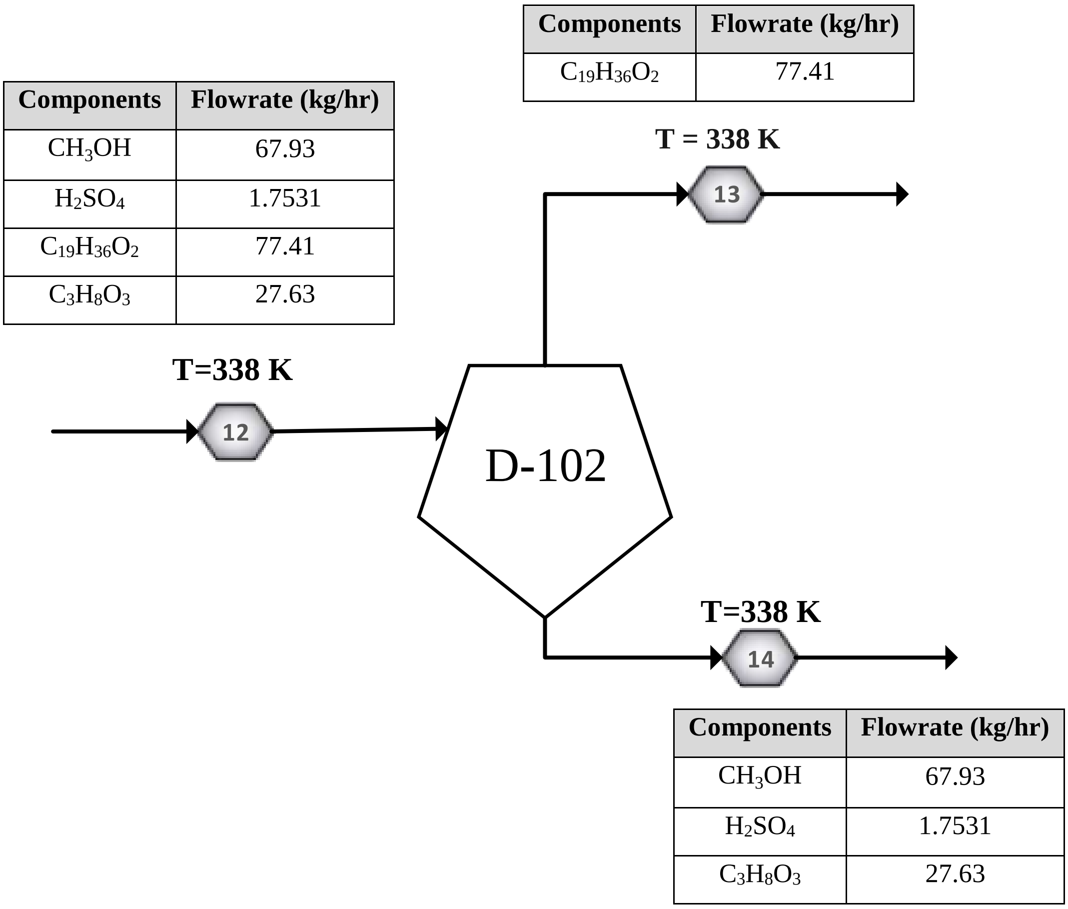
Components	Flowrate (kg/hr)
CH3OH	67.93
H_2SO_4	1.7531
$C_{19}H_{36}O_2$	77.41
$C_3H_8O_3$	27.63

Figure 3.5: Decanter (D-101)

Table 3.5: Streamwise Material Balance on D-101

Components	Inlet Stream kg/hr	Outlet Stream kg/hr	
	10	**11**	**12**
CH_3OH	67.93	-	67.93
$C_{57}H_{104}O_6$	0.08	0.08	-
H_2SO_4	1.7531	-	1.7531
$C_{19}H_{36}O_2$	77.41	-	77.41
$C_3H_8O_3$	27.63	-	27.63
Total	174.80	174.80	

3.7 Material Balance at Decanter (D-102):



Components	Flowrate (kg/hr)
$C_{19}H_{36}O_2$	77.41

Components	Flowrate (kg/hr)
CH_3OH	67.93
H_2SO_4	1.7531
$C_{19}H_{36}O_2$	77.41
$C_3H_8O_3$	27.63

Components	Flowrate (kg/hr)
CH_3OH	67.93
H_2SO_4	1.7531
$C_3H_8O_3$	27.63

Figure 3.6: Decanter (D-102)

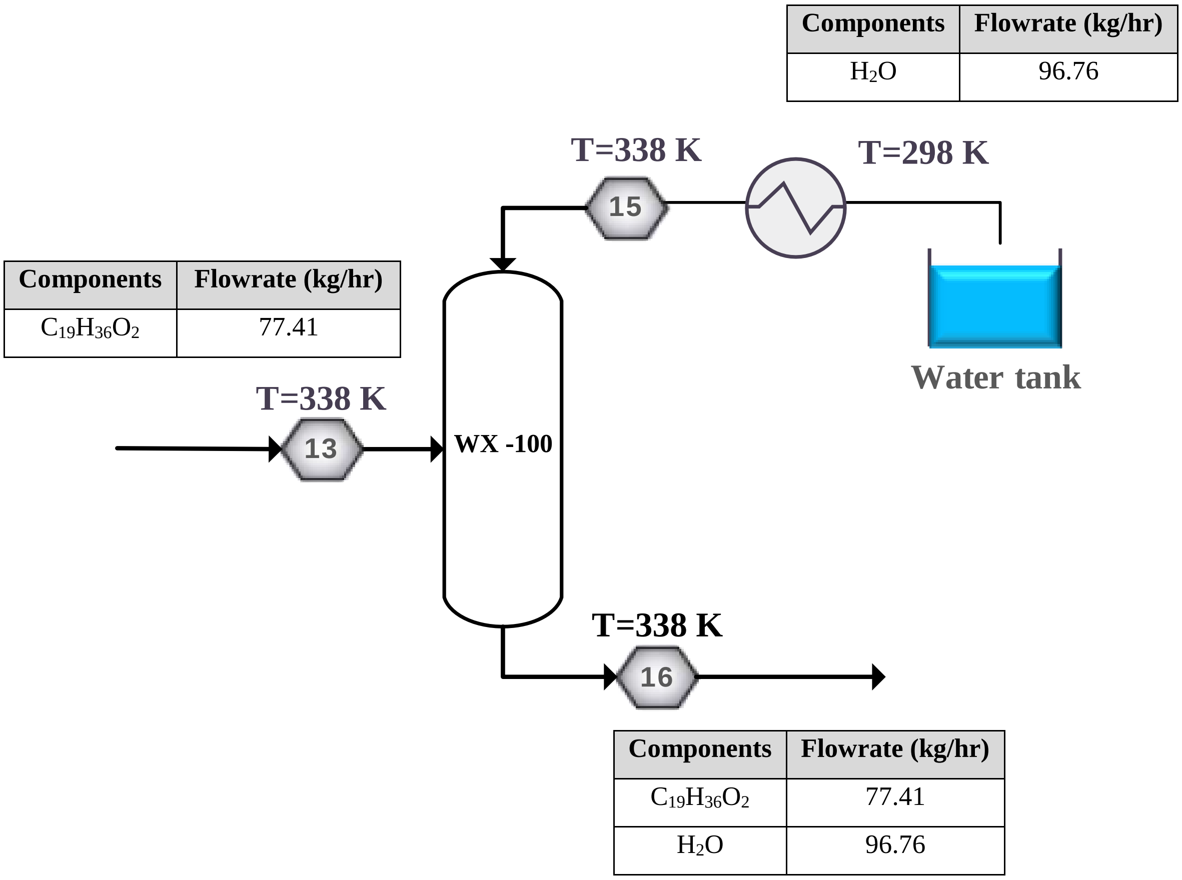
Overall Material Balance:

Hexane + Methanol + H_2SO_4 + Biodiesel = Top (Biodiesel) + Bottom (Hexane + Methanol + H_2SO_4) …………. (3.6)

Table 3.6: Streamwise Material Balance on D-102

Components	Inlet Stream kg/hr	Outlet Stream kg/hr	
	12	13	14
CH_3OH	67.93	-	67.93
H_2SO_4	1.7531	-	1.7531
$C_{19}H_{36}O_2$	77.41	77.41	-
$C_3H_8O_3$	27.63	-	27.63
Total	174.80	174.80	

3.8 Material Balance at Washing Unit (WX-100):



Components	Flowrate (kg/hr)
H_2O	96.76

Components	Flowrate (kg/hr)
$C_{19}H_{36}O_2$	77.41

Components	Flowrate (kg/hr)
$C_{19}H_{36}O_2$	77.41
H_2O	96.76

Figure 3.7: Washing Unit (WX-100)

Overall Material Balance:

Input + ~~Generation~~ = Output + ~~Consumption~~ + ~~Accumulation~~ .... (3.7)

Ratios = Water: Biodiesel

= 1.5: 1

Water amount = 96.76 kg/hr

Table 3.6: Streamwise Material Balance on WX-100

Components	**Inlet Stream kg/hr**		**Outlet Stream kg/hr**
	13	**15**	**16**
$C_{19}H_{36}O_2$	77.41	-	77.41
H_2O		96.76	96.76
Total	174.17		174.17

3.9 Material Balance at Decenter (D -103):

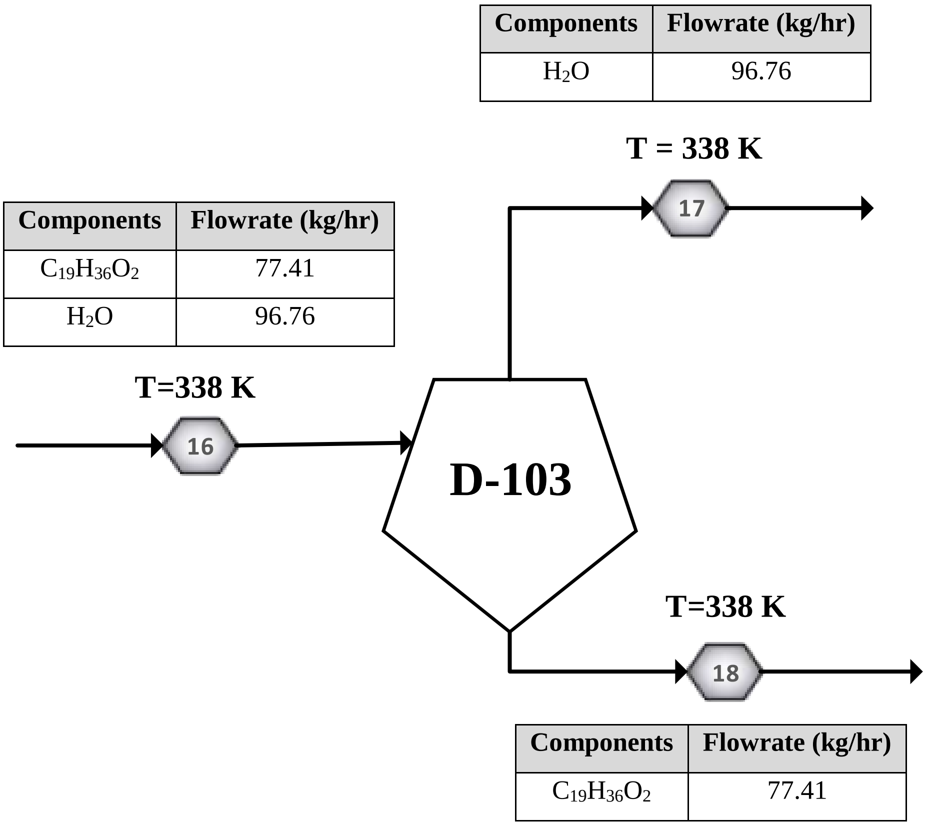


Figure 3.8: Decanter (D-103)

Overall Material Balance:

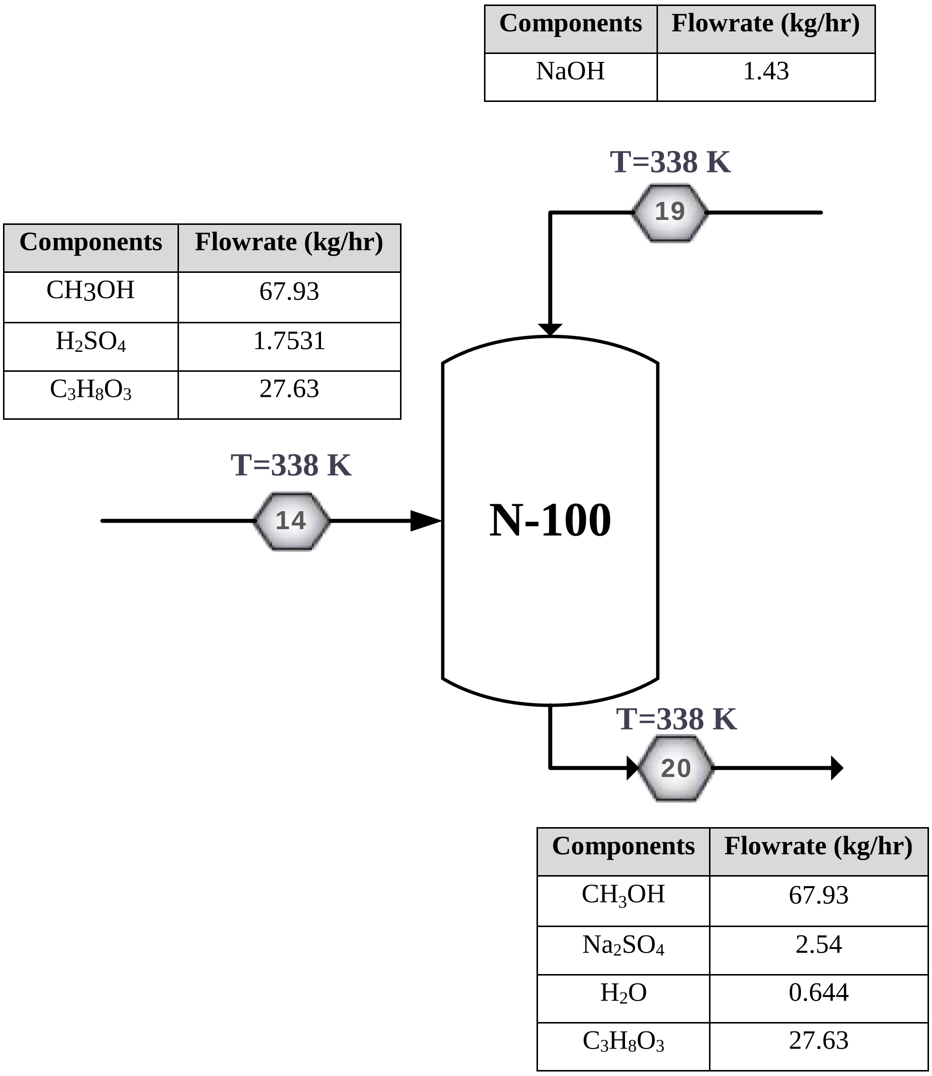
Water + Biodiesel = Top (Water) + Bottom (Biodiesel) …………. (3.8)

Table 3.7: Streamwise Material Balance on Decanter (D-103)

Components	Inlet Stream kg/hr	Outlet Stream kg/hr	
	16	17	18
$C_{19}H_{36}O_2$	77.41	-	77.41
H_2O	96.76	96.76	-
Total	174.17	174.17	

3.10 Material Balance at Neutralizer:

$2NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$ …………… (3.9)



Components	Flowrate (kg/hr)
NaOH	1.43

Components	Flowrate (kg/hr)
CH3OH	67.93
H_2SO_4	1.7531
$C_3H_8O_3$	27.63

Components	Flowrate (kg/hr)
CH_3OH	67.93
Na_2SO_4	2.54
H_2O	0.644
$C_3H_8O_3$	27.63

Figure 3.9: Neutralizer (N-100)

Overall Material Balance:

Input + ~~Generation~~ = Output + ~~Consumption~~ + ~~Accumulation~~ …………. (3.10)

No. of moles of $H_2SO_4 = \frac{1.75}{98}$

$n_{(H2SO4)} = 0.018$ kmol

No. of moles of NaOH = 2 × moles of H_2SO_4

$n = 2 \times 0.018$ mol

$n_{(NaOH)} = 0.036$ kmol

Weight of NaOH = $n_{(NaOH)} \times$ Mass of NaOH

$= 0.036 \times 39.997$

$= 1.431$ kg

No. of moles of Na_2SO_4 = Stoichiometric Coefficient of $Na_2SO_4 \times n(H_2SO_4)$

$= 1 \times 0.018$ kmol

$n_{(Na2SO4)} = 0.018$ kmol

Weight of $Na_2SO_4 = n_{(Na2SO4)} \times$ mass of Na_2SO_4

$= 0.018 \times 142$

$= 2.540$ kg

No. of moles of $H_2O = 2 \times n(H_2SO_4)$

$= 2 \times 0.018$

$n_{(H2O)} = 0.036$ kmol

Weight of $H_2O = n_{(H2O)}) \times$ mass of H_2O

$= 0.036 \times 18$

$= 0.644$ kg

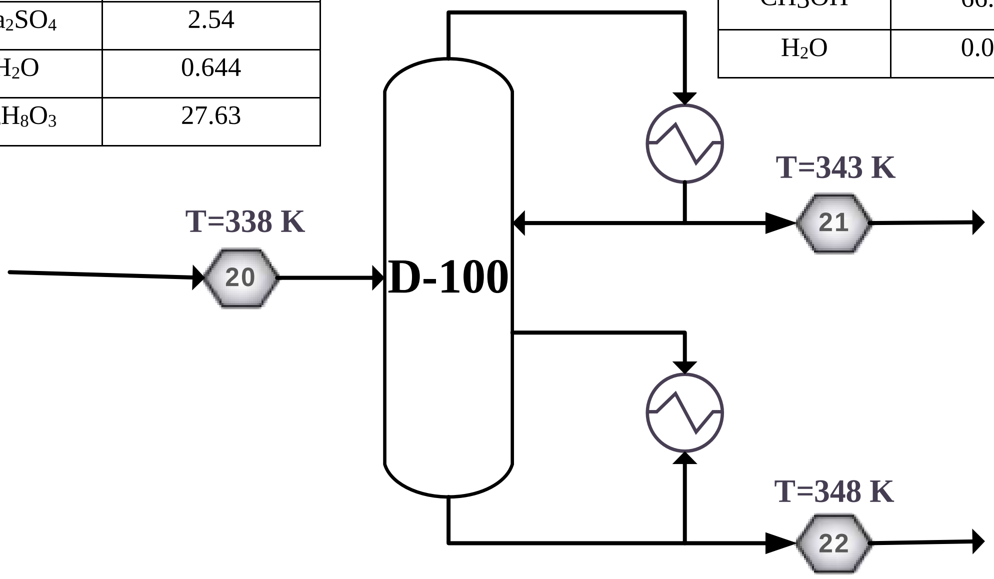
Table 3.8: Streamwise Material Balance on N-100

Components	**Inlet Stream kg/hr**		**Outlet Stream kg/hr**
	14	**19**	**20**
CH_3OH	67.93	-	67.93
H_2SO_4	1.7531	-	-
Na_2SO_4	-	-	2.54
H_2O	-	-	0.644
$C_3H_8O_3$	27.63	-	27.63
NaOH	-	1.43	-
Total	98.75		98.75

3.11 Material Balance at Distillation Column:

Components	Flowrate (kg/hr)
CH_3OH	67.93
Na_2SO_4	2.54
H_2O	0.644
$C_3H_8O_3$	27.63

Components	Flowrate (kg/hr)
CH3OH	66.58
H_2O	0.013



Components	Flowrate (kg/hr)
CH_3OH	1.36
Na_2SO_4	2.54
H_2O	0.631
$C_3H_8O_3$	27.63

Figure 3.10: Distillation (D-100)

Table 3.9: Streamwise Material Balance on D-100

Components	Inlet Stream kg/hr	Outlet Stream kg/hr	
	20	21	22
CH_3OH	67.93	66.58	1.36
Na_2SO_4	-		2.54
H_2O	0.644	0.013	0.631
$C_3H_8O_3$	27.63		27.63
Total	98.75	98.75	

CHAPTER # 4

ENERGY BALANCE

CHAPTER # 4

ENERGY BALANCE

4.1 Introduction:

The estimates of the energy requirements for the operation, such as heating, cooling, temperature, friction, and enthalpy, are known as energy balance. Kinetic energy, potential energy, heat energy, electrical energy, and mechanical energy are all types of energy. Energy cannot be produced or lost, according to the law of conservation. A general equation of conservation of energy is:

Energy in + Generation - Consumption - accumulation = Energy out …………. (4.1)

It is also called 1st law of thermodynamics. The total enthalpy of outlet stream is not equal to inlet stream if it's generated or consumed.

4.1.1 Energy Balance:

Formula Used:

$Q = \dot{m}\, C_p\, dT$ ……….. (4.2)

$H_i = a\,(T - T_{ref}) + \frac{b}{2}\,(T^2 - T_{ref}{}^2) + \frac{c}{3}\,(T^3 - T_{ref}{}^3) + \frac{d}{4}\,(T^4 - T_{ref}{}^4)$ ……….. (4.3)

So, by using above formula and by using the values of constants in table. We calculate $\mathbf{H^O}$ of the components of both inlet and the outlet streams.

4.1.2 Heat of Reaction:

In any process involves chemical reaction heat must be added or removed. The heat of reaction is released when the process is operating on standard conditions like l atm pressure and 25°C temperature. In process design normally heat of reaction is expressed in terms of moles of product produced.

The general form is:

$\mathbf{\Delta H_r, t = \Delta H_r + \Delta H_{products} - \Delta H_{reactants}}$ …………. (4.4)

Where,

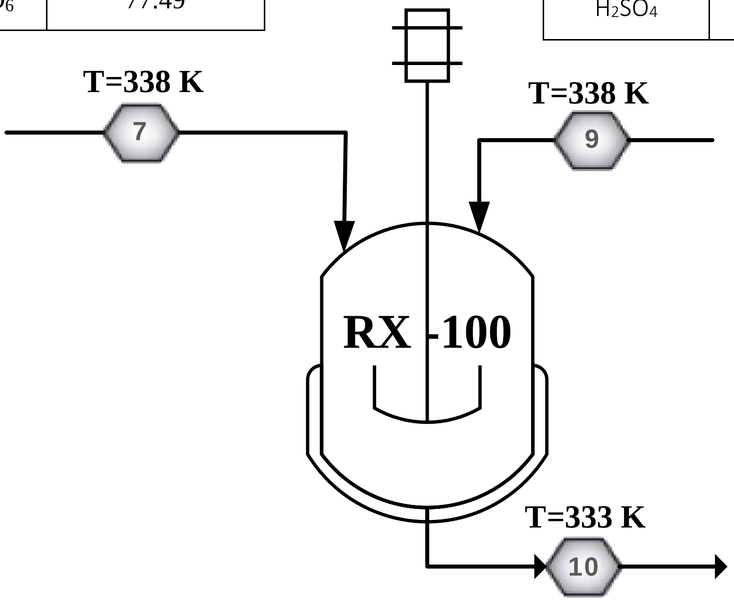
- ΔH_r = Heat of reaction at temperature T (°C).
- $\Delta H_{reactants}$ = Change of the reactant at standard temperature.

- ➢ $\Delta H_{products}$ = Change in enthalpy to get products to temperature T.

4.2 Energy Balance at Reactor (RX-100):

Components	Flowrate (kg/hr)
CH_3OH	95.57
$C_{57}H_{104}O_6$	77.49

Components	Flowrate (kg/hr)
H_2SO_4	1.7531



Components	Flowrate (kg/hr)
CH_3OH	67.93
$C_{57}H_{104}O_6$	0.08
H_2SO_4	1.7531
$C_{19}H_{36}O_2$	77.41
$C_3H_8O_3$	27.63

Figure 4.1: Reactor (RX-100)

Inlet temp = T_{in} = 313 K

Outlet temp = T_{out} = 338 K

T_{ref} = 298 K

Stream 7:

$Cp = A + BT + CT^2 + DT^3$ …………. (4.5)

Table 4.1: Specific Gravity (Cp) for Stream 7 Components

Components	Constant				Outlet Stream
	A	B	C	D	K J/kg×K
CH_3OH	40	-3.28E-2	2.45E-4	-2.17E-7	1.42
$C_{57}H_{104}O_6$	-	-			2.00

Table 4.2: Weighted Cp for Stream 7 Components

Components	Flow Rate	Fraction	Cp	Weighted Cp
	kg/hr		KJ/kg × K	KJ/kg × K
CH_3OH	95.4	0.55	1.42	0.82
$C_{57}H_{104}O_6$	77.36	0.45	2.00	0.9
	172.76	1.00		1.72

$H = Q = \dot{m}\, C_p\, dT$

$H = (172.76) \times (1.72) \times (313 - 298)$

$H = 4463.41$ KJ/hr

Stream 9:

$Cp = A + BT + CT^2 + DT^3$ ………… (4.6)

Table 4.3: Specific Gravity (Cp) for Stream 9 Components

Components	Constant				Outlet Stream
	A	B	C	D	K J/kg × K
H_2SO_4	26	7.03E-1	-1.38E-3	1.03E-6	1.45

$H = Q = \dot{m}\, C_p\, dT$ ………… (4.7)

$H = (1.7531) \times (1.45) \times (313 - 298)$

$H = 38.08$ KJ/hr

Stream 10:

$Cp = A + BT + CT^2 + DT^3$ …………… (4.8)

Table 4.4: Specific Gravity (Cp) for Stream 10 Components

Components	Constant				Outlet Stream
	A	B	C	D	K J/kg × K
CH_3OH	40	-3.28E-2	2.45E-4	-2.17E-7	1.46
$C_{57}H_{104}O_6$	-	-	-	-	2.08
H_2SO_4	26	7.03E-1	-1.38E-3	1.03E-6	1.48
$C_{19}H_{36}O_2$	183.5	2.9014	-6.25E-3	5.69E-6	2.26
$C_3H_8O_3$	132.2	8.60E-1	-1.97E-3	-1.81E-6	1.38

$H = Q = \dot{m}\, C_p\, dT$ ………… (4.9)

$H = (174.58) \times (1.80) \times (338 - 298)$

H = 12580.42 KJ/hr

4.2.1 Heat of Reaction:

The amount of heat that must be provided or eliminated during a chemical reaction in order to retain all of the compounds present at the same temperature is known as the heat of reaction. As a result, the enthalpy of teaetion, denoted by the symbol H. is also known as the heat of reaction measured at constant pressure. The reaction is considered to be endothermic if the heat of reaction is positive, and exothermic if the heat of reaction is negative.

$\Delta H_r = \Sigma (n\Delta H_f)_{product} - \Sigma (n\Delta H_f)_{reactant}$ …………… (4.10)

$\Delta H_f = A + BT + CT^2$ …………… (4.11)

Table 4.5: Heat of Reaction of Reactants

Components	Constant			Outlet Stream
	A	B	C	KJ/mol
CH_3OH	-188.2	-4.98E-2	2.08E-5	-201.75
$C_{57}H_{104}O_6$	-	-	-	-43.202
H_2SO_4	-	-	-	-809.21

Sulfuric Acid = ΔH_f^o = -811.32 KJ/mol

$\boldsymbol{\Delta H_{f\,313} = \Delta H_{f\,298} + \int_{298}^{313} cp\, \Delta T}$ ………….. (4.12)

Sulfuric Acid = $\Delta H_{f\,=}$ -809.204 KJ/mol

Table 4.6: Heat of Reaction of Product

Components	Constant			Outlet Stream
	A	B	C	KJ/mol
H_2SO_4	-	-	-	-805.61
$C_{19}H_{36}O_2$	-532.4	-3.72E-1	1.93E-4	-636.27
$C_3H_8O_3$	-250.4	-8.79E-2	4.31E-5	-275.14

Sulfuric Acid = ΔH_f^o = -811.32 KJ/mol

$\Delta H_{f\,338} = \Delta H_{f\,298} + \int_{298}^{338} cp\, \Delta T$ …………… (4.13)

Sulfuric Acid = $\Delta H_{f\,=}$ -805.61 KJ/mol

$\Delta H_r = \Sigma (n\Delta H_f)_{product} - \Sigma (n\Delta H_f)_{reactant}$ ………….. (4.14)

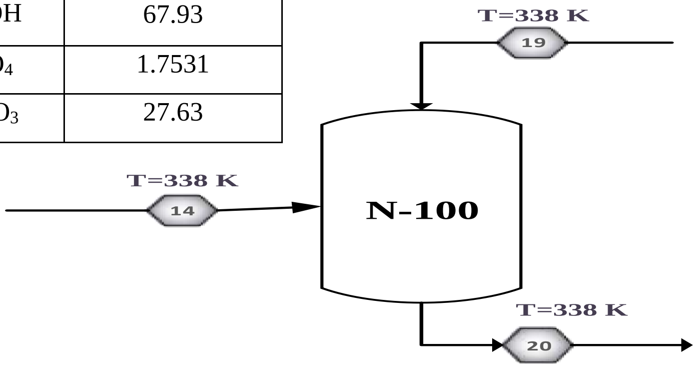
$\Delta H_f = (-2989.56) + (-1457.66)$

$\Delta H_f = -1531.9$ KJ/mol

4.3 Energy Balance at Neutralizer (N-100):

Components	Flowrate (kg/hr)
NaOH	1.43

Components	Flowrate (kg/hr)
CH3OH	67.93
H_2SO_4	1.7531
$C_3H_8O_3$	27.63



Components	Flowrate (kg/hr)
CH_3OH	67.93
Na_2SO_4	2.54
H_2O	0.644
$C_3H_8O_3$	27.63

Figure 4.2: Neutralizer (N-100)

Inlet temp = T_{in} = 338 K

Outlet temp = T_{out} = 338 K

T_{ref} = 298 K

Stream 14:

$Cp = A + BT + CT^2 + DT^3$ …………… (4.15)

Now find heat of formation from literature at 298 K

Table 4.7: Heat of Formation

Components	Heat of Formation	
	KJ/mol at 298K	KJ/Kmol
CH_3OH	-201.3	-201300
H_2SO_4	-895.76	-895760
Na_2SO_4	-1387	-1387000
H_2O	-285.83	-285830
$C_3H_8O_3$	-669.6	-699600
NaOH	-470.11	-470110

Now heat of reaction at 298 K

$= 2 \times \Delta H_{r(water)} + \Delta H_{r\,(Na2SO4)} - \Delta H_{r(H2SO4)} - 2 \times \Delta H_{r\,(NaOH)}$ ………… (4.16)

$= 2 \times (-285.83) + (-1387) - (-895.76) - 2 \times (-470.11)$

= -122.68 KJ/mol = -122680 KJ/mol

Table 4.8: Heat of Reaction of Components at 298K

Components	Kmoles/hr	H' = ∫Cp dT	H
		(KJ/kmol)	KJ/hr
H_2SO_4	0.0178	-4976	-88.58
NaOH	0.025	-3047	-82.28
Na_2SO_4	0.0179	7964	142.56
H_2O	0.0357	2634	94.05

Table 4.9: Heat of Reaction at 333 K

ΔHr,333K KJ/Kmol	ΔHr 333K KJ/hr	ΔHr 333K Kcal/mol
-120105	-2137.87	-28.705

Now find reactant enthalpy

Table 4.10: Reactant Enthalpy

Components	Reactant Enthalpy			
	Stream 14 Kmol/hr	Stream 18 Kmol/hr	Total	H' = ∫ Cp dT (KJ/kmol)
CH_3OH	2.076	0.00	2	2843
H_2SO_4	0.0178	0.00	0.0178	4976
Na_2SO_4	0.00	0.00	0.00	7964
H_2O	0.00	0.00	0.00	2634
$C_3H_8O_3$	0.301	0.00	0.301	9228
NaOH	0.00	0.027	0.027	3047
Total	2.39	0.03	2.32	30694.3

Now find product enthalpy

Table 4.11: Product Enthalpy

Components	**Product Enthalpy**	
	Stream 20 Kmol/hr	**H' = ∫ Cp dT (KJ/kmol)**
CH_3OH	2.076	2843
H_2SO_4	0.0178	4976
Na_2SO_4	0.00	7964
H_2O	0.00	2634
$C_3H_8O_3$	0.301	9228
NaOH	0.00	3047
Total	2.39	30694.3

4.4 Energy Balance at Heat Exchanger (EX-101):

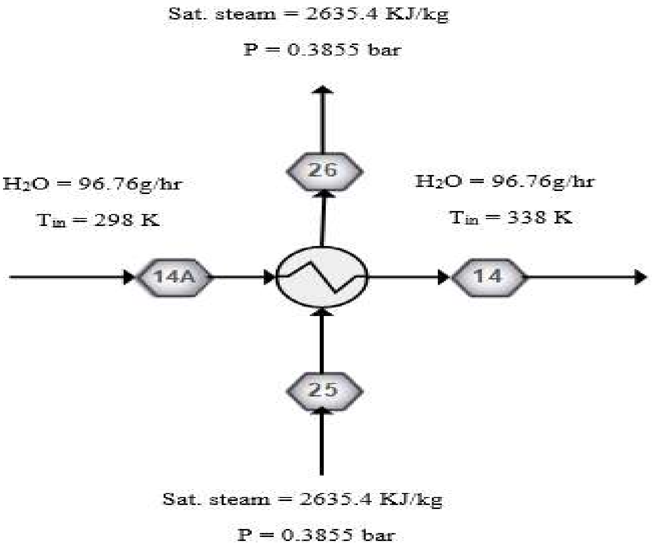


Figure 4.3: Heat Exchanger (EX-100)

We will find the specific enthalpies of the components of the inlet and the outlet streams by the following method:

4.4.1 Formula Used:

$Q = mC_p\ dT$ ………..... (4.17)

So, by using above formula and by using the values of constants in table above. We calculate H^O of the components of both inlet and the outlet streams.

Table 4.12: Specific Gravity (Cp) of Water

Component	Flowrate (KJ/hr)	Heat Capacity, Cp KJ/kg. K
H_2O	96.76	4.145

T_{in} = 298 K

T_{out}= 338 K

ΔT = 40 K

Q = 96.76 × 4.145 × 40

Q = 16042.81 KJ/hr

4.4.2 Steam Requirement:

Assuming sat. steam at 0.3855 bar and 348.15 K

λ (latent heat) = 2635.4 KJ/kg

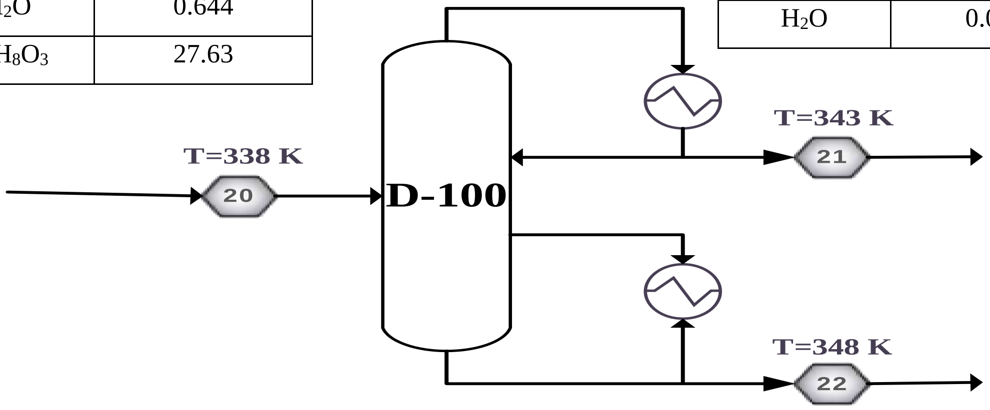
m = Q / λ ………… (4.18)

$m = 6.087 \text{ kg/hr}$

4.5 Energy Balance at Distillation Column (D-100):

Components	Flowrate (kg/hr)
CH_3OH	67.93
Na_2SO_4	2.54
H_2O	0.644
$C_3H_8O_3$	27.63

Components	Flowrate (kg/hr)
CH_3OH	66.58
H_2O	0.013



Components	Flowrate (kg/hr)
CH_3OH	1.36
Na_2SO_4	2.54
H_2O	0.631
$C_3H_8O_3$	27.63

Figure 4.4: Distillation (D-100)

$Cp = A + BT + CT^2 + DT^3$ ……………… (4.19)

Table 4.13: Constant Values for Cp

Components	Constant			
	A	B	C	D
CH_3OH	40	-3.28E-2	2.45E-4	-2.17E-7
Na_2SO_4	26.004	7.03E-1	-1.39E-3	1.03E-6
H_2O	87.639	-4.84E-4	-4.54E-6	1.19E-9
$C_3H_8O_3$	2.3E+2	-9.53E-3	-3.47E-5	1.58E-8

Then

Table 4.14: Weighted Cp for Stream 20

Cp Mean =	**Component**	**Flow Rate**	**Fraction**	**Cp**	**Cp × x**
	CH_3OH	66.51	0.68	4.54	3.10
	Na_2SO_4	2.54	0.03	1.60	0.04
	$C_3H_8O_3$	27.7	0.28	1.38	0.39
	H_2O	0.643	0.01	4.17	0.03
		97.393	1.00		**3.57**

$Q_F = H = m. Cp_{mean} (T - T_{ref})$ …………… (4.20)

$Q_F = 13890.33$ KJ/hr

Table 4.15: Weighted Cp for Stream 21

Cp Mean =	**Component**	**Flow Rate**	**Fraction**	**Cp**	**Cp × x**
	CH_3OH	65.18	1.00	4.56	4.56
	H_2O	0.013	0.00	4.17	0.00
		65.193	1.00		4.56

$Q_D = H = m. Cp_{mean} (T - T_{ref})$ …………… (4.21)

$Q_D = 13382.8$ KJ/hr

Table 4.16: Weighted Cp for Stream 22

Cp Mean =	**Component**	**Flow Rate**	**Fraction**	**Cp**	**Cp × x**
	CH_3OH	1.33	0.04	4.58	0.19
	Na_2SO_4	2.54	0.08	1.60	0.13
	$C_3H_8O_3$	27.7	0.86	1.26	1.09
	H_2O	0.63	0.02	4.17	0.08
		32.2	1.00		1.48

$Q_W = H = m. Cp_{mean} (T - T_{ref})$ …………… (4.22)

$Q_W = 2385.99$ KJ/hr

$R = \frac{L}{D} = \frac{77.49}{0.3}$ $R = 3$

$V = 3D + D$

$V = 4D$

V = 260.722 kg

L = 3D

L = 195.579 kg

Amount of Methanol in V = 0.9998 × 260.772

Amount of Methanol in V = 260.7198 kg

Amount of Water in V = 0.00017 × 195.57

Amount of Water in V = 0.04433 kg

Cp_{Mean} = 1.49 KJ/kg.K

$Q_V = H = m\ Cp_{mean}\ (T - T_{ref})$ …………… (4.23)

$Q_V = 260.72 \times 1.49 \times (343 – 298)$

Q_V = 17481.3 kg

Latent Heat of methanol = 1085 KJ/kg.K

Latent Heat of water = 2257 KJ/kg.K

$Q_V = 282981 + 17481.3$

Q_V = 300462 KJ/kg.K

Amount of Methanol in L = 0.9998 ×195.579

Amount of Methanol in L = 195.5399 kg

Amount of Water in L = 0.00017 ×195.57

Amount of Water in L = 0.03325 kg

Cp_{Mean} = 2.641 KJ/kg.K

$Q_L = H = m.\ Cp_{mean}\ (T - T_{ref})$ …………. (4.24)

$Q_L = 195.54 \times 2.64 \times (343 – 298)$

Q_L = 23238.9 kg

Latent Heat of methanol = 1085 KJ/kg.K

Latent Heat of water = 2257 KJ/kg.K

$Q_L = 2122356 + 23238.9$

Q_L = 235475 KJ/kg.K

$Q_V = Q_D + Q_L + Q_C$ ………… (4.25)

$Q_C = 300462 – 23238.9 – 13382.8$

Q_C = 51604.8 KJ/kg.K

$Q_F + Q_R = Q_L + Q_D + Q_C$ …………. (4.26)

$Q_R = 13382.8 + 51604.8 + 235475 – 13890.3$

Q_R = 63339.4 KJ/kg.K

CHAPTER # 5

EQUIPMENT DESIGN

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EQUIPMENT DESIGN

5.1 Introduction:

An area of human engineering concerned with the design of work tools, home appliances, and machines of all kinds, including their displays and controls. One particularly important application is the design of transport systems, such as roads, road signs, and the vehicles that use them. Chemical process plants include a number of important equipment such as reactors, distillation columns, absorbers, heat exchangers, evaporators, crystallizers, etc. Design of such equipment should be carried out a priory to setup a process plant and thus, it is the basic step in a chemical process.

5.2 Design of Extractor:

5.2.1 Introduction:

Chemical extractor is a machine that extract deuterium from water and required by a fusion reactor. This can work with build craft pipes to transport deuterium and water buckets. To use the deuterium extractor, first attach the extractor to electrical wire or place a charged battery in the lower left slot to make sure it is powered. Then, place a filled water bucket in the top left slot. An empty bucket will be left behind in the top left slot and a deuterium cell will be produced in the top right slot. Deuterium is required for the fusion reactor to run.

5.2.2 Important Terms Related to Extractor:

- **Heavy Phase Inlet:** The higher density, or heavy, the phase will fall to the bottom of the extractor. Depending on the design of the extractor it could be the dispersed phase or the continuous phase. Likewise, it could be the solute carrier or the solvent.
- **Light Phase Inlet:** With a lower density, the light phase will rise to the top of the extractor. This phase will have the opposite characteristic of the heavy phase in terms of dispersion vs continuous and solvent vs solute carrier.
- **Light Phase Outlet:** The light phase exits out the top of the extractor. Whether it had started out as a dispersed or continuous phase, it is now a continuous phase. If it was carrying the solute, it is now solute free. If it was the solvent, it carries the solute out of the column with it.

- **Heavy Phase Outlet:** The heavy phase exits out the bottom of the extractor. Whether it had started out as a dispersed or continuous phase, it exists as a continuous phase. If it was carrying the solute, it is now solute free. If it was the solvent, it carries the solute out of the column with it. The key elements to successful liquid extraction are solvent selection and effective mass transfer. The solvent needs to be able to extract the desired solute from the feed stream, be immiscible with the other components of the feed stream, and have high recoverability. Recoverability is the ability of the solvent to be separated from the solutes after the extraction process is complete. This will greatly reduce operations costs because the solvent is usually quite expensive. Distillation is a common method of recovering the solvent. Droplet formation is the most common method of mass transfer. The droplets are formed in either the heavy phase or the light phase so as to maximize surface area and solvent contact. Often liquid extraction processes include a dispersion coalescence cycle. Dispersion is the breaking up of the intact phase of liquid into the droplets necessary for mass transfer. Coalescence is the coming together of the droplets.

5.2.3 Objective of Extractor:

To perform solvent extraction for the extraction of Algae oil

5.2.4 Assumptions Related to Extractor:

Key component = Algae oil

Constant of extraction at feed side = C = 0.5

Algae oil recovery = 99 %

$x_{2K} = (1-\varepsilon)\, x_{1k}$ ………… (5.1)

Here:

x_{2K} = Mole fraction of 2nd key component

ε = Efficiency of algae oil recovery

x_{1k} = Mole fraction of 1st key component

So,

$= (1- 0.99) \times 0.575$

$= 5.75 \times 10^{-3}$

Operating feed to minimum solvent flowrate ratio:

$\frac{mf}{msm} = \frac{Kk \times x1k - y2k}{x1k - x2k}$ …………… (5.2)

Here:

k = Constant for feed operation

x_1 = Mole fraction of feed component

y_2 = Mole fraction of solvent

So,

$\frac{\mathrm{mf}}{\mathrm{msm}} = \frac{2(0.575)-0}{0.575-5.75*10^{\wedge}-3}$ ……………. (5.3)

= 1.15/0.56925

= 2.02

5.2.5 Minimum Solvent Flowrate:

As

$\frac{mf}{msm}$ = 2.02 …………… (5.4)

Here:

m_f = Total operating flowrate of feed

m_{sm} = Total operating flowrate of solvent mixture

Hence from equation (5.4)

$m_{sm} = m_f / 2.02$

= 448.6242 / 2.02

= 222.1 kg/hr

5.2.6 Operating Solvent flowrate:

$\frac{mf}{ms} = C\,\frac{mf}{msm}$ ……………. (5.5)

$\frac{448.6242}{ms}$ = 0.5 (2.02)

m_s = 444.2 kg/hr

5.2.7 Mass fraction of solvent:

$Y_{1k} = y_{2k} + \frac{mf}{ms}(x_{1k} - x_{2k})$ ………… (5.6)

= 0 + 1.01 (0.575 – 0.00575)

= 0.5749

5.2.8 Extractor factor A_E:

Assume constant of extraction (k_k) = 2

$\frac{mf}{ms}$ =1.01

$\frac{\frac{mf}{ms}}{kk} = AE$ ………….. (5.7)

A_E = 1.01 /2

= 0.505

5.2.9 Number of equilibrium stages (N_E):

$$N_E = \frac{\log[\frac{x1k-\left(\frac{y2k}{k}\right)(1-AE)+AE}{x2k-(\frac{y2k}{k})}]}{\log(\frac{1}{AE})} \text{ ……………. (5.8)}$$

Here:

N_E = Number of equilibrium stage

y_2= Mole fraction of solvent

x_1 = Mole fraction of 1st key component

x_2 = Mole fraction of 2nd key component

k = Constant of extraction

A_E = Cross – sectional area of extractor

So,

By using this formula, we obtained

$N_E = 6.7 \approx 7$

Determination of height equivalent tower stage HETS:

Minimum HETS = 11 stages

5.2.10 Cross-sectional Area of Extractor's Column:

Feed stream flow volumetric flowrate except solvent is

Density of algae = 0.908 g/cm^3

= 908 kg/m^3

5.2.11 Volumetric Flowrate of Algae:

Algae = 257.83 / 908

= 0.284 m^3/hr

5.2.12 Volumetric Flowrates of Solvents:

Density of methanol = 790 kg/m^3

Density of Hexane = 639 kg/m^3

V = 190.7942/1429

= 0.1335 m^3/hr

Cross – sectional area is:

$$A = \frac{\left(\frac{mf}{\mathrm{p}f}\right)+(\frac{ms}{\mathrm{p}s})]}{JT} \text{ ……………. (5.9)}$$

Here:

A = Cross sectional area

m_f = Mole fraction of feed

p_f = Density of feed

ms = Mole fraction of solvent

ps = Density of solvent

J_T = Efficiency of joints

A = 0.284 + 0.1335/ 69.023

= 0.4175 / 69.023

= 0.006 m^2

5.2.13 Extractor Column Diameter:

As;

$A = \frac{\pi\ Di\text{^}2}{4}$ ………… (5.10)

Here:

D_i = Inner diameter of extractor column

A = Cross – sectional area of extractor

So,

$D_i = [\ (4\times0.006)/3.14]^{1/2}$

D_i = 0.0878 m

5.2.14 Plate Extractor Scale Up:

$\frac{[HETSc]}{[HETS]} = \left[\frac{Dc}{D}\right]^{0.3}$ ………… (5.11)

Here:

HETSc = Plate extractor scale up

HETS = Height equivalent tower stage

D_c = Total diameter of the column

D = Assumed diameter

So,

[HETSc] = 11.05 [10.42/12]^0.38

= 0.266 m

Now 20 % increment is done to prevent flooding at extractor column. Therefore, design of HETS after 20% increment is 0.47 m.

5.2.15 Extractor Height:

$Z_E = N_E \times (HETSc) + D_i$ ………… (5.12)

Here:

Z_E = Extractor height

N_E = Number of equilibrium stage

HETSc = Plate extractor scale up

D_i = Inner diameter of an extractor

So,

= 7 (0.47) + 0.087

= 3.38 m

5.2.16 Top and Bottom Settler Diameter and Height:

Ds = 1.5 (0.266)

= 0.399 m

Total height of both settler

Z_s = 2 (0.399)

= 0.798 m

Total height of plate extractor tower:

$Z = Z_E + Z_S$ ………… (5.13)

Here:

Z = Total height of plate extractor tower

Z_E = Extractor height

Zs = Height of both settler

So,

Z = 3.1 m

Table 5.1: Extractor Specification Sheet

SPECIFICATION SHEET	
Identification	
Item	Extractor (Ex-101)
Type	Solvent plate Extractor
Function	
To extract algae oil from algae by mean of solvent extraction	
Number of equilibrium stages	7
Area of the column	0.006 m^2
Column diameter	0.0878 m
Height of column	3.1 m
Settler diameter	0.399 m
Settler height	0.798 m

5.3 Design of Decanter (D-100):

A Decanter is defined as a vessel used to separate a stream continuously into two liquid phases using the force of gravity. Decanters are essentially are vessel which gives sufficient residence time for the droplets of the dispersed phase to rise or settle to the interface between the phases and coalesce. Decanters are used to separate liquids where there is sufficient difference in density between the liquids for the droplets to settle readily. It is a continuous gravity settler vessel that does not run full and lighter phase overflows from top or near the top of the vessel.

5.3.1 Types of Decanters:

Basically, the decanters also have the same conventional types based upon the process, which are:

- Batch Decanters.
- Continuous Decanters.

But it must be known that the design steps in both cases remain same. On the basis of fluid type:

- Continuous gravity settlers.
- Centrifugal decanters.

5.3.2 Selection Criteria of Decanter:

Basically, the selection is made between continuous gravity settler and centrifugal decanter through the following procedure. If density difference between the liquids is about unity, then centrifugal one is best. As in our case there is much difference between the liquid densities, so gravity settlers are used.

5.3.3 Selection Type of Decanter:

- Continuous gravity settler.

5.3.4 Reason of Decanter Type Selection:

Basically, the selection is made between continuous gravity settler and centrifugal decanter through the following procedure:

- If density difference between the liquids is about unity, then centrifugal one is best. As in our case there is much difference between the liquid densities, so gravity settlers used.

5.3.5 Operating Conditions of Decanter:

Design Pressure = 1 atm

Design temperature = 298 K

5.3.6 Densities of Feed:

Density of methanol =790 kg/m^3

Density of algae oil = 912 kg/m^3

Density of hexane = 639 kg/m^3

Volumetric flowrate of light component = 4.15 × 10^-5 m^3/s

Volumetric flowrate of heavy component =5.597 × 10^-5 m^3/s

Viscosity of Methanol = 0.533 Cp

Viscosity of algae = 51.95 Cp

Viscosity of hexane = 0.3 Cp

5.3.7 Assumption for Decanter:

d_d = 50 µm

(Because the residence time is obtained in the range with this diameter. Recommended range is 40µm to 150µm) [22].

5.3.8 Calculation for the Dispersed Phase:

By using selker and sleicher correlation for prediction of dispersed phase;

$$\theta = 0.0835$$

5.3.9 Settling Velocity Calculation:

$u_d = \frac{dd^\wedge 2 \times g \times (\rho d - \rho c)}{18 \times \mu c}$ …………… (5.13)

Where

d_d = droplet diameter, m,

u_d = settling (terminal) velocity of the dispersed phase droplets, m/s.

ρ_c = density of the continuous phase, kg/m^3.

ρ_d = density of the dispersed phase, kg/m^3.

μ_c = viscosity of the continuous phase, N s/m^2.

g = gravitational acceleration, 9.81 m/s^2.

So,

$$u_d = \frac{(50\times10^{-6})^2 \times (9.81) \times (639 - 1702)}{18 \times (26.38)}$$

$= 1.5281\times10^{-4}$ m/s

Area is calculated as:

$A_i = \frac{Qc}{ud}$ ………… (5.14)

$= \frac{5.597 \times 10^{-5}}{1.5281\times 10^\wedge{-4}}$

$= 0.37$ m^2

5.3.10 Diameter of Decanter:

$A = \frac{\pi D^\wedge 2}{8}$ …………… (5.15)

$D = (\frac{8A}{\pi})^{1/2}$ …………… (5.16)

D = 0.97 m

5.3.11 Residence Time:

$H_D = 0.1 \times D$

$= 0.097$

Now find the residence time of droplets in dispersion band.

Residence time = $\frac{\text{Dispersion band}}{\text{ud}}$ …………… (5.15)

$= 0.097 / 1.568\times10^{-4}$

= 635s

Residence time = 635 sec or 10.5 min. For this, first find velocity of light phase

Velocity of light phase (Hexane) = $\frac{\text{Mass flowrate of hexane}}{\text{Density of hexane}} \times \frac{1}{A}$ ………… (5.16)

$= 6.72 \times 10^{-3}$ m/s

5.3.12 Droplet Diameter:

Now find droplet dia 'd_d' is:

$D_d = [(1.5281 \times 10^{-4} \times 18 \times 1.243 \times 10^{\wedge} -3) / 9.8 (857.3 - 639)]^{1/2}$

$= 49$ µm

As, it is less than from the assumed values. Hence it is acceptable.

5.3.13 Length of Decanter:

$V_H = \frac{8QH}{\pi D^{\wedge}2}$ ………… (5.17)

$= 1.515 \times 10^{-4}$ m/s

5.3.14 Settling Length:

$L_s = \frac{VH\ D}{2Ud}$ ………… (5.18)

$= 0.481$ m

5.3.15 Area Required for Coalescence:

$Ai = \frac{2QHtR}{Hd}$ ………… (5.19)

$= 0.73$ m

5.3.16 Dispersion Length:

$L_D = \frac{Ai}{D}$ ………… (5.20)

$= 0.75$m

5.3.17 Total Decanter Length:

$L = L_S + L_D$ ………… (5.21)

$= 1.23$ m

And

$L/D = 1.27$

5.3.18 Piping Arrangement:

To minimize entrainment by the jet of liquid entering the vessel, the inlet velocity for a decanter should keep below 1 m/s.

Volumetric flowrate $= [4.15\times 10^{-5} + 5.597 \times 10^{-5}]$

$v = 9.75 \times 10^{-5}\ m^3/s$

Area of pipe $= (9.75 \times 10^{-5}\ m^3/s) / 1$ m/s

$= 9.75 \times 10^{-5}\ m^2$

Pipe diameter $= [\{9.75 \times 10^{-5} \times (4)\}/3.14]^{1/2}$

Pipe diameter = 0.011 m

Take the position of the interface as half way up the vessel and the light liquid off take as at 90% of the vessel length.

$Z_1 = 0.9 \times 1.23$

$Z_1 = 1.10$ m

$Z_3 = 0.1 \times 1.23$

$Z_3 = 0.123$ m

$Z_2 = \{(Z_1 - Z_3) / p_H\} \times p_L + Z_3$ …………… (5.22)

$= \{(1.10 - 0.123) / 857.3\} \times 639 + 0.123$

$Z_2 = 0.85$ m

Where

Z_1 = Height from surface to light liquid overflow.

Z_2 = Height from surface to heavy liquid overflow.

Z_3 = Height from surface to the interface.

Table 5.2: Decanter (D-100) Specification Sheet

SPECIFICATION SHEET	
Identification	
Item	Decanter (Dc-100)
Type	Gravity decanter
Function	
To separate hexane from algae oil and methanol.	
Dispersed phase	Light liquid
Continuous phase	Heavy liquid
Area of interface	0.37 m^2
Diameter of decanter	0.97 m
Height of decanter	1.23 m
Dispersion band	0.75 m
Height of liquid-liquid interface	0.123 m
Height of light liquid overflow	1.10 m
Height of heavy liquid overflow	0.85 m
Residence time of doplets in dispersion band	10 min
Piping Specification	
Area of pipe	9.75×10^{-5} m^2
Diameter of pipe	0.011 m

5.4 Design of Reactor:

5.4.1 Reactors:

Chemical reactor is the heart of the chemical reaction process. Chemical reactors are containers that are designed for a chemical reaction to occur inside of them. The design of a chemical reactor deals with multiple aspects of chemical engineering.

5.4.2 Types of Reactor:

There are two main types of reactors:

- Batch reactors.

- Flow reactors.

Flow reactors are further classified into two main categories:

- Continuous stirred tank reactors (CSTR).
- Plug flow reactor (PFR).

5.4.3 Selection of Reactor:

We have selected continuous stirred tank reactors (CSTR) due to following reasons:

- The process is continuous.
- Uniform temperature distribution in reactor.
- Maintenance and cleaning are easy.
- Provides high production, better product quality due to constant conditions. Hence reaction rate is constant.

5.4.4 Reaction:

$C_{57}H_{104}O_6 + 3CH_3OH \rightarrow 3C_{19}H_{36}O_2 + C_3H_8O_3$ ………… (5.23)

5.4.5 Operating Condition of Reactor:

Pressure = 1 atm

5.4.6 Selection Criteria of Reactor:

Reaction in liquid form:

- A lot of agitation.
- Large residence time.
- High efficiency of mass and heat transfer.
- Better temperature control.

For Venth's equation

$\Delta G = -RT \ln K$ ………… (5.24)

Here:

ΔG = Gibbs free energy

R = Gas constant

T = Temperature in kelvin

K = Rate constant

So,

$\Delta G = -14.43$ K J / mol

$-14.43 = -8.314/1000 \times 333 \times \ln K$

$\ln K = 0.1918$

$K = 183.57 \gg 1$

5.4.7 Rate Equation:

$-r_A = k\ C_A^n$ …………. (5.25)

Here:

$-r_A$ = Rate of reaction

k = Rate constant

C_A = Concentration of reactor A

n = Order of reaction which is 1 in this case.

5.4.8 Arrhenius Law:

$k = A\ e^{(-E/RT)}$ …………. (5.26)

Here:

E = 14.518 KJ/mol

$A = 2.31 \text{min}^{-1}$

$k = 2.31\ \text{min}^{-1}$

5.4.9 Volumetric Flow Rate V_o:

$V_o = 0.003507\ m^3 / \text{min}$

5.4.10 Feed Rate F_{Ao}:

$F_{AO} = 862.359$ mol / hr

$C_{AO} = F_{AO} / V_o$ …………. (5.27)

$C_{AO} = 4098.252\ \text{mol} / m^3$

$C_A = C_{AO} \times (1 - X_A)$ …………. (5.28)

$C_A = 409.825\ \text{mol}/m^3$

$-r_A = k\ C_A$ ………… (5.29)

$-r_A = 946.6962\ \text{mol}/m^3\ \text{min}$

5.4.11 Volume of Reactor:

$V = F_{Ao} \times \Delta X_A / -r_A$ …………. (5.30)

$V = 0.01366\ m^3$

5.4.12 Diameter of Reactor:

L/D = 1.5

Dia = 0.226 m = 0.743 ft

5.4.13 Length of Reactor:

L = 0.340 m

5.4.14 Residence Time:

Space Time = V/V_o ………… (5.31)

t = 0.0137 / 0.003507

t = 3.89 min

Table 5.3: Reactor (RX -100) Specification Sheet

SPECIFICATION SHEET	
Identification	
Item	Reactor
No. of required	1
Type	Continuous Stirred Tank Reactor
Function	
To produce biodiesel from algae oil	
Length of reactor	0.340 m
Diameter of reactor	0.743 m
Volume of reactor	0.0136 m^3
Space Time	3.89 min
Space Velocity	62.5 min^{-1}
Speed of Impeller	0.016 m
Length of Impeller	0.226 m
Diameter of Impeller	0.0754 m

5.5 Design of Distillation Column:

5.5.1 Introduction to Distillation Column:

In industry, it is common practice to separate a liquid mixture by distilling the components, which have lower boiling points when they are in pure condition from those having higher boiling points. This process is accomplished by partial vaporization and subsequent condensation. It is a process in which a liquid or vapor mixture of two or more substances is separated into its component fractions of desired purity, by the application and removal of heat. The creation or addition of another phase in distillation is obtained by the repeated vaporization and condensation of the fluid. The separation process exploits the differences in vapor pressure of key components in the mixture initiate the separation. The advantages of distillation are its simple flow sheet, low capital investment and low risk. The separation process is able to handle wide ranges of feed concentrations and throughputs while producing a high purity product.

5.5.2 Types of Distillation Column:

There are many types of distillation columns, each designed to perform specific types of separations, and each design differs in terms of complexity.

- Batch columns.
- Continuous columns.

5.5.3 Batch Columns:

In batch operation, the feed to the column is introduced batch wise. That is, the column is charged with a 'batch' and then the distillation process is carried out. When the desired purification of product is achieved, a next batch of feed is introduced.

5.5.4 Continuous Columns:

In contrast, continuous columns process a continuous feed stream. No interruptions occur unless there is a problem with the column or surrounding process units. They are capable of handling high throughputs and are the more common of the two types. We shall concentrate only on this class of columns. Choice between packed and plate column vapor liquid mass transfer operation may be carried either in plate column or packed column. These two types of operations are quite different. A selection scheme considering the factors under four headings,

- Factors that depend on the system i.e. scale, foaming, fouling factors, corrosive systems, heat evolution, pressure drop, liquid holdup.
- Factors that depend on the fluid flow moment.
- Factors that depends upon the physical characteristics of the column and its internals i.e. maintenance, weight, side stream, size and cost.
- Factors that depend upon mode of operation i.e. batch distillation, continuous distillation, turndown, and intermittent distillation.

5.5.5 Selection of Column:

- Plate column.

5.5.6 Reasons of Selection of Distillation Column:

- Cost effective.
- For large column heights, weight of the packed column is more than plate column.
- When temperature change is involved, packing may be damaged.

5.5.7 Choice of Plates in Column:

There are four main tray types, the bubble cap, sieve tray, ballast or valve trays and the counter flow trays.

I have selected sieve tray because:

- They are lighter in weight and less expensive.
- It is easier and cheaper to install.
- Pressure drop is low as compared to bubble cap trays. Peak efficiency is generally high.
- Maintenance cost is reduced due to the ease of cleaning.

5.5.8 Objective of Design:

Design a distillation column for the recovery of methanol.

5.5.9 Assumptions of Distillation Column:

- Percent of flooding at maximum flowrate = 85%
- Percent of down-comer area of total area = 12 %
- Weir height = 50 mm
- Hole diameter = 5 mm
- Plate thickness = 5 mm
- 100 mm of liquid drops per plate

5.5.10 Operating Temperature:

T_{top} = 348 K

T_{bottom} = 353 K

5.5.11 Lk and HK Component:

- Methanol is light key component.
- Water is heavy key component.

$\alpha_{(avg)}$ of Methanol = 3.48

$\alpha_{(avg)}$ of water =1

5.5.12 Minimum Number of Plates:

The minimum no. of plate N_{min} is obtained from Fenske relation represented in Richardson and Coulson volume 6. So, from this equation we get:

N_{min} = 9.6

Which is approximately 10. So,

N_{min} =10

5.5.13 Minimum Reflux Ratio:

Minimum reflux ratio is obtained from underwood equation which is;

$$\frac{\alpha Na2SO4 * Xf\ Na2SO4}{\alpha Na2SO4 - \theta} + \frac{\alpha CH3OH * Xf\ CH3OH}{\alpha CH3OH - \theta} + \frac{\alpha CH3H8 * Xf\ CH3H8}{\alpha CH3H8 - \theta} + \frac{\alpha H2O * Xf\ H2O}{\alpha H2O - \theta} = 1 - q \text{ .... (5.32)}$$

Put q = 0 in order to find θ

After solving we get;

$$\theta = 0.193$$

For minimum reflux we have equation which is;

$$\frac{\alpha CH3OH * Xd\ CH3OH}{\alpha CH3OH - \theta} + \frac{\alpha H2O * Xd\ H2O}{\alpha H2O - \theta} = R_m + 1 \text{ .... (5.33)}$$

From this we obtained

$R_{min} = 3.4$

Actual reflux ratio is:

$R = 1.2\ R_{min}$

R = 4

5.5.14 Theoretical No. of Plates:

R / R+1 = 0.8

Rm/Rm+1 = 0.78

Then from Erban Maddson correlation graph from Richardson and Coulson volume 6. So,

Nm/N = 0.6

10 /N = 0.6

N= 17

As, one plate is removed from reboiler = N -1

= 17 – 1

= 16

5.5.15 Tray Calculation:

we obtained overall efficiency = 84.9

So,

Actual number of tray = 16 /0.85

= 19

5.5.16 Location of Feed Plate:

The Kirk-bridge method is used to determine the ratio of trays above and below the feed point.

D = 1.29 kmol/hr

B = 0.1094 kmol /hr

$\log [N_D/N_B] = 0.206 \log [(B/D) \times (x_{Hk}/x_{LK}) \times ((x_{Lk})_B/(x_{HK})_D)^2]$ ………… (5.34)

After solving $N_D/N_B = 0.329$

As

$N_D + N_B = N$

For N = 19

$N_D + N_B = 19$ ………… (5.35)

As

$N_D/N_B = 0.329$

$N_D = 0.329\ N_B$

Put N_D in equation (5.35). So,

$0.329 \times N_B + N_B = 19$

$N_B = 13$

and

ND = 5

Hence:

NF = 6 plates

So, this means feed will introduced at the 6th plate of the column from bottom.

$F_{Lv\ top} = \frac{Lw}{Vw} \times \sqrt{\frac{pV}{pL}}$ ………… (5.36)

$= (219.75/284.4) \times (1.12/742)^{1/2}$

$= 0.0302$

$F_{Lv\ bottom} = \frac{Lw}{Vw} \times \sqrt{\frac{pV}{pL}}$ ………… (5.37)

$= (315.462/284.38) \times (3.71 / 1261)^{1/2}$

$= 0.0602$

Now select trial spacing. Initially let’s assume that our diameter of column is 1 to 3 m and for that a tray spacing of Ts = 600 mm. Now from the graph the flooding parameter is selected. We have $K_1 = 0.16$ (for top condition) and also $K_1 = 0.14$ (for bottom condition).

σ bottom = 0.019 N/m

V_{nf} = gas velocity through the net area at flood, m/s

For Bottom of Tray:

$V_{nf} = K_1 \times (\sigma/20)^{0.2} \times [(\rho_L - \rho_V)/\rho v]^{0.5}$ ………… (5.38)

$= 0.14\ (0.019/20)^{0.2} \times [\ (1261 - 3.71)/3.71]^{0.5}$

$V_{nf} = 2.55$ m/sec

For Top of Tray:

$V_{nf} = K_1 \times (\sigma/20)^{0.2} \times [(\rho_L - \rho_V)/\rho_V]^{0.5}$ ………… (5.39)

$= 0.16\ (0.0176 / 0.02)^{0.2} \times [\ (742 - 1.12)/1.12]^{0.5}$

$V_{nf} = 4.01$ m/sec

As it is assuming that our flooding = 85 %

Actual Velocity for Top:

Actual velocity (V_n) = 0.85 × V_{nf} ………… (5.40)

$V_n = 3.41$ m/s

Actual Velocity for Bottom:

Actual velocity (V_n) = 0.85 × V_{nf} ………… (5.41)

$V_n = 2.17$ m/s

Net column area used in separation is:

An = Maximum volumetric flowrate /Vn ………… (5.42)

An = 1.74 /3.41

An = 0.5103 m^2

An = 2.165 /2.17

An = 0.998 m^2

Assume that down comer occupies 12% of cross-sectional area (Ac) of column thus:

Ac= An / 0.88 ………… (5.43)

Ac = 0.998 / 0.88

= 1.134 m^2

Ac = 0.5103 /0.88

= 0.58 m^2

Diameter of the column at the bottom is obtained by:

$D = \sqrt{}\ (4 \times Ac/\pi)$ ………… (5.44)

$= \sqrt{}\ (4 \times 1.134)/\ (3.14)$

D = 1.201 m

Diameter of the column at the top is obtained by:

$D = \sqrt{}\ (4 \times Ac/\pi)$ …………. (5.45)

$= \sqrt{}\ (4 \times 0.58)\ /\ (3.14)$

D = 0.86 m

So near standard is about 1.201 m so diameter of our column is 1.201m.

$D_c = 1.201$ m

Provisional plate design is calculated as:

D_c = 1.201 m

Column area = Ac = $(\pi / 4) \times D_c^{2}$ ………….. (5.46)

$= (3.14 / 4) \times (1.201)^2$

$= 1.13\ m^2$

Down comer area $A_d = 0.12\ A_c$ …………. (5.47)

$= 0.12 \times 1.13$

$= 0.136\ m^2$

Net area $A_n = A_c - A_d$ ………… (5.48)

$= 1.13 - 0.136$

$= 0.9944\ m^2$

Active area $A_a = A_c - 2A_d$ ………… (5.49)

$= 1.13 - 2 \times 0.136$

$= 0.858\ m^2$

Hole area A_h = 0.14 Aa ………… (5.50)

$= 0.14 \times 0.858$

$=0.12\ m^2$

Now weir length is calculated but first calculate the ratio of down comer area to total cross sectional area.

Ad/Ac = (0.136/1.13) × 100

= 12 %

Now obtained L_w/Dc from the graph.

L_w/Dc = 0.76

$L_w = 0.76 \times 1.201$

= 0.913 m

Take weir height, hw = 50 mm = 0.05 m

Hole diameter, dh = 5 mm = 0.005 m

Plate thickness = 5 mm= 0.005 m

Now check weeping. So,

Maximum liquid rate = 1.95 kg/sec

Maximum liquid rate at 70 % turndown = 0.75 × 1.95

= 1.365 kg/sec

Weir crest liquid = how = $750 \times (Lw / p_L \times L_w)^{2/3}$ ………… (5.51)

$= 750 \times (1.365 / 1261 \times 0.913)^{2/3}$

= 8.4 mm

hw + how = 50 + 8.4

= 58.4 mm

From the graph in the appendix A, it is found that:

$K_2 = 30.2$

$u_h = \frac{\text{k2}-0.9\ (25.4-\text{dh})}{(\text{pv})\text{^}1/2}$ ………… (5.52)

$= [30.2- 0.9\ (25.4 - 5)] / (3.71)^{1/2}$

= 6.135 m/s

$u_{act} = \frac{\text{Vapour flow rate}}{\text{Ah}}$ …………. (5.53)

= 1.74 / 0.12

= 14.5 m/sec

If $u_{act} > u_h$ then no weeping will happen.

Entrainment checking is obtained by:

Percentage flooding = $\frac{\text{Vapour flowrate/An}}{\text{uf}}$ …………. (5.54)

$= \frac{1.74\ /0.9944}{4.01}$

= 44 %

$F_{LV\ (Top)} = 0.0302$

It is obtained that:

$\Psi = 0.013 < 0.1$

∴ No entrainment will happen

5.5.17 Pressure Drop Calculation:

Plate thickness /hole diameter = 5/5

= 1

$Ah / A_P = (0.12/0.858) \times 100$

= 14 %

$C_o = 0.88$

$h_d = 51(\frac{Un}{Co})^2 \times (\frac{\text{p}v}{\text{p}L})$ …………. (5.55)

$h_d = 51\ (16.47)^2 \times (0.0029)$

= 40.1mm

$hr = (12.5 \times 1000) / p_L$

$= (12.5 \times 1000) / 1261$

= 9.91mm

$ht = h_d + h_w + h_{ow} + h_r$ ………… (5.56)

$= 40.1 + 50 + 8.4 + 9.91$

$= 108.41$ mm

(100 mm) was assumed to calculate the bass pressure. The calculation could not be repeated with a revised estimate, but the small change in physical properties will have little effect on the plate design. So (135.6 mm) per plate is considered to be acceptable.

Total drop pressure = $\rho \times g \times h \times N$ ………… (5.57)

$= 1261 \times 9.81 \times 108.41 \times 10^{-3} \times 19$

$= 25.5$ kPa

Bottom pressure =101.3 + 25.5

=126.8 kPa

Down comer liquid backup is obtained by:

$h_{ap} = h_w - 10$ ………… (5.58)

$= 50 - 10$

$= 40$ mm

Area under apron, $A_{ap} = h_{ap} \times l_w$ ………… (5.59)

$= 40 \times 10^{-3} \times 0.913$

$= 0.0365\ m^2$

$A_d = 0.136\ m^2$

$A_{ap} < A_d$, so take A_{ap} to use in calculation of h_{dc}.

$h_{dc} = 166\ (Lw/p_L \times A_{ap})^2$

$= 166\ [0.913 / (1261 \times 0.0365)]^2$

$= 0.0653$ mm

Back-up down comer is calculated as:

$h_b = h_t + h_w + h_{ow} + h_{dc}$ ………… (5.60)

$= 108.41 + 50 + 8.4 + 0.0653$

$=166.8$ mm

$= 0.167$ m

$0.5\ (Ts + h_w) = 0.5\ (0.6 + 0.05) = 0.32$ m

$\therefore h_b < 0.5\ (Ts + h_w)$

So, plate spacing is acceptable.

Now check residence time. So,

$t_r = (A_d \times h_b \times p_t) / L_w$ ………… (5.61)

$= (0.136 \times 0.167 \times 1261) / 0.913$

t_r = 31 sec > 3sec

5.5.18 Trial Layout:

Use cartridge-type construction, allow (50 mm) unperforated strip round plate edge, (50 mm) wide calming zone.

$l_w/D_c = 0.76$

Angle subtended by the edge of the plate = 180 – 99 = 81°

Mean length unperforated edge strips (the two area):

= (Dc – hw) × θ ×2 π/360 …………. (5.62)

= $(1.201 – 50 \times 10^{-3}) \times 81 \times 2\pi/360$

= 1.626 m

Area of unperforated edge straight strips = hw × Mean length

= $50\times10^{-3} \times 1.626$

= 0.0813 m^2

Mean length of unperforated straight side is obtained by:

Approx. = weir length - width of unperforated strips ………… (5.63)

= $0.913 - (50\times10^{-3})$

= 0.863 m

Area of calming zone = 2 × (Approx. length × h_{ow})

= 0.0863 m^2

Total area p_f unperforated (A_p) = A_a – unperforated ………… (5.64)

= 0.858 – 0.0863 – 0.0813

= 0.6904 m^2

Now

Ah/Ap = 0.12 / 0.6904

= 0.174

$lp/d = 2.4$

Hole pitch l_p = 2.4 × 5

= 12 mm

Area of one hole = $\pi/4\,(d_h)^2$ ………… (5.65)

= $\pi/4\,(0.005)^2$

= $1.9349 \times 10^{-4}\ m^2$

No. of holes = Ah / Area of one hole ………... (5.66)

= $0.12 / 1.9349 \times 10^{-4}$

= 620.2 holes

Now height of column is calculated as:
H = (N + 1) Z ………… (5.67)

Here;

Z = Tray spacing

N = Actual no. of stage

H = (19 +1) × 0.6

= 12 m

Table 5.4: Distillation Column (D-100) Specification Sheet

<table>
<tr><th colspan="4">SPECIFICATION SHEET</th></tr>
<tr><th colspan="4">Identification</th></tr>
<tr><td colspan="2">Item</td><td colspan="2">Distillation column (D-100)</td></tr>
<tr><td colspan="2">Type</td><td colspan="2">Multi component Distillation column</td></tr>
<tr><th colspan="4">Function</th></tr>
<tr><td colspan="4">To recover methanol from by-products</td></tr>
<tr><td>Operating Pressure</td><td>101.32KPa</td><td>Active holes</td><td>620.2</td></tr>
<tr><td>No of stages</td><td>19</td><td>Feed plate location</td><td>6th from bottom</td></tr>
<tr><td>Plate Type</td><td>Sieve Plate</td><td>Hole diameter</td><td>0.005 m</td></tr>
<tr><td>Plate Spacing</td><td>0.6 m</td><td>Total pressure drop</td><td>25.5 kPa</td></tr>
<tr><td>Plate thickness</td><td>0.005m</td><td>Residence time</td><td>31s</td></tr>
<tr><td>Dia of Column</td><td>1.201m</td><td>Reflux ratio</td><td>4</td></tr>
<tr><td>Height of column</td><td>12 m</td><td>Percent flooding</td><td>85%</td></tr>
</table>

CHAPTER # 06

MECHANICAL DESIGN

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MECHANICAL DESIGN

6.1 Introduction:

Self-supporting tall equipments are widely used in chemical process industries. Tall vessels may or may not be designed to be self-supporting. Distillation column, fractionating columns, absorption tower, multistage reactor, stacks, chimneys etc comes under the category of tall vertical vessels. In earlier times high structure (i.e. tall vessels) were supported or stabilized by the use of guy wires. Design of self-supporting vertical vessels is a relatively recent concept in equipment design and it has been widely accepted in the chemical industries because it is uneconomical to allocate valuable space for the wires of guyed towers. In these unit's ratio of height to diameter is considerably large due to that these units are often erected in the open space, rendering them to wind action. Many of the units are provided with insulation, number of attachments, piping system etc.

6.2 Stresses in the Shell:

Primarily the stresses in the wall of a tall vessel are:

- Circumferential stress, radial stress and axial stress due to internal pressure or vacuum in the vessel.
- Compressive stress caused by dead load such as self-weight of the vessel including insulation, attached equipments and weight of the contents.
- Dead load is the weight of a structure itself including the weight of fixtures or equipment permanently attached to it.

Live load is moving or movable external load on a structure. This includes the weight of furnishing of building, of the people, of equipment etc. But doesn't include wind load. If the vessels are located in open, it is important to note that wind load also act over the vessel. Under wind load, the column acts as cantilever beam. Therefore, while designing the vessel stresses induced due to different parameters have to be considered such as:

- Compressive and tensile stress induced due to bending moment caused by wind load acting on the vessel and its attachments.
- Stress induced due to eccentric and irregular load distributions from piping, platforms etc.
- Stress induced due to torque about longitudinal axis resulting from offset piping and wind loads.
- Stress resulting from seismic forces. Apart from that, always there are some residual

stresses resulting due to methods of fabrication used like cold forming, bending, cutting, welding etc.

6.3 Design Calculations of Reactor:

Inner diameter of the column, Di = 743 mm

Operating pressure of the reactor = 1 bar = 0.1 N/mm^2

Design pressure = 10 % more than the operating pressure.

Design pressure, Pi = 1.1× 1

= 1.1 bar = 0.11 N/mm^2

Design temperature = 60 ^{o} C

Material of construction of the shell and the covers is carbon steel.

6.4 Thickness of Shell:

Material = Carbon Steel

Diameter = D_i = 743 mm

Height = 340 mm

Corrosion allowance = C_c = 2 mm

Stress Factor = f = 117.2 N/mm^2 at 60 ^{o} C

Joint Efficiency = J = 1. Put the above data in equation below:

e = $\frac{PiDi}{2fJ-Pi}$ ……….. (6.1)

e = 4.40 mm

By adding the corrosion allowance. So,

e = (4.40 + 2) mm

e = 6.40 mm

e = 6 mm thickness of shell.

6.5 Calculations for Head and Closures:

The ends of a cylindrical vessel are closed by heads of various shapes. The principal types used are:

- Flat plates and formed flat heads.
- Hemispherical heads.
- Ellipsoidal heads.
- Torispherical heads.

6.6 Domed Head:

Try a standard dished head (torisphere):
Crown radius = R_C = Di = 2.5m

Knuckle radius = 6 % (R_C) = 0.15m

A head of this size would be formed by pressing: no joints, so J =1. Put in the following relation:

$$C_S = 1.77$$

6.7 Thickness of Head:

$$e = \frac{Pi \times Rc \times Cs}{2fJ + Pi\,(Cs - 0.2)} \ldots\ldots\ldots\ldots (6.2)$$

By putting the above values, we get:

e = 18.36mm

Try a “standard” ellipsoidal head:

Minor axes 2:1

$$e = \frac{Pi \times Di}{2fJ - 0.2Pi} \ldots\ldots\ldots\ldots (6.3)$$

Put the values in above equation e = 10.37 mm taken as 11mm. So, an ellipsoidal head would probably be the most economical.

6.8 Weight Load:

$W_v = 240 \times C_v \times D_m \times (H_v + 0.8 + Dm) \times t$ ………… (6.4)

Here:

W = Total weight of shell

Cv = A factor to account for the weight of nozzles, man ways, internal supports, etc which can be taken as = 1.08 for vessels with only a few internal fittings.

Dm = Mean diameter = (D_i + t) = 0.723 m

Hv = height of vessel = 0.340 m

t = thickness of shell = 0.013 m

W_V = 62.4 kN

Total weight = 62.4 KN

6.9 Wind Load:

Wind pressure = 1280 N/m^2

Total diameter = D + 2t …………. (6.5)

= 0.823 m

F = P×D …………. (6.6)

F = 1280 × 0.823

F = 1053.4 N/m

6.10 Stress Calculations:

6.10.1 Longitudinal Stress:

Put the above in the given equation:

Longitudinal stress $= \frac{P \times Di}{2 \times t}$ ……….. (6.7)

$= 42.6 \text{ N/mm}^2$

6.10.2 Circumferential Stress:

Circumferential stress $= \frac{P \times Di}{4 \times t}$ ……….. (6.8)

$= 22.4 \text{ N/mm}^2$

6.10.3 Dead Weight Stress:

Dead weight stress $= \frac{W}{\pi \times (Di + t) \times t}$ ……….. (6.9)

$= 0.712 \text{ N/mm}^2$

6.10.4 Bending Moment:

Bending moment $= \frac{W \times X^{\wedge}2}{2}$ ……….. (6.10)

$= 46.4 \times 10^3 \text{ N/mm}^2$

6.10.5 Bending Stress:

Bending stress $= \frac{Mx}{lv} \left(\frac{Di}{2} + t \right)$ ……….. (6.11)

$= 0.89 \text{ N/mm}^2$

CHAPTER # 07

PUMPS

CHAPTER # 07

PUMPS

7.1 Introduction:

In centrifugal pumps, the mechanical energy of the liquid is increased by centrifugal action. The liquid enters through a suction connection concentric with the excess of a high-speed rotary element, called the impeller in properly functioning pump; the space between the vanes is completely filled with a liquid flowing without cavitation. The liquid leaving the outer periphery of the impeller is collected in a spiral casing, called the volute and leaves the pumps through a tangential discharge connection. In the volute, the velocity head of the liquid from the impeller is converted into pressure head. Centrifugal pumps may be single stage or multi stage, propeller, mixed flow and peripheral. We have selected centrifugal pumps for a process because of the following advantages:

- They are simple in operation and cheap.
- Fluid is delivered at uniform pressure without shocks or pulsation.
- They are no valves involved in pump operation.

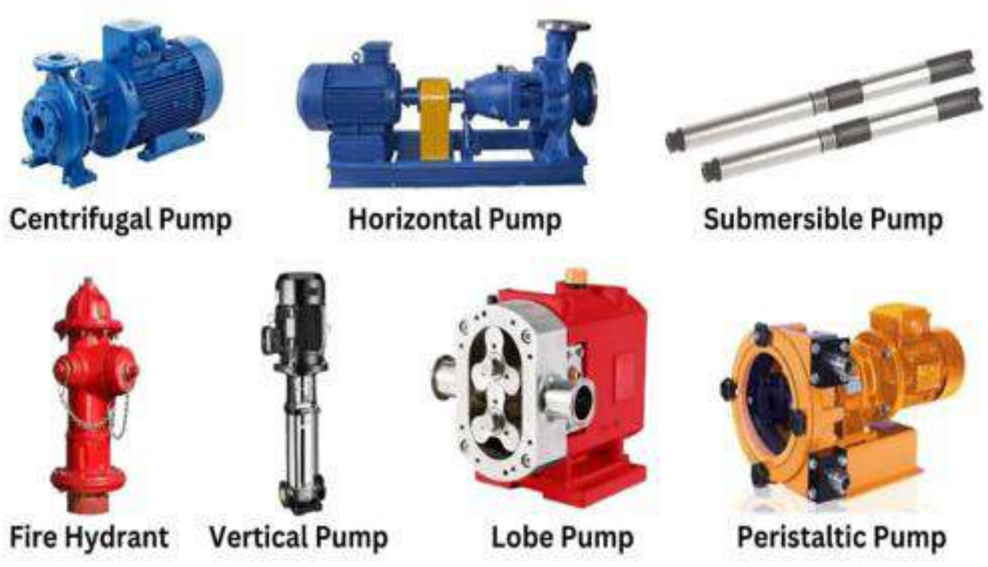


Figure 7.1: Different Types of Pumps

7.2 Selection of Pumps:

Design steps for pump sizing:

- Define the flow system i-e locate points 1 and 2. The pressures P_1 and P_2 will be known at these points.
- Locate the process equipment according to the rules of thumbs.
- Estimate Z_1 and Z_2.
- Estimate frictional pressure losses E_D and E_S.
- Calculate pump work.
- Calculate pump shaft horsepower and estimate its efficiency.
- Calculate electric motor horsepower and estimate its efficiency.
- Select a standard electric motor horsepower.

7.3 Calculation of Pumps:

Step 1: Pressure at Suction and Discharge of the Pump:

Inlet pressure = P_1 = 1 bar

Step 2: Rule of Thumbs for Locating the Process Equipment's:

Table 7.1: Locating the Process Equipment's

Process Equipment's	Location Above Ground Level (m)
Pumps	0
Condensers	20
Reflux drums	10
Phase separators	3 to 5
Skirt height for column	3 to 6
Heat exchanger	1 to 4

Step 3: Estimate Z_1 and Z_2 that is Height at Suction and Discharge:

Suction height = Z_1 = 0 ft = 0 m (As by rule of thumb pump will always consider at ground level)

Discharge height = Z_2 = height of equipment + skirt height = 3.3 m.

Step 4: Estimate Frictional Pressure Losses E_D and E_S:

From appendix B, table B.2.

E_s = 0.35 bar

E_D = 0.35 bar

Step 5: Calculate Pump Work:

Density = 1720 kg/m^3

W = - 52.7 Nm /kg

The negative sign shows that the work is done on the system.

Step 6: Pump Power Calculations:

Flow rate = m = 10.2 kg/s

Pump efficiency = η = 0.45

Pump Power = $\frac{m \times W}{\eta}$ ………… (7.1)

P_p = 892 W

Step 7: Calculate Electric Motor Horsepower and Estimate its Efficiency:

An induction motor with an efficiency of motor is selected to be 86%.

$P_E = \frac{\text{Pump Power}}{\text{Efficiency}}$ ………… (7.2)

= 1036 W

A safety factor of 10% is taken Safety factor = 1.1.

So, P_E = 1.39 × 1.1

= 1139.6 W

Select a standard electric-motor horsepower the standard motor selected is of 2237.1 W.

7.4 Net Positive Suction Head:

We know that:

$$\text{NPSH} = \frac{1}{g} \times \left(\frac{pa - pv}{p} - hfs\right) - Za \text{ ………… (7.3)}$$

Here:

H_{fs} = Friction in suction line = 0 bar

Za = 0

Pa = 1bar

NPSH = 6.01 m

Table 7.2: Pump (P-101) Specification Sheet

Specification Sheet P-101	
Total mass flow rate	10.2 kg/s
Discharge height = Z_2	3.3 m
Work required by pump	- 52.7 Nm/kg
Pump power	892 W

Electric motor Power	2237.1 W
NPSH	6.01 m

Table 7.3: Pump (P-102) Specification Sheet

Specification Sheet P-102	
Total mass flow rate	9 kg/s
Discharge height = Z_2	2.9 m
Work required by pump	- 50.7 Nm /kg
Pump power	782 W
Electric motor power	1491.4 W
NPSH	5.02 m

Table 7.4: Pump (P-103) Specification Sheet

Specification Sheet P-103	
Total mass flow rate	7.5 kg/s
Discharge height = Z_2	2.01m
Work required by pump	-48.2 Nm/kg
Pump power	720 W
Electric motor power	1491.4 W
NPSH	4.8 m

Table 7.5: Pump (P-104) Specification Sheet

Specification Sheet P-104	
Total mass flow rate	6 kg/s
Discharge height = Z_2	1.98 m
Work required by pump	- 46.8 Nm/kg
Pump power	680 W
Electric motor power	1491.4 W
NPSH	4.2 m

CHAPTER # 08

COST ESTIMATION

CHAPTER # 08

COST ESTIMATION

8.1 Introduction:

Cost estimation is a specialized subject and a profession in its own right. The design engineer, however, needs to be able to make quick, rough, cost estimates to decide between alternative designs and for project evaluation. Chemical plants are built to make a profit, and an estimate of the investment required and the cost of production are needed before the profitability of a project can be assessed. In this chapter, the various components that make up the capital cost of a plant and the components of the operating costs are discussed, and the techniques used for estimating reviewed briefly. Simple costing methods and some cost data are given, which can be used to make preliminary estimates of capital and operating costs at the flow-sheet stage. They can also be used to cost out alternative processing schemes and equipment. For a more detailed treatment of the subject the reader should refer to the numerous specialized texts that have been published on cost estimation.

8.2 Fixed and Working Capital:

Fixed capital is the total cost of the plant ready for start-up. It is the cost paid to the contractors. It includes the cost of:

- Design, and other engineering and construction supervision.
- All items of equipment and their installation.
- All piping, instrumentation and control systems. Buildings and structures. Auxiliary facilities, such as utilities, land and civil engineering work.
- It is a once only cost that is not recovered at the end of the project life, other than the scrap value.

Working capital is the additional investment needed, over and above the fixed capital, to start the plant up and operate it to the point when income is earned. It includes the cost of:

- Start-up.
- Initial catalyst charges.
- Raw materials and intermediates in the process.
- Finished product inventories.
- Funds to cover outstanding accounts from customers.

Most of the working capital is recovered at the end of the project. The total investment needed for a project is the sum of the fixed and working capital. Working capital can vary from as low as 5 percent of the fixed capital for a simple, single product, process, with little or no finished product storage; to as high as 30 percent for a process producing a diverse range of product grades for a sophisticated market, such as synthetic fibers. A typical figure for petrochemical plants is 15 per cent of the fixed capital.

8.3 Cost Escalation (Inflation):

The cost of materials and labor has been subject to inflation since. All cost estimating methods use historical data, and are themselves forecasts of future costs. Some method has to be used to update old cost data for use in estimating at the design stage, and to forecast the future construction cost of the plant. The method usually used to update historical cost data makes use of published cost indices.

8.4 Types of Capital Cost Estimates:

- Order-of-magnitude estimate (ratio estimate) based on similar previous cost data; probable accuracy of estimate over + 30 percent.
- Study estimate (factored estimate) based on knowledge of major items of equipment; probable accuracy of estimate up to 30 percent.
- Preliminary estimate (budget authorization estimate; scope estimate) based on sufficient data to permit the estimate to be budgeted; probable accuracy of estimate within 20 percent.
- Definitive estimate (project control estimate) based on almost complete data but before completion of drawings and specifications; probable accuracy of estimate within 10 percent.
- Detailed estimate (contractor’s estimate) based on complete engineering drawings, specifications, and site surveys; probable accuracy of estimate within + 5 percent.

8.5 Methods for Estimating Capital Investment:

- Method A detailed-item estimate.
- Method B unit-cost estimate.
- Method C percentage of delivered-equipment cost.
- Method D “lang” factors for approximation of capital investment.
- Method E power factor applied to plant-capacity ratio.

- Method F investment cost per unit of capacity.
- Method G turnover ratios.

8.6 Assumption of Plant:

- Plant projection year N = 20 years.
- Steady state.
- MACRS method.

8.7 Estimations of Cost of Plant:

8.7.1 Extractor:

Vessel height = 3.1m

Diameter = 0.52 m

Bare cost = $7500 cost in 2004

Material factor = 1.0

Pressure factor = 1.1

Cost = bare cost × Material factor × Pressure factor cost ……….. (8.1)

= $7500 × 1.0 × 1.1

Cost = $7500

Cost index in 2022 = 808.8

Cost index in 2004 = 111

Cost in 2022 = (cost in 2004) × $\frac{\text{Cost index in 2022}}{\text{Cost index in 2004}}$………… (8.2)

= $7500 × 7.286

= $54645

8.7.2 Decanter:

Diameter = S = 0.97 m

Cost Constant = C = $ 58000

Index for that equipment = n = 1.3

Purchased equipment cost = Ce =?

$Ce = CS^n$ …………. (8.3)

$= \$58000 \times (0.97)^{1.3}$

= $55748 in 2004

Purchased cost of decanter in 2004 = $ 55748

Cost index in 2022 = 808.8

Cost index in 2004 = 111

Cost in 2022 = (cost in 2004) × $\frac{\text{Cost index in 2022}}{\text{Cost index in 2004}}$ ………… (8.4)

= $55748 × 7.286

= $406179

8.7.3 Reactor:

Table 8.1: Purchase Cost of Reactor

Material of Construction	Stainless steel
Length of reactor (m)	1.295
Diameter of reactor (m)	0.8635
Volume of reactor (m^3)	0.758
M.F	2
P. F	1
Bare equipment cost	6000
Purchase equipment cost in 2004 ($)	12000
Cost index in 2022	808.7
Cost index in 2004	444.2
Purchase equipment cost (2022) ($)	14540

8.7.4 Washing Unit:

Table 8.2: Purchase Cost of Washing Unit

Material of construction	Carbon steel
Length of washing unit (m)	0.5
Diameter of washing unit (m)	0.388
volume of vessel (m^3)	0.05918
M.F	1
P. F	1
Bare equipment cost ($)	285
Purchase equipment cost in 2004 ($)	285
Cost index in 2022	808.7
Cost index in 2004	444.2
Purchase equipment cost (2022) ($)	519

8.7.5 Neutralizer:

Table 8.3: Purchase Cost of Neutralizer

Temperature (ºC)	60
Material of construction	Carbon steel
Length of reactor (m)	4.87
Diameter of reactor (m)	0.08
volume of reactor (m^3)	0.01
M.F	1
P. F	1
Bare equipment cost	9000
Purchase equipment cost in 2004 ($)	9000
Cost index in 2022	808.7
Cost index in 2004	444.2
Purchase equipment cost (2022) ($)	16385.19

8.7.6 Distillation Column:

Cost of Vessel:

Height: h = 12 m

Diameter: Dc = 1.201 m

Pressure: P = 1.13 bar

Material of constriction: Carbon steel

Cost = $20000

Pressure factor = 1

Material factor = 1

Purchased cost = Bare cost × Material factor × Pressure factor …………. (8.5)

Cost = $20000 × (1) × (1)

= $20000 in 2004

Cost index in 2022 = 808.8

Cost index in 2004 = 111

Cost in 2022 = (cost in 2004) × $\frac{\text{Cost index in 2022}}{\text{Cost index in 2004}}$ ………… (8.6)

= $20000 × 7.286

= $145729

Cost of Plates:

Diameter: Dc = 1.201 m

Type: Sieve

Material of constriction: Carbon steel

Cost = 330 $

Material factor = 1

Purchased cost = Bare cost × Material factor cost …………. (8.7)

= 330 ×1

= 330 $ for one plate

Total cost of plates = No. of plates × Cost of one plate × Total cost of plates

=19 × 330

= $6270 in 2004

Cost in 2022 = (cost in 2004) × $\frac{\text{Cost index in 2022}}{\text{Cost index in 2004}}$ ………… (8.8)

= $6270 × 7.286

= $45686

Total purchased cost of DC = Total cost of plates + Cost of vessel ………… (8.9)

= $145729 + $45686

= $191415

8.7.7 Pump:

Type: Centrifugal pump

Capacity = S = 0.39 L/s

a = 3300

b = 48

n = 1.2

$Ce = a + bS^n$ ………… (8.10)

$= 3300 + 48 \times (0.39)^{1.2}$

= $3301

Cost in 2022 = (cost in 2004) × $\frac{\text{Cost index in 2022}}{\text{Cost index in 2004}}$ ………… (8.11)

= $3301 × 7.286

= $24051

8.7.8 Heat Exchanger (Ex – 101):

Hot fluid = Steam

Cold fluid = Methanol + Algae oil

Heat transfer area = 30.0129 ft^2

= 2.78 m^2

Bare cost of double pipe heat exchanger in 2004 = $ 3000

Cost index 2004 = 444.2

Cost index 2022 = 808.8

Cost for 2022 = Cost of 2004 × 808.8/444.2

= $5462

8.7.9 Heat Exchanger (Ex – 102):

Hot fluid = Steam

Cold fluid = Sulfuric acid

Heat transfer area = 0.0824 ft^2

= 0.0076 m^2

Bare cost of double pipe heat exchanger in 2004 = $529

Cost index 2004 = 444.2

Cost index 2022 = 808.8

Cost for 2022 = Cost of 2004 × 808.8/444.2

= $963

8.7.10 Heat Exchanger (Ex – 103):

Hot fluid = Steam

Cold fluid = Water

Heat transfer area = 16.966 ft^2

= 1.5761 m^2

Bare cost of double pipe heat exchanger in 2004 = $ 2500

Cost index 2004 = 444.2

Cost index 2022 = 808.8

Cost for 2022 = Cost of 2004 × 808.8/444.2

= $4552

8.7.11 Heat Exchanger (Ex – 104):

Hot fluid = Steam

Cold fluid = NaOH

Heat transfer area = 0.888 ft^2

= 0.0824 m^2

Bare cost of double pipe heat exchanger in 2004 = $623

Cost Index 2004 = 444.2

Cost Index 2022 = 808.8

Cost for 2022 = Cost of 2004 × 808.8/444.2

= $1134

8.8 Total Equipment Purchased Cost:

Table 8.4: Total Equipment Purchased Cost

Equipments	No. Required	Cost ($)
Extractor	1	54645
Decanter	4	523078
Reactor	1	14570
Washing Unit	1	519
Heat exchangers	4	12111
Neutralizer	1	16385
Distillation column	1	191415
Pumps	12	245612
Filter Press	1	9000
Total		**1067335**

8.9 Direct Cost of Plant:

Table 8.5: Direct Cost

Items	Percentage (%)	Cost ($)
Purchased equipment	100 % PEC	1067335
Purchased equipment installation	39 % PEC	416260.65
Instrumentation and control	26% PEC	277507.1
Piping	31 % PEC	330873.85

Electrical system	10 % PEC	106733.5
Building	29 % PEC	309527.15
Yard improvement	12 % PEC	128080.2
Service facilities	55 % PEC	587034.25
Total	**302**	**3223351.7**

Direct Cost of plant:

Direct cost = 3.02 × Equipment cost …………. (8.12)

Direct cost =$3223351.7

8.10 Indirect Cost of Plant:

Table 8.6: Indirect Cost

Items	Percentage (%)	Cost ($)
Engineering and supervision	32 % PEC	341547.2
Construction expenses	34% PEC	362893.4
Legal expenses	4 % PEC	42693.4
Contractor’s fee	19 % PEC	202793.65
Contingency	37 % PEC	394913.95
Total	**126**	**1344842.1**

Indirect Cost of Plant:

Indirect cost = 1.26 × Equipment cost indirect …………. (8.13)

Cost = 1344842.1 $

8.11 Fixed Capital Investment (FCI):

FCI = Direct cost + Indirect cost ………… (8.14)

FCI = 4568193.8 $

8.12 Working Capital Investment (WCI):

WCI = 75% PEC ………… (8.15)

WCI = 800501.25 $

8.13 Total Capital Investment:

Total Capital Investment = WCI + FCI ………… (8.16)

Total Capital Investment = 5368695.05 $

Raw Materials:

Algae:

Flowrate = 0.28 ton/h

Cost = 1 $/ton

Methanol:

Flowrate = 0.1ton/h

Cost = 392 $/ton

Total cost = 0.34 million $/yr

Hexane:

Flowrate = 0.1ton/h

Cost = 1580 $/ton

Total cost = 1.3 million $/yr

NaOH:

Flowrate = 0.0013 ton/hr

Cost = 345 $/ton

Total cost = 3931 $/yr

H_2SO_4:

Flowrate = 0.0023 ton/hr

Cost = 146 $/ton

Total cost = 2943 $/yr

Utilities:

Water:

Flowrate = 0.48 ton/hr

Cost = 0.01 $/ton

Total cost = 42.1 $/yr

Steam:

Cost = 90 $ / year

8.14 Total Production Cost:

Variable Cost:

Variable cost = Raw Materials + Utilities ………… (8.17)

Variable cost = 3512664.518 $/yr

8.15 Direct Production Cost:

Table 8.6: Direct Production Cost

Items	Cost ($)
Variable cost	3540073.681
Operating labor	0.15 TPC
Laboratory Cost	0.0225 TPC
Supervision	0.0225 TPC
Maintenance	274091.63
Operating supplies	34261.4535
Patent and Royalties	0.03TPC
Total	**3848426.7645 + 0.225 TPC**

8.16 Depreciation:

FCI = V = 4568193.8 $

Salvage value = Vs = 5% of FCI = 228409.69$

Number of years = N = 20 yr

D = 216989.2055 $

8.17 Fixed Charges:

Table 8.7: Fixed Charge

Items	Costs ($)
Depreciation	216989.2055
Local taxes	114204.845
Insurance	31977.36
Rent	49097.41
Financing	26843.4525
Total	**439112.2725**

8.18 Manufacturing Cost:

= 0.1 × TPC ………… (8.18)

Manufacturing cost = DPC + FC + POC …………. (8.19)

= $ 4287539.04 + 0.325 TPC

General Expenses:

= 0.2 × TPC …………. (8.20)

Total production cost = MC + GE …………. (8.21)

= $9026397.98/yr

Production Cost Per Ton:

= $ 902639.6 /530

= 1163 $/ton

8.19 Gross Earning:

Selling price = 1663 $/ton

Total income = 1128306 $/yr

Gross income = Total income – Total production cost – Depreciation …………. (8.22)

= 203967.2 $/yr

Taxes = 22 % Gross income ………… (8.23)

Taxes = 44872.6 $/yr

Net Income = Gross Income – Taxes ………… (8.24)

= 159094.9 $/yr

8.20 Rate of Return (ROR):

ROR = $\frac{\text{Net income}}{\text{Total capital investment}}$ ×100 …………. (8.25)

= 29.6 %

8.21 Payback Period:

Payback period = $\frac{1}{ROR}$ × 100 …………. (8.26)

= 3.3 yrs.

CHAPTER # 09

PROCESS SIMULATION AND MODELLING

CHAPTER # 09

PROCESS SIMULATION AND MODELLING

9.1 Introduction:

Aspen Hysys is the energy industry's leading process simulation software that's used by top oil and gas producers, refineries and engineering companies for process optimization in design and operations. Aspen Hysys is a work flow oriented process simulation software for the optimization of conceptual design and operations [25]. With a broad array of features and functionalities, Aspen Hysys can be used to address engineering challenges in multiphase flow modeling, gas processing, refining and LNG making it the most versatile solution. Aspen Hysys is more powerful with enhanced functionalities [26]. Access relief valve sizing, blow down analysis, higher fidelity solutions for acid gas cleaning, heat exchanger design, sulfur recovery, and refinery reactors, dynamic modeling for compressor analysis, and upstream and hydraulics design all with same easy-to-use interface. Aspen Hysys (or simply Hysys) is a chemical process simulator currently developed by used to mathematically model chemical processes, from unit operations to full chemical plants and refineries. Hysys is able to perform many of the core calculations of chemical engineering, including those concerned with mass balance, energy balance, vapor-liquid equilibrium, heat transfer, mass transfer, chemical kinetics, fractionation, and pressure drop [27]. Hysys is used extensively in industry and academia for steady-state and dynamic simulation, process design, performance modeling, and optimization.

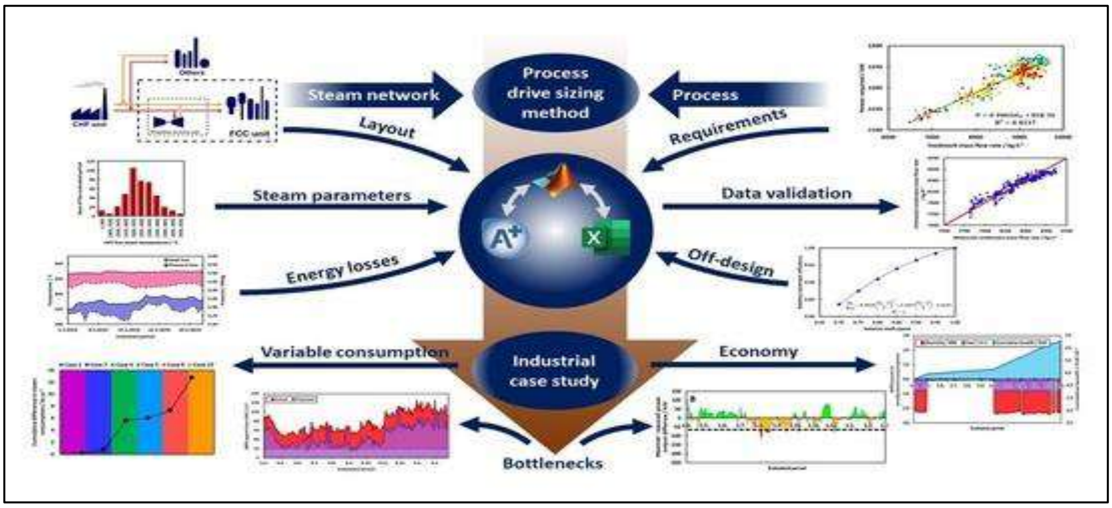


Figure 9.1: Services Available in Aspen Tech

9.2 History of Aspen Hysys:

Hysys was first conceived and created by the Canadian Company Hygrotech, founded by researchers from the University of Calgary. The Hysys Version 1.1 Reference Volume was published in 1996. In May 2002, Aspen Tech acquired Hygrotech, including Hysys. Following a 2004 ruling by the United States Federal Trade Commission, Aspen Tech was forced to divest its Hygrotech assets, including Hysys source code, ultimately selling these to Honeywell. Honeywell was also able to hire a number of Hysys developers, ultimately mobilizing these resources to produce UniSim [28]. The divestment agreement specified that Aspen Tech would retain rights to market and develop most Hyprotech products (including Hysys) royalty free. As of late 2016, Aspen Tech continues to produce Hysys.

9.3 Applications of Aspen Hysys:

Hysys is used extensively in industry and academia for:

- Steady-state and dynamic simulation.
- Process design.
- Performance modeling.
- Optimization.

9.4 Process Overview Related to Aspen Hysys:

Since straight vegetable oil (SVO), a triglyceride, is excessively used and does not have other needed properties to proficiently fuel cutting edge diesel motors without decreasing motor life, the SVO must experience a methodology of transesterification whereby one of its R-gatherings is supplanted by the R-gathering of a liquor, normally methanol, consequently shaping alkyl esters, or biodiesel. A basic catalyst, normally NaOH, is utilized to deprotonate the methanol making it a stronger nucleophile that wills all the more openly responds with the triglyceride. Through this process, the breaking point of the recently created biodiesel is much lower, as it stands its thickness and propensity to polymerize. All things considered, it can be utilized as a part of customary diesel motors without gambling motor wellbeing. It is additionally frequently blended with ordinarily extricated diesel because of its predominant lubricity. Given the undeniably strict laws on sulfur content in traditional diesel for ecological reasons, the expansion of biodiesel gives a significant advantage in supplanting the ointment. Glycerol is additionally framed through the procedure and is effortlessly tapped. It can then be refined and sold for utilization in the production of cleansers and other non-essential and pharmaceutical items. In a run of the mill persistent procedure biodiesel plant, the reaction happens in two stages and the general methodology can be compressed in the accompanying steps:

9.4.1 Extractor:

In extractor, we add algae, methanol and hexane at 298 K and 1 bar. Here methanol and hexane are solvents that are used to extract algae oil from algae in extractor. The temperature of output stream is 363 K.

9.4.2 Filter Press:

After extraction, the slurry moves towards filter press where algae cake is separated from algae oil and removed from the stream. The both output stream temperature is 363 K.

9.4.3 Decanter I:

In this decanter, hexane is separated and the remaining components in stream are methanol and algae oil. The input temperature in decanter is 363K and both output stream temperature is 358K.

9.4.4 Reactor:

This is continuous stirred tank reactor. In this reactor, large amount of algae oil is converted into biodiesel, glycerol. The reactor outlet stream temperature is 338 K.

9.4.5 Decanter II:

In second decanter, the remaining algae oil is removed from the stream and recycle into the extractor. The both output stream temperature is 333 K.

9.4.6 Decanter III:

In third decanter, biodiesel is separated from other component and move in top stream while the other components move towards bottom stream. The temperature of top and bottom stream is 328 K.

9.4.7 Washing Unit:

The top stream of third decanter move towards washing unit where washing of biodiesel occur with the help of water. The temperature of water is 298 K. The output temperature of washing unit is 313 K.

9.4.8 Dryer:

In Dryer, the water is removed from biodiesel and we get our pure biodiesel. The bottom stream of decanter III first come into neutralizer where NaOH is added to neutralize the sulphuric acid. The Inlet stream temperature is 328 K and outlet stream temperature is 338 K.

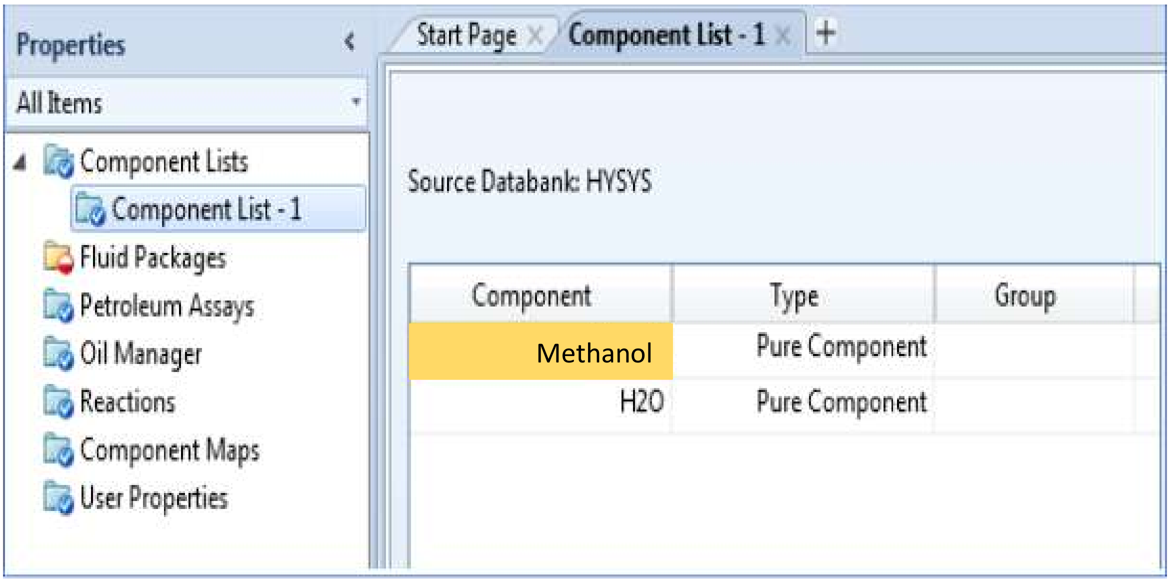
9.4.9 Distillation Column:

In top distillate we get some amount of methanol and water and in bottom product we get methanol, water, glycerol and Na_2SO_4. The temperature of top product stream is 343 K and the temperature of bottom product is 348 K.

9.5 Simulation of Plant:

9.5.1 Procedure:

Create a new simulation in Aspen Hysys V11. Create a component list. In the component lists folder select “Add”.



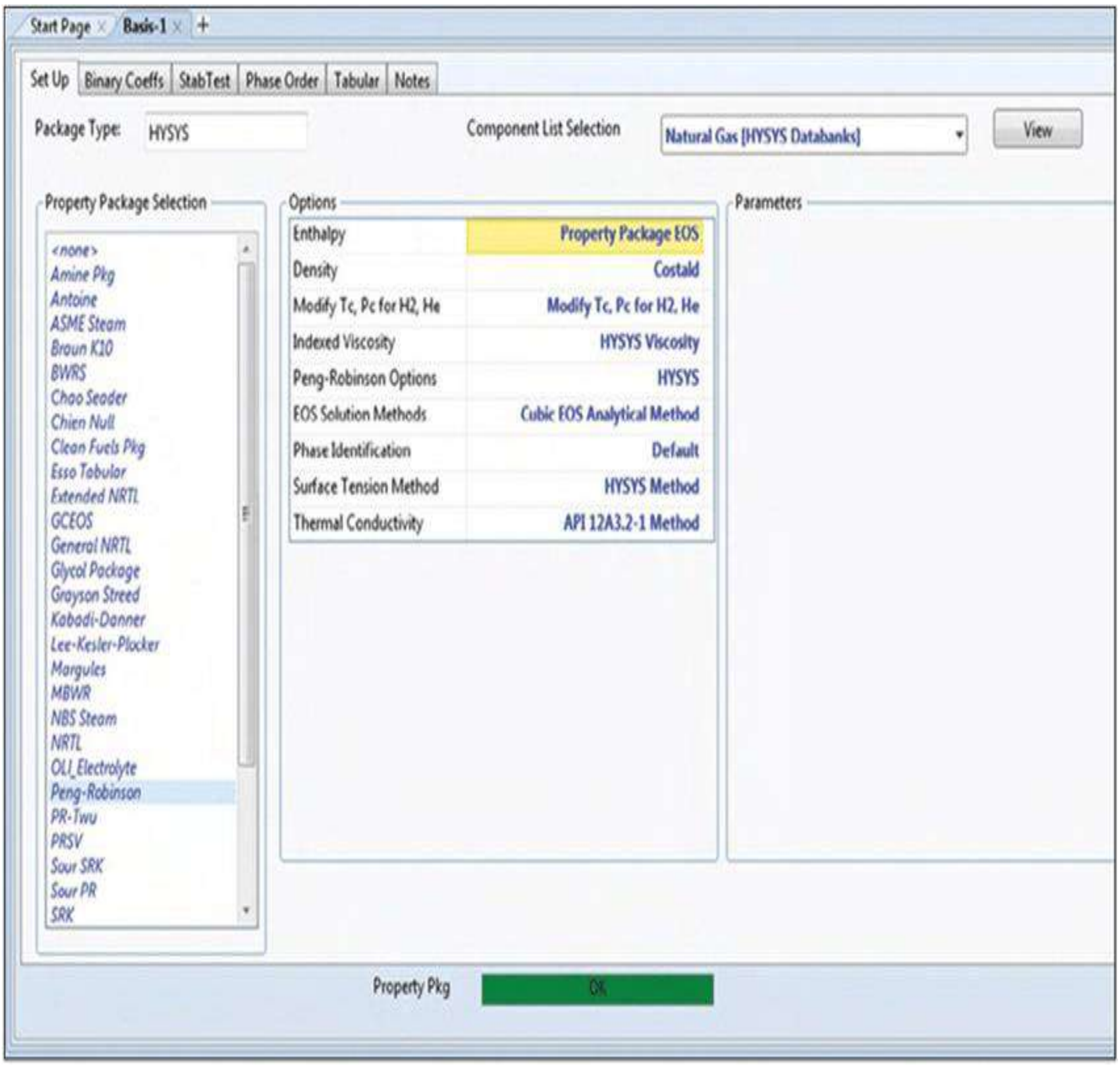
Source Databank: HYSYS

Component	Type	Group
Methanol	Pure Component	
H2O	Pure Component	

Figure 9.2: Component Selection Display in Aspen Hysys

Define property package. In the fluid packages folder select Add. Select NRTL as the property package. Select RK as the vapour model. The non-random, two liquid (NRTL) model works well for very non ideal liquid systems which is important because of the hydrogen bonding present. The

Redlich-Kwong equation model works much better at high pressures than the ideal gas assumption in the vapour phase.



Package Type: HYSYS

Component List Selection: Natural Gas [HYSYS Databanks]

Options

Enthalpy	Property Package EOS
Density	Costald
Modify Tc, Pc for H2, He	Modify Tc, Pc for H2, He
Indexed Viscosity	HYSYS Viscosity
Peng-Robinson Options	HYSYS
EOS Solution Methods	Cubic EOS Analytical Method
Phase Identification	Default
Surface Tension Method	HYSYS Method
Thermal Conductivity	API 12A3.2-1 Method

Property Pkg: OK

Figure 9.3: Fluid Package Display in Aspen Hysys

Go to the simulation environment by clicking the simulation button in the bottom left of the screen. Add the flowsheet from the model palette. Double click all the equipments. Enter the following information and click “Next” when complete. Go to the composition form under the worksheet tab to define the composition of the feed and other stream.

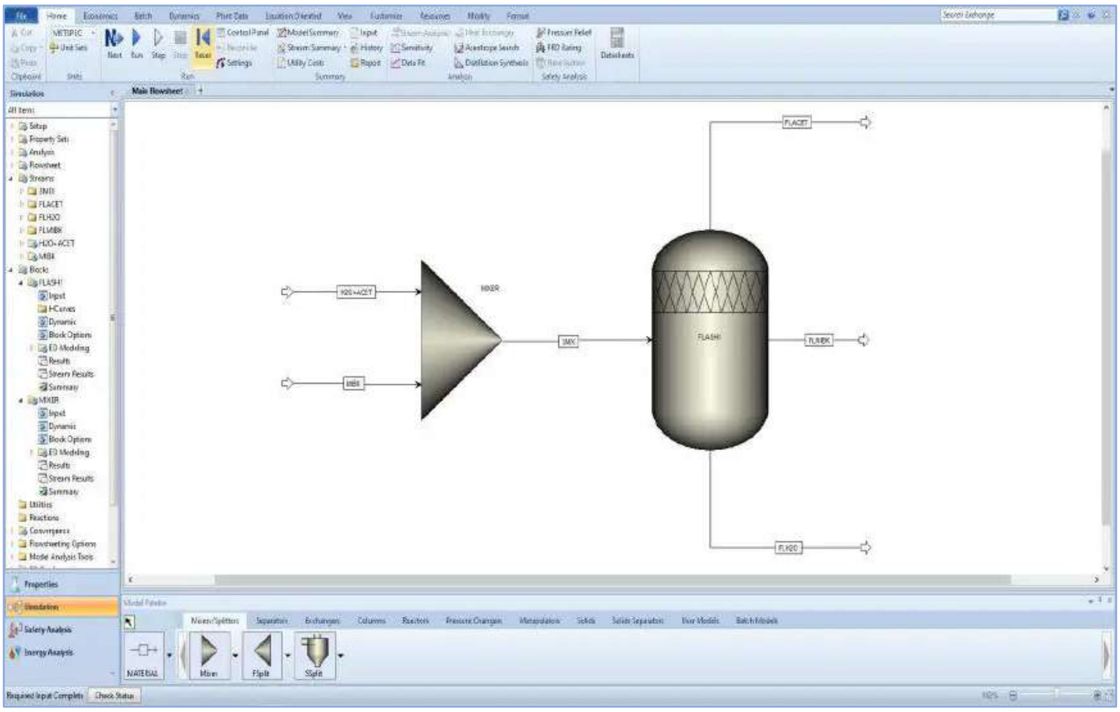


Figure 9.5: Simulation Environment of Aspen Hysys

Go to the "Specs Summary" form under the design tab. Make sure that the only specification marked as active are comp recovery and comp fraction. The flowsheet is now complete. Further analysis can be performed to optimize the column size, feed location, and energy requirements.

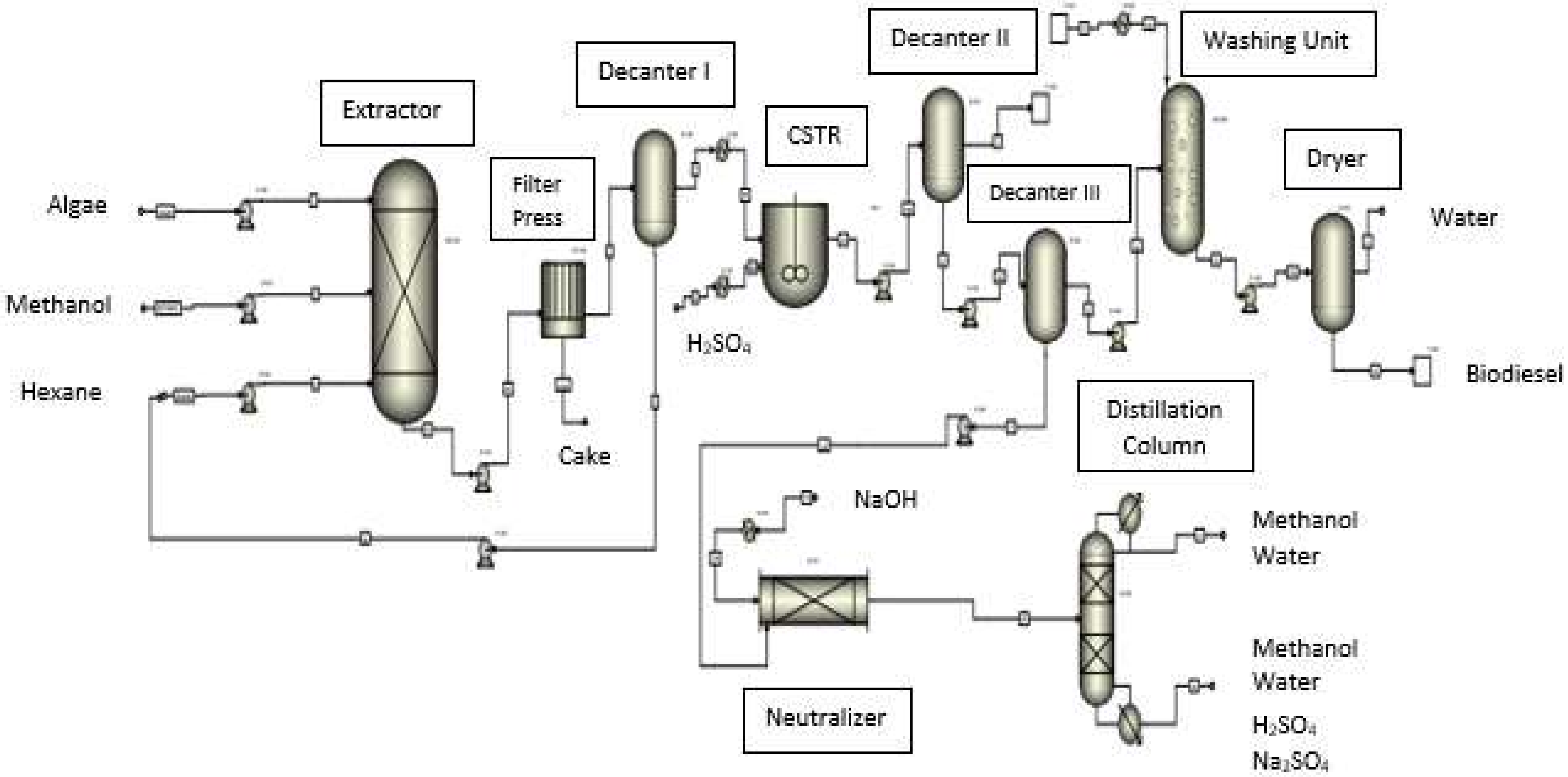
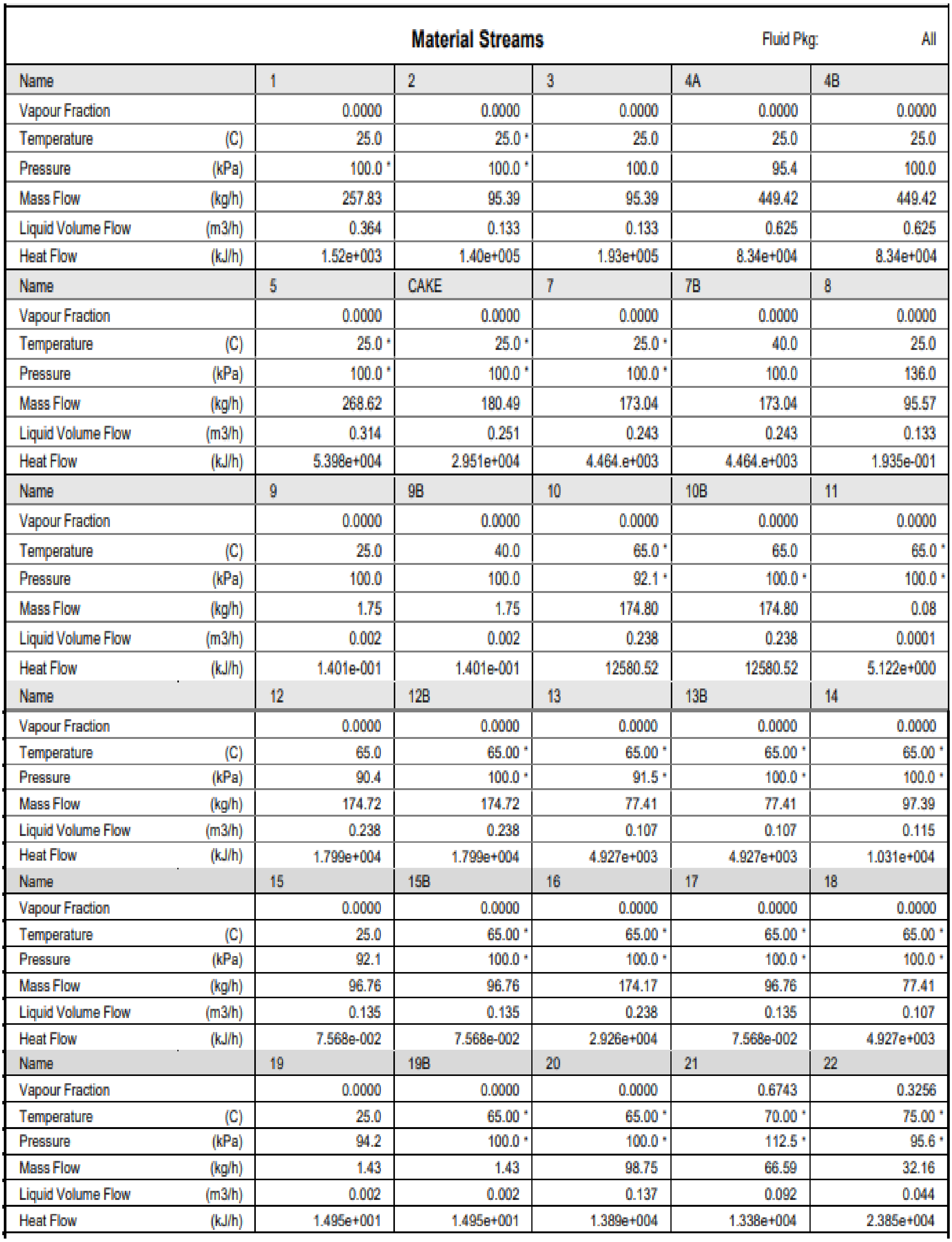


Figure 9.6: Simulated Process Flow Diagram

9.6 Results of Simulation:

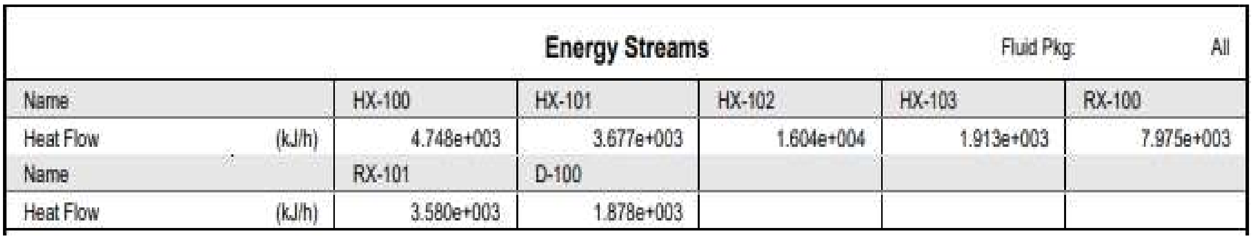
Table 9.1: Material Stream Result on Aspen Hysys



Material Streams Fluid Pkg: All

Name		1	2	3	4A	4B
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	25.0	25.0 *	25.0	25.0	25.0
Pressure	(kPa)	100.0 *	100.0 *	100.0	95.4	100.0
Mass Flow	(kg/h)	257.83	95.39	95.39	449.42	449.42
Liquid Volume Flow	(m3/h)	0.364	0.133	0.133	0.625	0.625
Heat Flow	(kJ/h)	1.52e+003	1.40e+005	1.93e+005	8.34e+004	8.34e+004
Name		5	CAKE	7	7B	8
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	25.0 *	25.0 *	25.0 *	40.0	25.0
Pressure	(kPa)	100.0 *	100.0 *	100.0 *	100.0	136.0
Mass Flow	(kg/h)	268.62	180.49	173.04	173.04	95.57
Liquid Volume Flow	(m3/h)	0.314	0.251	0.243	0.243	0.133
Heat Flow	(kJ/h)	5.398e+004	2.951e+004	4.464.e+003	4.464.e+003	1.935e-001
Name		9	9B	10	10B	11
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	25.0	40.0	65.0 *	65.0	65.0 *
Pressure	(kPa)	100.0	100.0	92.1 *	100.0 *	100.0 *
Mass Flow	(kg/h)	1.75	1.75	174.80	174.80	0.08
Liquid Volume Flow	(m3/h)	0.002	0.002	0.238	0.238	0.0001
Heat Flow	(kJ/h)	1.401e-001	1.401e-001	12580.52	12580.52	5.122e+000
Name		12	12B	13	13B	14
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	65.0	65.00 *	65.00 *	65.00 *	65.00 *
Pressure	(kPa)	90.4	100.0 *	91.5 *	100.0 *	100.0 *
Mass Flow	(kg/h)	174.72	174.72	77.41	77.41	97.39
Liquid Volume Flow	(m3/h)	0.238	0.238	0.107	0.107	0.115
Heat Flow	(kJ/h)	1.799e+004	1.799e+004	4.927e+003	4.927e+003	1.031e+004
Name		15	15B	16	17	18
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	(C)	25.0	65.00 *	65.00 *	65.00 *	65.00 *
Pressure	(kPa)	92.1	100.0 *	100.0 *	100.0 *	100.0 *
Mass Flow	(kg/h)	96.76	96.76	174.17	96.76	77.41
Liquid Volume Flow	(m3/h)	0.135	0.135	0.238	0.135	0.107
Heat Flow	(kJ/h)	7.568e-002	7.568e-002	2.926e+004	7.568e-002	4.927e+003
Name		19	19B	20	21	22
Vapour Fraction		0.0000	0.0000	0.0000	0.6743	0.3256
Temperature	(C)	25.0	65.00 *	65.00 *	70.00 *	75.00 *
Pressure	(kPa)	94.2	100.0 *	100.0 *	112.5 *	95.6 *
Mass Flow	(kg/h)	1.43	1.43	98.75	66.59	32.16
Liquid Volume Flow	(m3/h)	0.002	0.002	0.137	0.092	0.044
Heat Flow	(kJ/h)	1.495e+001	1.495e+001	1.389e+004	1.338e+004	2.385e+004

Table 9.2: Energy Streams Result on Aspen Hysys



Energy Streams

Fluid Pkg: All

Name		HX-100	HX-101	HX-102	HX-103	RX-100
Heat Flow	(kJ/h)	4.748e+003	3.677e+003	1.604e+004	1.913e+003	7.975e+003
Name		RX-101	D-100			
Heat Flow	(kJ/h)	3.580e+003	1.878e+003			

CHAPTER # 10

INSTRUMENTATION AND PROCESS CONTROL

CHAPTER # 10

INSTRUMENTATION AND PROCESS CONTROL

10.1 Introduction:

Control in process industries refers to the regulation of all aspects of the process. Precise control of level, temperature, pressure and flow is important in many process applications. This module introduces you to control in process industries, explains why control is important, and identifies different ways in which precise control is ensured. The objective of an automatic process control is to use the manipulated variable to maintain the controlled variable at its set point in spite of disturbances. Instruments are provided to monitor the key process variables during plant operations. Instruments monitoring critical process variables will be fitted with automatic alarms to alert, the operations to critical and hazardous situations. Pneumatic instruments are used in this plant. The main process parameters are all indicated in the control room where automatic or remote control is carried out centrally. The process parameters e.g. temperatures, pressure flow, liquid level etc. are converted to signals with transducers and then indicated, recorded and controlled with secondary instruments.

10.2 Importance of Process Control:

Refining, combining, handling, and otherwise manipulating fluids to profitably produce end products can be a precise, demanding, and potentially hazardous process. Small changes in a process can have a large impact on the end result. Variations in proportions, temperature, flow, turbulence, and many other factors must be carefully and consistently controlled to produce the desired end product with a minimum of raw materials and energy. Process control technology is the tool that enables manufacturers to keep their operations running within specified limits and to set more precise limits to maximize profitability, ensure quality and safety.

10.3 Process of Instrumentation:

Process as used in the terms process control and process industry, refers to the methods of changing or refining raw materials to create end products. The raw materials, which either pass through or remain in a liquid, gaseous, or slurry (a mix of solids and liquids) state during the process, are transferred, measured, mixed, heated or cooled, filtered, stored, or handled in some other way to produce the end product. Process industries include the chemical industry, the oil and gas industry, the food and beverage industry, the pharmaceutical industry, the water treatment industry, and the power industry.

10.4 Process Control:

Process control refers to the methods that are used to control process variables when manufacturing a product. For example, factors such as the proportion of one ingredient to another, the temperature of the materials, how well the ingredients are mixed, and the pressure under which the materials are held can significantly impact the quality of an end product. Manufacturers control the production process for three reasons:

- Reduce variability.
- Increase efficiency.
- Ensure safety.

10.5 Reduce Variability:

Process control can reduce variability in the end product, which ensures a consistently high-quality product. Manufacturers can also save money by reducing variability. For example, in a gasoline blending process, as many as 12 or more different components may be blended to make a specific grade of gasoline. If the refinery does not have precise control over the flow of the separate components, the gasoline may get too much of the high-octane components. As a result, customers would receive a higher grade and more expensive gasoline than they paid for, and the refinery would lose money. The opposite situation would be customers receiving a lower grade at a higher price.

10.6 Increase Efficiency:

A run-away process, such as an out of control nuclear or chemical reaction, may result if manufacturers do not maintain precise control of all of the processing variables. The consequences of a run-away process can be catastrophic. Precise process control may also be required to ensure safety. For example, maintaining proper boiler pressure by controlling the inflow of air used in combustion and the outflow of exhaust gases is crucial in preventing boiler implosions that can clearly threaten the safety of workers.

10.7 Safe Plant Operation:

- To keep the process variables within known safe operating limits.
- To detect dangerous situations as they develop and to provide alarms and automatic shutdown systems.

- To provide interlocks and alarms to prevent dangerous operating procedures.

10.8 Process Control Terms:

10.8.1 Process Variable:

A process variable is a condition of the process fluid that can change the manufacturing process in some way. In the example of you sitting by the fire, the process variable was temperature. Common process variables include:

- Pressure.
- Flow.
- Level.
- Temperature.
- Density.
- Ph (acidity or alkalinity).
- Mass.
- Conductivity.

10.8.2 Set Point:

The set point is a value for a process variable that is desired to be maintained. For example, if a process temperature needs to keep within 5°C of 100 °C, then the set point is 100 °C. A temperature sensor can be used to help maintain the temperature at set point. The sensor is inserted into the process, and a controller compares the temperature reading from the sensor to the set point. If the temperature reading is 110 °C, then the controller determines that the process is above set point and signals the fuel valve of the burner to close slightly until the process cools to 100 °C. Set points can also be maximum or minimum values.

10.8.3 Measured Variables:

The measured variable is the condition of the process fluid that must be kept at the designated set point.

10.8.4 Manipulated Variable:

The variable that can be variate in order to manage the control variable at its desired value. Hardware elements of control system:

1. **The Measuring Instruments or Sensors:**

These are the instruments which are used to measure disturbance, controlled variables.

2. **Transducers:**

   A transducer is device that converts one form of energy to another. Usually a transducer converts a signal in one form of energy to a signal in another.

3. **Transmission Line:**

   It is used to carry out the measurement signal from the measuring device to controller.

4. **Controller:**

   This receives the formation from the measuring devices that decides either the information correct or not.

5. **The Final Controller Element:**

   The final control element is a device controlled by a controller to change the operating conditions of a process. Final control elements require energy to operate against the process. It is the hardware element that implements the decision taken by controller.

10.9 Classification of Control Systems:

For instrumentation and control of different sections and equipments of plants, following control loops are most often used.

- Feed back control loop.
- Feed forward control loop.
- Ratio control loop.
- Split range control loop.
- Cascade control loop.

Here is given a short outline of these control schemes, so that to justify out selection of a control loop for specified equipment.

10.9.1 Feed Back Control Loop:

A method of control in which a measured value of a process variable is compared with the desired value of the process variable and any necessary action is taken. Feed back control is considered as the basic control loops system. Its disadvantage lies in its operational procedure. For example, if a certain quantity is entering in a process, then a monitor will be there at the process to note its value. Any changes from the set point will be sent to the final control element through the controller so that to adjust the incoming quantity according to desired value (set point). But in fact, changes have already occurred and only corrective action can be taken while using feed back control system.

10.9.2 Feed Forward Control Loop:

A method of control in which the value of disturbance is measured than action is taken to prevent the disturbance by changing the value of a process variable. This is a control method designed to prevent errors from occurring in a process variable. This control system is better than feed back control because it anticipates the change in the process variable before it enters the process and takes the preventive action. While in feed back control system action is taken after the change has occurred.

10.9.3 Ratio Control:

A control loop in which, the controlling element maintains a predetermined ratio of one variable to another. Usually this control loop is attached to such a system where two different systems enter a vessel for reaction that may be of any kind. To maintain the stoichiometric quantities of different streams, this loop is used so that to ensure proper process going on in the process vessel.

10.9.4 Split Range Loop:

In this loop controller is preset with different values corresponding to different actions to be taken at different conditions. The advantage of this loop is to maintain the proper conditions and avoid abnormalities at very differential levels.

10.9.5 Cascade Control Loop:

This is a control in which two or more control loops are arranged so that the output of one controlling element adjusts the set point of another controlling element. This control loop is used where proper and quick control is difficult by simple feed forward or feed backward control. Normally first loop is a feed back control loop.

10.10 Control Scheme of Reactor:

10.10.1 Control Objectives:

Temperature inside the reactor.

10.10.2 Manipulated Variables:

The manipulated variable is coolant flow rate Fc.

10.10.3 Loads or Disturbances:

Following are typical disturbances:

- Flow rate of feed.
- Temperature of feed.
- Coolant flow rate.

- Coolant temperature.

10.10.4 Description of Process:

The reaction is exothermic. A cooling system is provided to remove the excess energy of reaction. In the event of cooling function is lost, the temperature of reactor would increase. This would lead to an increase in reaction rate leading to additional energy release. The result could be a run away reaction with pressures exceeding the bursting pressure of the reactor. The temperature within the reactor is measured and is used to control the cooling water flow rate by a valve. We have to maintain the temperature inside the reactor constant at. The temperature in the CSTR reactor vary along the length of the reactor. The highest temperature is called the hot spot. The location of the hot spot moves along the length of the reactor depending on the feed conditions (temperature, concentration, flow rate) and the catalyst activity. The value of the temperature also depends on the factors listed above and the temperature and flow rate of the coolant. The cascade control loop is used to control the level and temperature inside the reactor. The control of such systems is a real challenge. The primary control objective is to keep the temperature below an upper limit. Therefore, we need a control system that can identify the temperature and provide the proper control action. This can be achieved through:

- Placement of several thermocouples along the length of the reactor.
- If T goes up, increase the flow rate of the coolant to remove heat. Decrease the coolant rate, when T decreases.
- We can have two control loops using two different measurements, T and Tc but sharing a common manipulated variable, Fc.
- The loop that measures T (controlled variable) is the dominant or primary, or master control loop and uses a set point supplied by the operator.
- The loop that measures Tc uses the output of the primary controller as its set point and is called the secondary or slave loop.

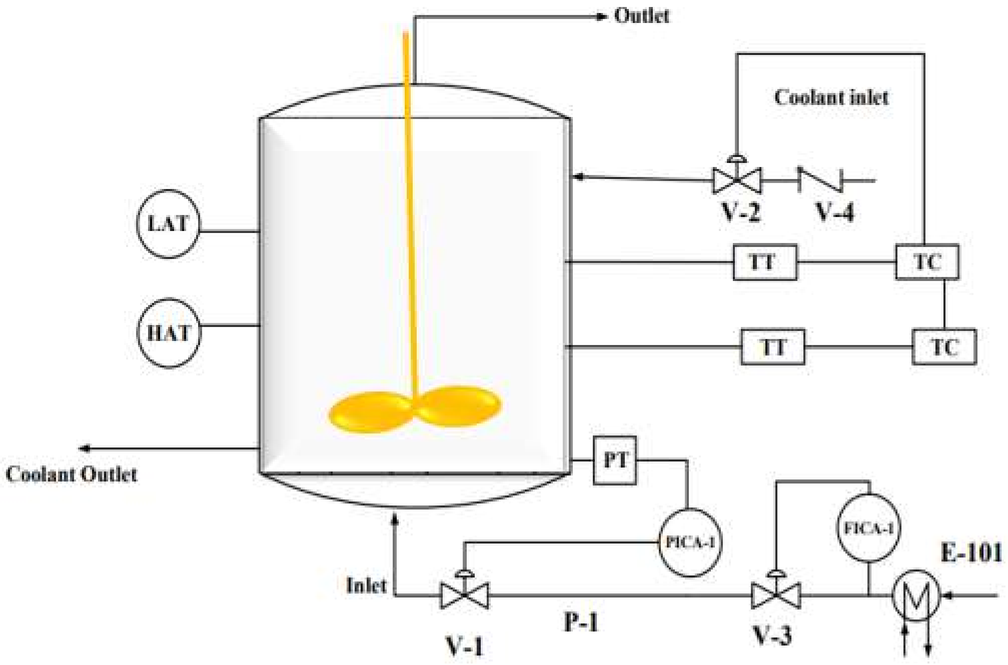


Figure 10.1: Cascade Loop on Reactor (RX-100)

CHAPTER # 11

HAZARD AND OPERABILITY ANALYSIS

CHAPTER # 11

HAZARD AND OPERABILITY ANALYSIS

11.1 Introduction:

A Hazard and operability (HAZOP) study is a structured and systematic examination of a planned or existing process or operation in order to identify and evaluate problems that may represent risks to personnel or equipment, or prevent efficient operation. The HAZOP technique was initially developed to analyze chemical process systems, but has later been extended to other types of systems and also to complex operations and to software systems. A HAZOP is a qualitative technique based on guide-words and is carried out by a multi-disciplinary team (HAZOP team) during a set of meetings.

11.2 Perform a HAZOP:

The HAZOP study should preferably be carried out as early in the design phase as possible to have influence on the design. On the other hand, to carry out a HAZOP we need a rather complete design. As a compromise, the HAZOP is usually carried out as a final check when the detailed design has been completed. A HAZOP study may also be conducted on an existing facility to identify modifications that should be implemented to reduce risk and operability problems.

11.3 Purpose of HAZOP:

To identify (areas of the design that may possess a significant hazard potential). To identify and study features of the design that influence the probability of a hazardous incident occurring.

- To familiarize the study team with the design information available.
- To ensure that a systematic study is made of the areas of significant hazard potential.
- To identify pertinent design information not currently available to the team.
- To provide a mechanism for feed back to the client of the study teams detailed comments.

11.4 Guide words Related to HAZOP:

These are simple words which are used to qualify or quantify the intention in order to guide and stimulate the brainstorming process and so discover deviations. The guide words shown in table are the ones most often used in a HAZOP, some organizations have made this list specific to their operations, to guide the team more quickly to the areas where they have previously found problems. Each guide word is applied to the process variables at the point in the plant (study node) which is being examined.

Table 11.1: HAZOP Terminology

Term	Definition
Process Sections or (Study Nodes)	Sections of equipment with definite boundaries (e.g., a line between two vessels) within which process parameters are investigated for deviations. The locations on P&IDs at which the process parameters are investigated for deviations (e.g. Distillation column).
Operating Steps	Discrete actions in a batch process or a procedure analyzed by a HAZOP analysis team. May be manual, automatic, or software implemented actions. The deviations applied to each step are somewhat different than the ones used for a continuous process.
Intention	Definition of how the plant is expected to operate in the absence of deviation. Takes a number of forms and can be either descriptive or diagrammatic (e.g., process description, flow sheets, line diagrams, P&IDs).
Guide Words	Simple words that are used to qualify the design intention and to guide and stimulate the brainstorming process for identifying process hazards.
Process Parameter	Physical or chemical property associated with the process. Includes general items such as reaction, mixing, concentration, pH, and specific items such as temperature, pressure, phase, and flow.

Deviations	Departures from the design intention that are discovered by systematically applying the guide words to process parameters (flow, pressure, etc.) resulting in a list for the team to review (no flow, high pressure, etc.) for each process section.
Causes	Reasons why deviations might occur. Once a deviation has been shown to have a credible cause, it can be treated as a meaningful deviation. These causes can be hardware failures, human errors, unanticipated process states (e.g. change of composition), external disruptions (e.g. loss of power), etc.
Consequences	Results of deviations (e.g. release of toxic materials). Normally, the team assumes active protection systems fail to work. Minor consequences, unrelated to the study objective, are not considered.
Safeguards	Engineered systems or administrative controls designed to prevent the causes or mitigate the consequences of deviations (e.g. process alarms, interlocks, procedures).
Actions (or Recommendations)	Suggestions for design changes, procedural changes, or areas for further study (e.g. adding a redundant pressure alarm or reversing the sequence of two operating steps).

11.5 Success or Failure:

The success or failure of the HAZOP depends on several factors.

- The completeness and accuracy of drawings and other data used as a basis for the study.
- The technical skills and insights of the team.
- The ability of the team to use the approach as an aid to their imagination in visualizing

deviations, causes, and consequences.

11.6 HAZOP Characteristics:

HAZOP is best suited for assessing hazards in facilities, equipment, and processes and is capable of assessing systems from multiple perspectives.

11.6.1 Design of HAZOP:

Assessing system design capability to meet user specifications and safety standards. Identifying weaknesses in systems.

11.6.2 Physical and Operational Environments:

Assessing environment to ensure system is appropriately situated, supported, serviced, contained, etc.

11.7 Advantages of HAZOP:

1.Helpful when confronting hazards that are difficult to quantify that is,

- Hazards rooted in human performance and behaviors.
- Hazards that are difficult to detect, analyze, isolate, count, predict, etc.
- Methodology doesn’t force you to explicitly rate or measure deviation probability of occurrence, severity of impact, or ability to detect.

2. Built-in brainstorming methodology.

3. Systematic & comprehensive methodology.

4. Simpler and more intuitive than other commonly used risk management tools.

11.8 Disadvantages of HAZOP:

- No means to assess hazards involving interactions between different parts of a system or process.
- No risk ranking or prioritization capability. Teams may optionally build-in such capability as required.
- No means to assess effectiveness of existing or proposed controls (safeguards). May need to interface HAZOP with other risk management tools.

11.9 Effectiveness of HAZOP:

The effectiveness of a HAZOP will depend on:

- The accuracy of information (including P&IDs) available to the team information should be complete and up-to-date.
- The skills and insights of the team members.
- How well the team is able to use the systematic method as an aid to identifying.

11.10 Key Elements Related to HAZOP:

Key elements of a HAZOP are:

- HAZOP team.
- Full description of process.
- Relevant guide words.
- Conditions conducive to brainstorming.
- Recording of meeting.
- Follow up plan.

Table 11.2: Hazop Study Guide Words

Guide Words	Meaning	Comments
No, Not, None	The complete negation of the intention	No part of the design intention is achieved, but nothing else happens.
More, Higher, Greater	Quantitative increase	Applies to quantities such as flow rate and temperature and to activities such as heating and reaction.
Less, Lower	Quantitative decrease	Applies to quantities such as flow rate and temperature and to activities such as heating and reaction.
As well as	Qualitative increase	All the design and operating intentions are achieved along

		with some activity.
Part of	Qualitative decrease	Only some of the design intentions are achieved, some are not.
Reverse	The logical opposite of the intention	Most applicable to activities such as flow or chemical reaction. Also applicable to substances, for example, poison instead of antidote.
Other Than	Complete substitution	No part of the original intention is achieved. The original intention is replaced by something else.

11.11 Hazop Study on Reactor (R- 100):

Table 11.3: Hazop Study of Reactor (R-100)

Guide	Deviation	Cause	Consequences	Action
No	Flowrate	➢ No Feed in storage tank. ➢ Feed pump rupture. ➢ Supply pipe rupture. ➢ Valve is closed. ➢ Pump is off.	Decrease production or no production.	➢ Cleaning of line Level control system. ➢ Maintenance of pipes. ➢ Automatic valve. ➢ Automatic pump.
	Level	➢ Valve is closed.	Decrease in production or no production.	➢ Maintenance of pipes. ➢ Automatic valve.
	Temperature	➢ Steam pipe rupture.	Decrease in production or no production.	Maintenance of pipes.

	Pressure	Fault in Preheater.	Decrease in production or no production.	Maintenance of Preheater.
More	Flowrate	More valve opening.	➢ Explosion. ➢ Less conversion.	➢ Automatic valve. ➢ Check reactor conditions.
	Level	More valve opening.	Overflow	Check Valve
	Temperature	Fault in Preheater.	Explosion	Maintenance
	Pressure	Fault in Preheater.	Less production.	Check valve.
Less	Flowrate	Less of opening of valves.	Less production.	➢ Automatic valve. ➢ Temperature control at reactor feed preparation.
	Level	Less of opening of valves.	Less Production.	Check Valve.
	Temperature	Fault in Preheater.	Low Conversion.	Temperature Control.
	Pressure	Fault in Preheater.	Less Production.	Maintenance
As well as	Impurities in feed stream.	➢ Problem in raw material ➢ Fouling in pipes.	➢ Low conversion rate. ➢ Decrease in product quality.	Quality control of raw material and product Maintenance.
Part of	Higher or lower percentage of algae oil.	➢ High quality of feed. ➢ Less quality of feed.	More or less pure production than intended.	Quality control of raw material and product.
Other than	Replacement of raw material.	Wrong connection during plant modification.	Explosion	Better management of changing procedure.

CHAPTER # 12

ENVIRONMENTAL IMPACT ASSESSMENT

CHAPTER # 12

ENVIRONMENTAL IMPACT ASSESSMENT

12.1 Introduction:

Environmental Impact Assessment (EIA) is the process of assessing the likely environmental impacts of a proposal and identifying options to minimize environmental damage. The main purpose of EIA is to inform decision makers of the likely impacts of a proposal before a decision is made. EIA provides an opportunity to identify key issues and stakeholders early in the life of a proposal so that potentially adverse impacts can be addressed before final approval decisions are made. The EIA also includes a description of the measures taken to avoid, reduce or remedy these effects.

12.2 Overview of Environmental Impact:

The US Environmental Protection Agency pioneered the use of pathway analysis to determine the likely human health impact of environmental factors. The technology for performing such analysis is properly called as environmental science. The principal phenomenon or pathways of impact are:

- Noise and health effects.
- Water pollution impacts.
- Ecology impacts including endangered species assessment.
- Air pollution impacts.
- Soil contamination impacts.
- Geological hazards assessment.

12.3 Objectives of Environmental Assessment:

- Ensuring environmental factors are considered in the decision making process.
- Ensuring that possible adverse environmental impacts are identified and avoided or minimized. Informing the public about the proposal.

12.4 Advantages of Environmental Assessment:

- Allows people to examine the underlying need for a project.
- Gives people the opportunity to identify problems.
- Helps a developer to design a more publicly acceptable project.

12.5 Environmental Sustainability:

The impact that the microalgal biodiesel production process has on the environment during its entire life cycle decides its environmental sustainability. Starting from the choice of the cultivation area to use of nutrients for growth and lipid accumulation enhancement, to use of different energy intensive harvesting techniques followed by extraction of lipids using different extracting solvents and then conversion of the extracted lipid to biodiesel, all contribute toward the environmental sustainability of the product. This sustainability index can be verified by the use of certain indicators such as GHG emissions, energy security, water management, soil and resource depletion, local pollution, etc. Tools such as Life Cycle Impact Assessment (LCIA) are used for measuring these indicators. Global warming due to increasing concentrations of greenhouse gases in the atmosphere is a daunting environmental challenge in today's world. Of the different greenhouse gases present, CO_2 is majorly responsible for this problem. CO_2 is naturally present in the atmosphere, but activities such as burning of forests, mining and burning coal increase their concentrations to dangerous levels in the atmosphere by converting the carbon stored in the solid state to gaseous state. Microalgae are widely known for being potential sequesters of large amounts of CO_2 from the atmosphere thus lowering GHG emissions relative to petroleum diesel. Additionally, their ability to recycle the released CO_2 from the different stages of the microalgal biodiesel process within their own system, categorizes them as an environmentally sustainable resource. Many researchers have reported that algal biodiesel has the ability to reduce the GHG emissions by half (55,400 g of CO_2 equivalent per million BTU) as compared to what is emitted by low sulfur diesel fuel (101,000 g of CO_2 equivalent per million BTU) The OECD Environmental Outlook 2050 at the 2011 United Nations Climate Change Conference, suggesting achieving CO_2 concentration targets at lower than 450 ppm by the Bioenergy for Carbon Capture and Storage Technology (BECCS). Microalgae are environmentally sustainable resources emitting greenhouse gases during biodiesel production in quantities lower than that emitted during petroleum diesel production. GHG emissions from microalgal biodiesel production systems lesser than 90 g CO_2 eq/MJ of fuel, recorded for petroleum diesel. EROI fossil and GHG emissions are indirectly proportional to each other with an increase in the value of one parameter bringing about a decrease in the other and vice versa. Hence strategies to reduce the GHG emissions from the microalgal biodiesel production process eventually raise the EROI fossil values, thus producing an environmentally sustainable biofuel. EROI is not an absolute indicator of sustainability, but it does help to indicate where a particular source fits in with regional, national and global energy markets. In that context, a competitive EROI for algae biodiesel provides support for a national energy policy that replaces petroleum. By-products from biofuel production such as proteins for animal feed make a positive contribution to climate change mitigation because they save energy and greenhouse gas emissions that would otherwise have been needed to produce the feed by other means. since the turn of the century, there has been a push towards cleaner-burning transportation fuels with fewer negative effects on the environment. Although algae fuel does not currently occupy a large space in the fuel market, the market for algae fuel is expected to increase from $6.8 billion (b) to $11.4 b by the year 2027. To understand the total carbon footprint of algae fuel, we must assess its life-cycle and each stage's carbon footprint. This life cycle assessment (LCA) is a method to evaluate the environmental impacts of products and materials. Over the years, companies have strategically used LCA to research and create more sustainable products. So, let's have a look at the LCA of algae fuel.

Table 12.1: Carbon Footprint for Algae Fuel

The Life Cycle Stages of Algae Fuel	Each Stage's Carbon Footprint
Building of algae fuel farm	CO_2 emissions from building the components of the algal farm.
Extracting of algae fuel	CO_2 emissions from either the transesterification or fermentation process.
Transportation of algae fuel	CO_2 emissions from transporting algae fuel by barges, tankers, pipelines, trucks, and railroads across distances.
Building back of algae fuel farm	CO_2 emissions from utilizing construction equipment to demolish the algal farm systems and construct new infrastructure in the old system's place.

The total carbon footprint of algae fuel would equal the carbon footprint from building + the carbon footprint from extracting + the carbon footprint from transportation + the carbon footprint from building back.

12.6 3 R’s Scheme:

Algae have a reduced impact on the environment compared with terrestrial sources of biomass used for biofuels. They can be grown on land that would not be used for traditional agricultural, and are very efficient at removing nutrients from water. The key to algae's potential as a renewable fuel source lies in the way they store energy. That's because some strains of algae store energy in the form of natural oils. Extract that oil and you have the raw material to make fuel for cars, trucks, trains, and planes. It’s an environmentally friendly. It can grow in any climate, as long as there is enough sunlight, meaning that it can be grown in areas that are inefficient for other agriculture. Algae biofuel is also virtually harmless to the environment. Final selling cost is $2/L. Furthermore, it is significant to consider a biorefinery strategy for valorizing the residual biomass into high-value compounds and to maximize the use of resources leading to a different product-market portfolio. Our FYDP topic mainly focused on it because our selection of topic before the proposal based on these points. Main points related to these 3R’s are written in below table:

Table 12.2: 3R’s Scheme

Points	Explanation
Reduce	One approach for reducing the costs of producing fuels from algae. Other approach is to reduce CO_2 emissions from algae fuel.
Recycle	In our plant, after transesterification there is algae oil that is still left. So, we recycle it again into the reactor for continuous reaction. Also, we use methanol and hexane as a solvent into the extractor, so after recover it by distillation unit we recycle these two chemicals into extractor.
Re-use	By recycling, we reuse that materials. And from extractor and filter press, we obtained algae waste which is not dumped into the environment, we stored that algae waste into storage tank and sold it because these wastes also use in many applications.

CHAPTER # 13

DESIGN OF AN EXTRACTOR ON LAB SCALE

CHAPTER # 13

DESIGN OF AN EXTRACTOR ON LAB SCALE

13.1 Introduction:

Liquid liquid extraction (LLE), also known as solvent extraction and partitioning, is a method to separate compounds or metal complexes, based on their relative solubilities in two different immiscible liquids, usually water (polar) and an organic solvent (non-polar). According to the actual needs of the majority of biopharmaceutical development companies, the glass dispenser is an improved by-product developed on the basis of the existing single-layer glass reactor. It is mainly used for liquid-liquid extraction and can also be used for reactions at room temperature. The glass separator (extraction separator) is used to mix various materials for chemical or physical reaction, and then separate and extract the newly generated materials according to the different specific gravity. This equipment can provide a fast and uniform reaction/collection effect under vacuum. According to the needs of use, this machine can also be used as a separate liquid separator or a conventional reactor.

13.2 Representation of Prototype Design of an Extractor:

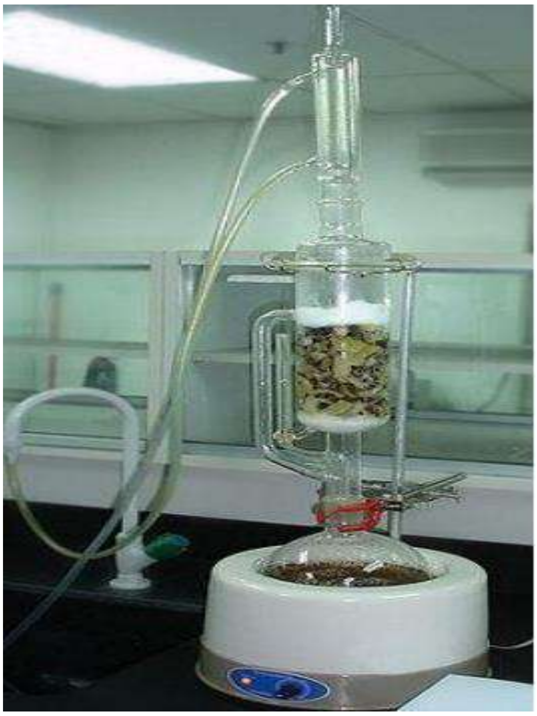


Figure 13.1: Prototype Design of an Extractor

13.2 Principle of Extractor:

The extraction method uses a small amount of solvent and is very cost-effective. The extraction uses the solvent reflux and siphon principle to continuously extract the solid matter by pure solvent, which saves the solvent extraction efficiency and high efficiency. The sold sample is placed on a thimble-shaped filter paper, positioned into the extractor, and the device is assembled. The solvent is added to the solvent reservoir flask and mounted onto a heating mantle. After heating, the condensed vapors of the solvent come in contact with the sample powder, and the soluble part of the powder gets mixed with the solvent for extraction. When the solvent surface exceeds the maximum height of the siphon, the solvent containing the extract is siphoned back. The flask is repeated, extracting a portion of the material each time so that the solid material is constantly used as a pure solvent and the extracted material is concentrated in the flask

13.3 Operation Related to Extractor:

The apparatus shown in figure 13.2, and the middle third of the device is the actual extractor.

- In practice, the solid sample is placed into a porous (typically cellulose) extraction thimble, positioned into the extractor, and the device is assembled.
- Solvent is added to the solvent reservoir flask, and mounted onto a heating mantle. As it boils, the solvent vapors rise through the solvent vapor tube side arm.
- As the solvent vapors hit the condenser (cooled with running water or other circulating fluid), the now liquid solvent flows down onto the sample, where it may permeate into the sample matrix and dissolve the target analytes.
- When the liquid solvent level reaches the top of the siphon tube, the solvent–solute mixture (the extract), is syphoned away from the extractor, and back into the solvent flask.
- This is one extraction cycle. The solvent re-evaporates (boils), and the solutes concentrate as they are left behind in the solvent flask.

This method is restricted to use by or under the supervision of trained analysts. Each analyst must demonstrate the ability to generate acceptable results with this method by performing an initial demonstration of capability and completing the record of training. After initial demonstration, ongoing demonstration is based on acceptable laboratory performance of at least a quarterly laboratory control sample or acceptable performance from an annual proficiency test sample. A major modification to this procedure requires demonstration of performance.

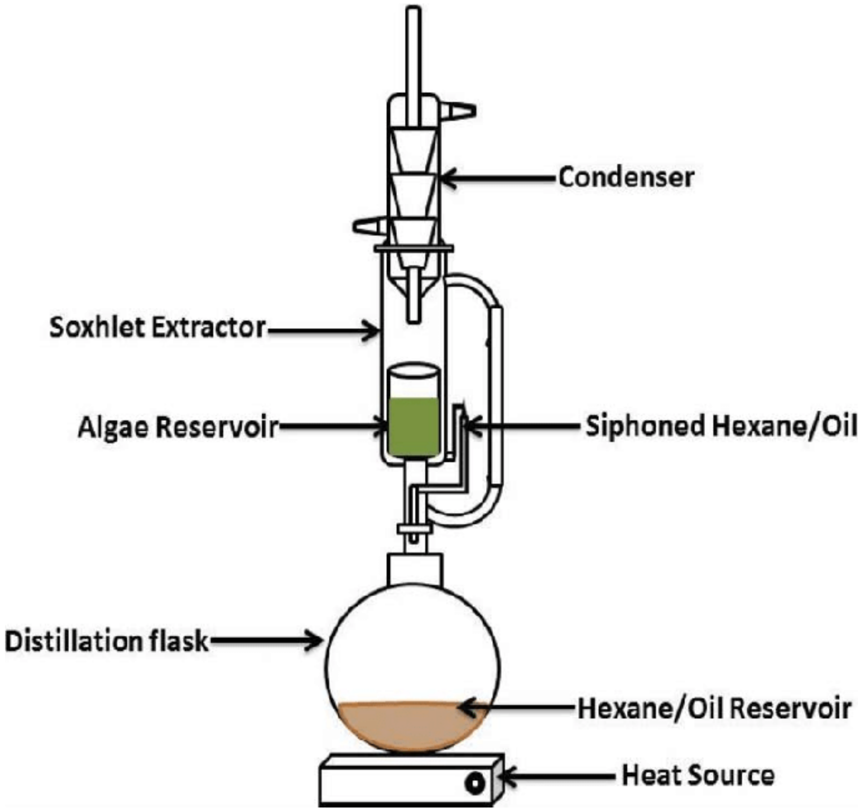


Figure 13.2: Systematic Diagram of an Extractor

13.4 Interferences of Extractor:

- The most common cause of contamination is from improperly cleaned glassware and lab supplies. All glassware and re-useable extraction equipment (i.e. spatulas) must be scrupulously cleaned, following the glassware cleaning SOP.
- Impurities in solvents and reagents may also yield artifact and/or interferences that may compromise the results of sample analysis. All of these materials must be demonstrated to free from interferences under the conditions of extract preparation and analysis by preparing method blanks with each extraction batch. The same solvents and reagents are used for the method blank and the associated samples.
- Phthalate esters contaminate many types of products used in the laboratory. Plastic materials must not contact the samples or extracts, as phthalates could be easily leached from the plastic. Additional specific interference or contamination concerns are addressed in the various analytical SOPs.

13.5 Health and Safety:

The toxicity or carcinogenicity of each reagent and standard used in this method is not fully established; however, each chemical compound should be treated as a potential health hazard.

From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. All personnel handling environmental samples known to contain or to have been in contact with municipal waste must follow safety practices for handling known disease causative agents.

- Lab coats, safety glasses, and gloves must be worn when handling samples, extracts, standards or solvents and when washing glassware.
- All extract concentration steps must be performed in the extraction hoods. All solvent and extract transfers must also be handled in the hood.
- All expired stock standards, working standards, and spent sample extracts must be placed into the waste bucket in the lab, for future disposal by the Hazardous Waste Manager. The container must be properly labelled with hazard warning labels indicating the container contents.
- Bottles containing flammable solvents must be stored in the flammable's cabinet or in the vented cabinets found under the hoods.
- All waste solvents must be transferred to the satellite waste storage containers located in the extraction lab. Separate containers are provided for chlorinated and non-chlorinated solvents and must be used accordingly. Under no circumstances are solvents to be poured down the sink drains. Inspect all glassware prior to use. Do not use any glassware that is chipped, cracked or etched if it could present a safety hazard. Damaged glassware is put aside for repair, otherwise discard the piece.

13.6 Instrument Maintenance:

13.6 .1 Refrigeration Re-circulator:

- The Refrigeration re-circulator should be checked periodically to ensure that it is running correctly and that the level of reagent water is constant with manufactures recommendation. The re-circulator tubing should be inspected for leaks, cracks, and crimps prior to each use.

13.6.2 Water Bath:

- The water bath should be kept full at all times. Add reagent water as necessary.
- Keep unit clean. Avoid solvent spills on or around unit. Clean periodically with a damp cloth.

13.6.3 Analytical Balance:

- All balances are calibrated and serviced every six months by an instrument service company. All service records are kept on file.
- Keep balances clean. Brush off any sample spills immediately. Keep the balance doors closed and the balance turned off when not in use.

13.6.4 Soxhlet Solvent Cycle Rate:

- Check quarterly check on heating mantels to insure proper cycling of solvent throughout the Soxhlet apparatus.

13.7 Experiment Perform for Optimization and Review the Performance of Solvent Extractor:

Compared to various biomasses available, the algae seem to have a higher level of photosynthetic effect. They can be grown in large quantities effectively in a controlled environmental condition. Some of the algae species contain high lipid content, and around 15,000 gallons of oil for one acre of land for one complete year can be produced from such a source globally extracted oil from the algae species. Cladophora glomerate using various solvents like n-hexane, toluene, chloroform, methanol, isopropanol, and co-solvent mixtures of chloroform/methanol, hexane/isopropanol and they found that the oil yield for hexane was highest compared to other types of solvents. For hexane, the oil production was around 11.7 w/wt% for 100 g of the biomass at an extraction temperature of 65°C and extraction time of 3.5 hours, used n-hexane as a solvent to extract oil from the algae species Chlorococcum. They found that with four grams of Chlorococcum sp. and 300 ml of hexane in a Soxhlet apparatus for an extraction time of 7.5 hours; the oil yield was around 5.5 w/wt%.

13.7.1 Materials and Methodology:

Materials:

The algae spirogyra species algae were cultivated in a water tank. Then, the collected algae were sun-dried and ground to a fine powder using a mechanical grinder. The algae were harvested with the help of a round metal mesh of a grid size of 1 mm. From 30-micron mesh, the powder obtained had an average size of 0.366 μm. Similarly, from a 40-micron mesh, the average powder size was 0.462 μm, and from a 60 micron mesh, the average powder size obtained was 0.641 μm. The n-hexane used for the experiments was purchased from the local dealer, and it specifies to the standard.

Methodology:

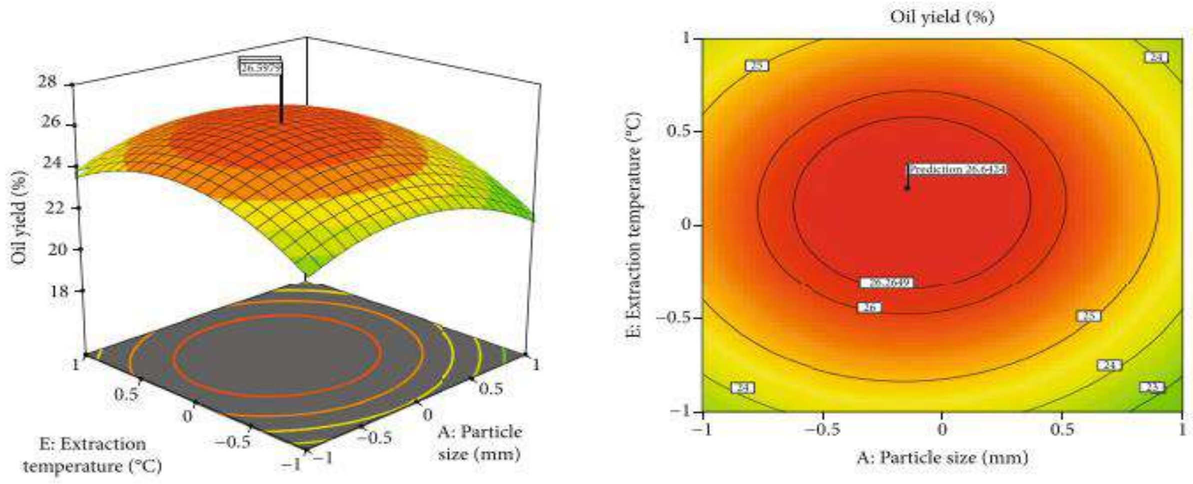
The Soxhlet apparatus was loaded with the algae powder in the thimble fitted with the filter paper. The round bottom flask was filled with n-hexane in the quantity of 750 ml, and the process was carried out as per the experimental design [27]. At the completion of each experiment, the oil was extracted from the oil-solvent mixture through the distillation process by heating them to a temperature of 75 ° C (boiling range of n-hexane).

13.7.2 Experimental Design and Response Surface Methodology Modelling:

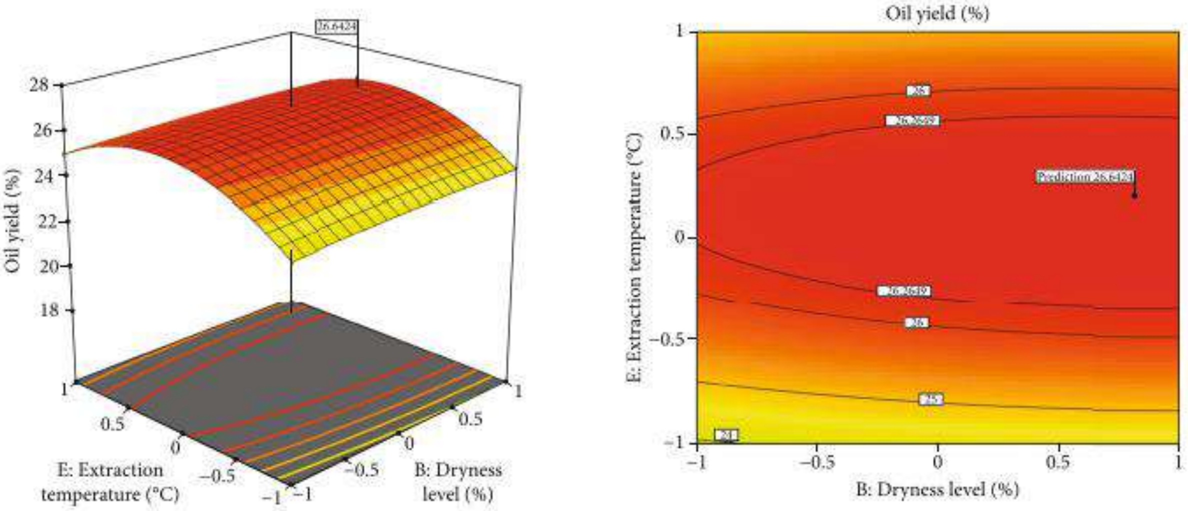
The response surface methodology (RSM) is defining the collaboration between the independent variables, modelling the system under design mathematically, and it saves time and cost by reducing the number of trials. With these advantages of RSM, a central composite design (CCD) factorial design with five input parameters and a second-order polynomial equation was employed to represent the oil yield (output parameter). The solid to solvent ratio, reaction temperature, reaction time, the powder’s particle size, and the algae powder’s dryness level were considered the input parameters for the modelling. The reason for selecting the input parameter for the optimization process is purely based on the factors influencing the extraction of the oil content from the algae. The factors which majorly influencing the oil extraction was found to be solid to solvent ratio, reaction temperature, reaction time, particle size of the powder, and the dryness level of the algae powder. The level codes are given as −1 low, 0 middle, and +1 upper. For RSM modelling, a second-order polynomial was chosen as given in the following equation:

$$Y = \beta_0 + \beta_1\theta_1 + \beta_2\theta_2 + \beta_3\theta_3 + \beta_4\theta_4 + \beta_5\theta_5 + \beta_{12}\theta_1\theta_2 + \beta_{13}\theta_1\theta_3 + \beta_{14}\theta_1\theta_4 + \beta_{15}\theta_1\theta_5 + \beta_{23}\theta_2\theta_3 + \beta_{24}\theta_2\theta_4 + \beta_{25}\theta_2\theta_5 + \beta_{34}\theta_3\theta_4 + \beta_{35}\theta_3\theta_5 + \beta_{45}\theta_4\theta_5 + \beta_{11}\theta_{12} + \beta_{22}\theta_{22} + \beta_{33}\theta_{32} + \beta_{44}\theta_{42} + \beta_{55}\theta_{52} \ldots\ldots\ldots\ldots (13.1)$$

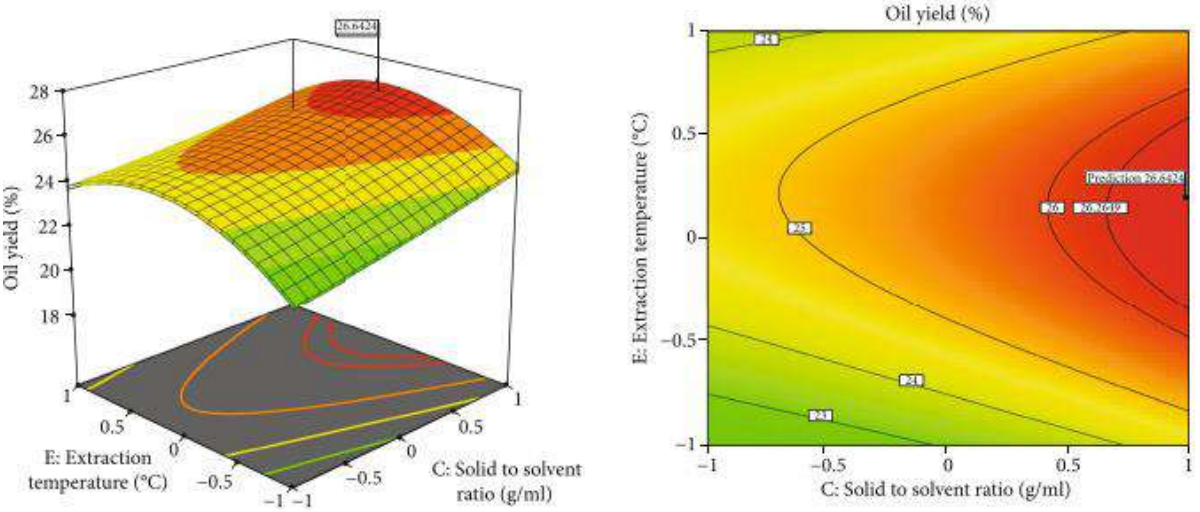
where Y represents the output variable (i.e., oil yield) and θ_1 to θ_5 represents the design factors. β_0 denotes the regression coefficient, and β_1 to β_{55} denotes the linear, interactive, and quadratic regression coefficients, respectively. According to the CCD factorial design, the number of experimental runs was found to be 50. All the experiments were carried out, and the coefficients of the second order polynomial equation were fitted through regression analysis.


26.5979
Oil yield (%)
28
26
24
22
20
18
E: Extraction temperature (°C)
A: Particle size (mm)
1
0.5
0
−0.5
−1
Oil yield (%)
Prediction 26.6424
26.2649
26
25
24
23
E: Extraction temperature (°C)
A: Particle size (mm)

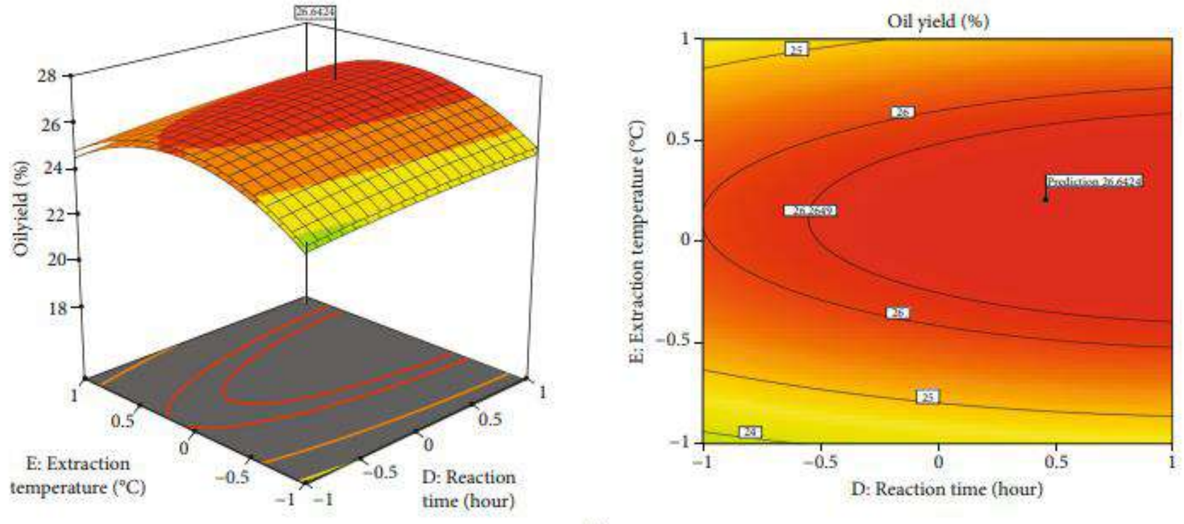
(a)


26.6424
Oil yield (%)
28
26
24
22
20
18
E: Extraction temperature (°C)
B: Dryness level (%)
1
0.5
0
−0.5
−1
Oil yield (%)
26
26.2649
Prediction 26.6424
25
24
E: Extraction temperature (°C)
B: Dryness level (%)

(b)


26.6424
Oil yield (%)
28
26
24
22
20
18
E: Extraction temperature (°C)
C: Solid to solvent ratio (g/ml)
1
0.5
0
−0.5
−1
Oil yield (%)
24
Prediction 26.6424
26
26.2649
25
23
E: Extraction temperature (°C)
C: Solid to solvent ratio (g/ml)

(c)



(d)

Figure 13.3: (a, b, c, d) 3D Surface Plot and Contour Plot of the Effect of Oil Yield % with the Design Factors.

13.7.3 Artificial Neural Network Modelling:

The artificial neural network (ANN) model can learn by itself with a limited set of input data and has high accuracy in predicting the output data. Also, the input data are stored in their database and have not been considered a separate data set, which is another benefit. This nature of ANN helps avoid the loss of data that does not work effectively in the model. Hence, based on these advantages, an ANN model was created using MATLAB R2009 a version with neural network toolbox. The experimental data were normalized to avoid surfeiting the data set due to low to high variations. This normalization enhances the training of the prediction model. Where α_{actual}, α_{min}, and α_{max} are the experimental data's actual, minimum and maximum values. The standardization process produces data from – 1 to +1. The performance of the ANN model relies on the number of the input layer, the number of neurons in the hidden layer and the number of output layers with different transfer functions and training algorithms. The ANN model was trained using different training algorithms, and the model with the best coefficient of determination (R_2) and mean square error (MSE) was selected as the best prediction model.

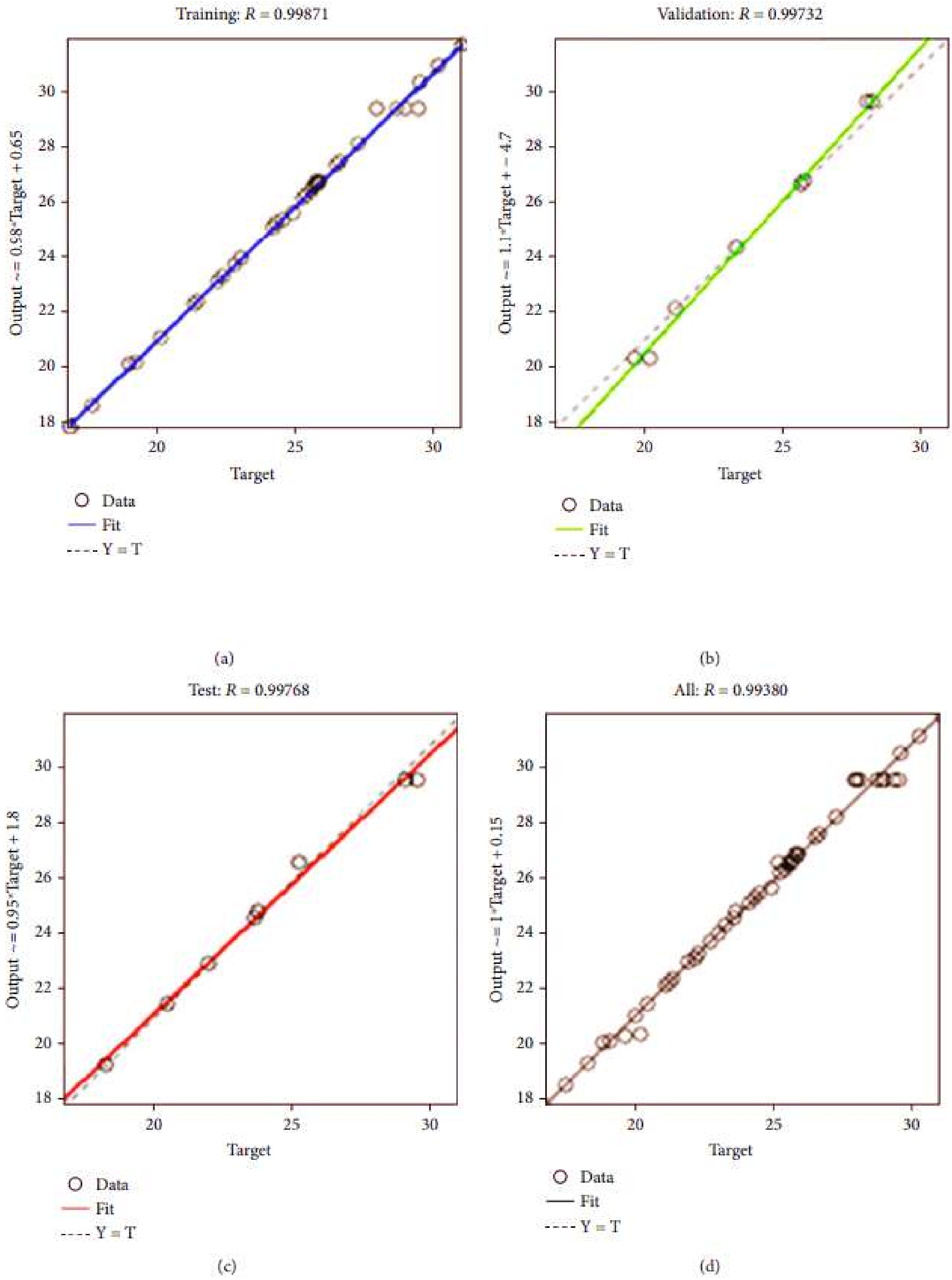


Figure 13.4: (a) Training Data (b) Validation Data (c) Test Data (d) Relation Between Predicted and Experimental Data Set of the Optimal ANN Model.

13.8: Results and Discussion of Modelling:

The experimental design based on CCD for full factorial was created, and the 50 sets of experiments were carried out. The optimal process parameters were found using the regression equation (RSM). On solving this equation, for an optimal oil yield of 26.62%, the optimal parameters were found to be 0.336 μm of particle size, 98.2% of dryness level, 1: 14.9 solid to solvent ratio, 1.75 hours of reaction time, and 70.98 ° C of extraction temperature. The ANN model built for this present study was investigated by considering three layers (x = 1) of input factors of feed-forward type, the hidden layer withstanding transfer function with neurons ranging from y = 5 to 20 and the output layer of z = 1 for various training algorithms like Traingda, Traingdm, Traingdx, Trainlm, Trainrp, and Trainseg. The experimental data set was segregated into 70% of data for training remaining 30% of data for testing and validation. The precision and accuracy of the developed RSM and ANN models were evaluated by calculating the performance parameters like R^2, adj R^2. The R_2 value for the RSM and ANN model seems to be nearby, making both the models better for optimizing the oil yield parameters. But the MAPD for RSM is higher than the ANN, which makes the ANN model reliable and consistent. It can be seen that the predicted values of the ANN model were very close to the experimental value when compared to the RSM predicted values. The capability of the ANN model for nonlinear data evaluation is more precise than the second-order polynomial model of RSM. Hence, the ANN model efficacy is better than the RSM model for optimization and modelling.

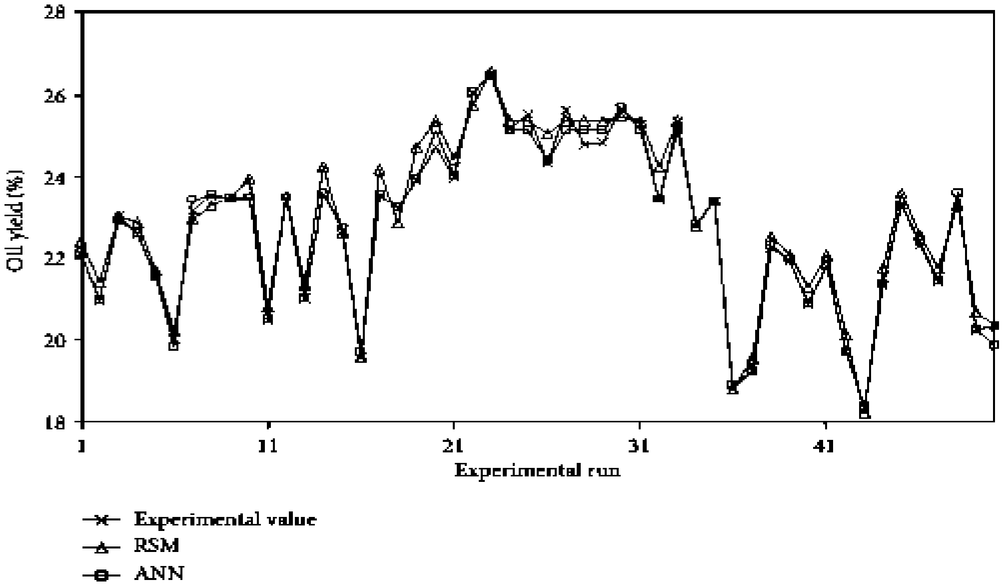


Figure 13.5: Comparison of Experimental, Predicted Values of RSM and ANN.

13.9 Applications of Extractor:

The extraction process is the most useful technique for solid liquid extraction in many fields like Agriculture, pharmaceuticals, foodstuffs, and also in the environment. This apparatus is allowed for continuous treatment of a sample with a solvent over a period of hours or days to extract the compound of interest. This technique is useful to determine the lipid and fat contents of animal and plant tissue. This is also used to determine the percent of fat content in a food sample by weight in a sample.

13.10 Specification Sheet of Extractor:

Table 13.1: Solvent Extractor Specification Sheet

Boiling Flask	
Capacity	60 mm
Bottom ground	19/26
Extraction Tube	
Area	30 mm
Height	60 mm
Bottom ground	34/35
Condenser	
Length	200 mm
Bottom ground	34/35
Q (ty/ctn)	12
Heating Mantle	
Heating element	Nichrome heating element
Temperature controller	Individual energy regulator
Heating surface	Fiber glass net
Optional	PID temperature controller

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APPENDICES

APPENDIX A

Heat Exchangers

Figures:

Tables:

Figures:

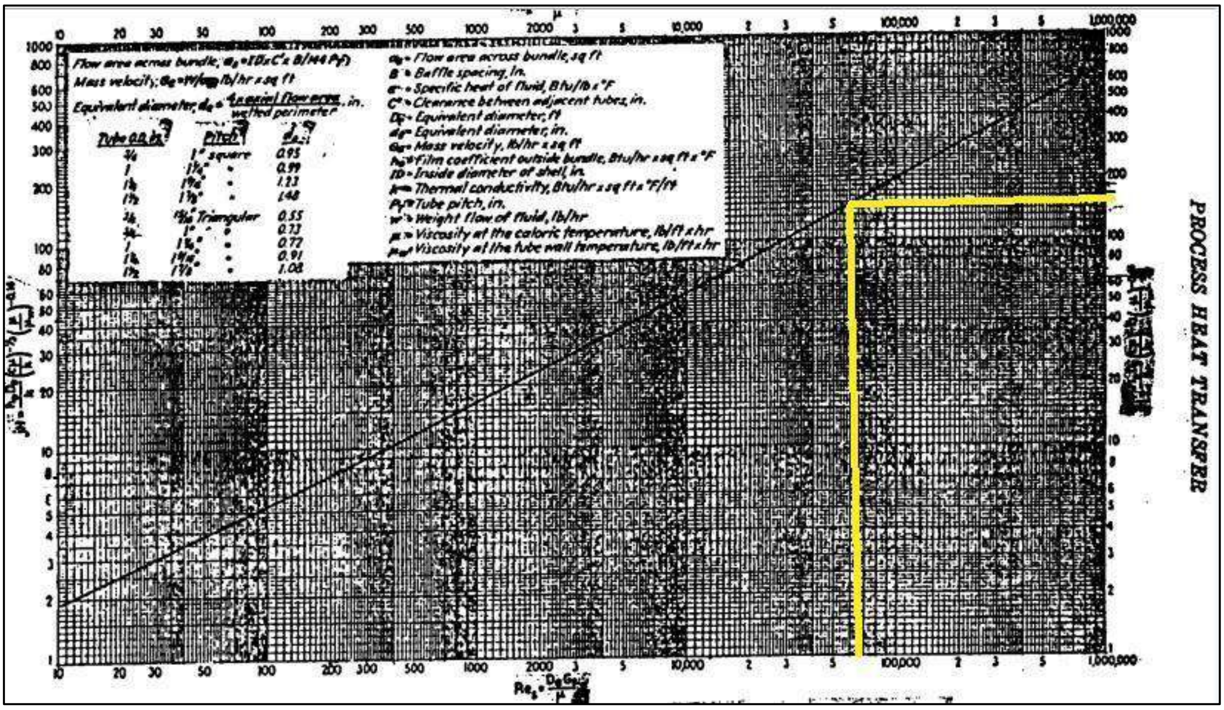


Figure A- 1: JH Factor

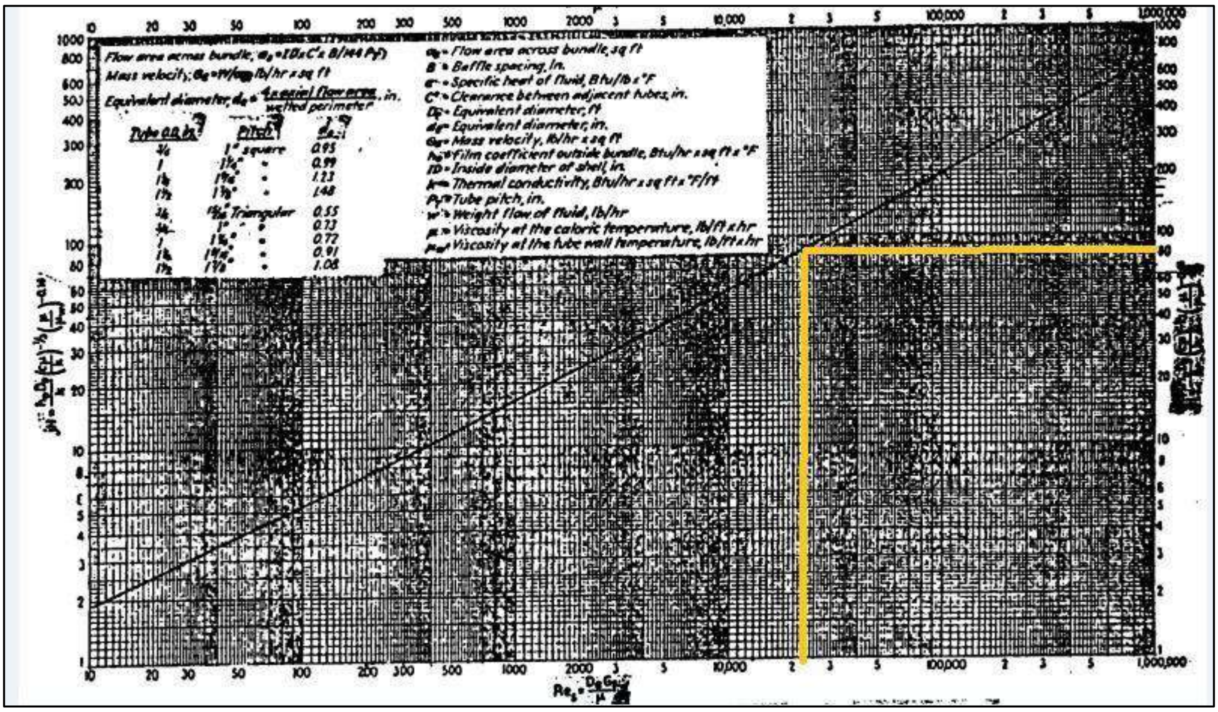


Figure A- 2: JH Factor

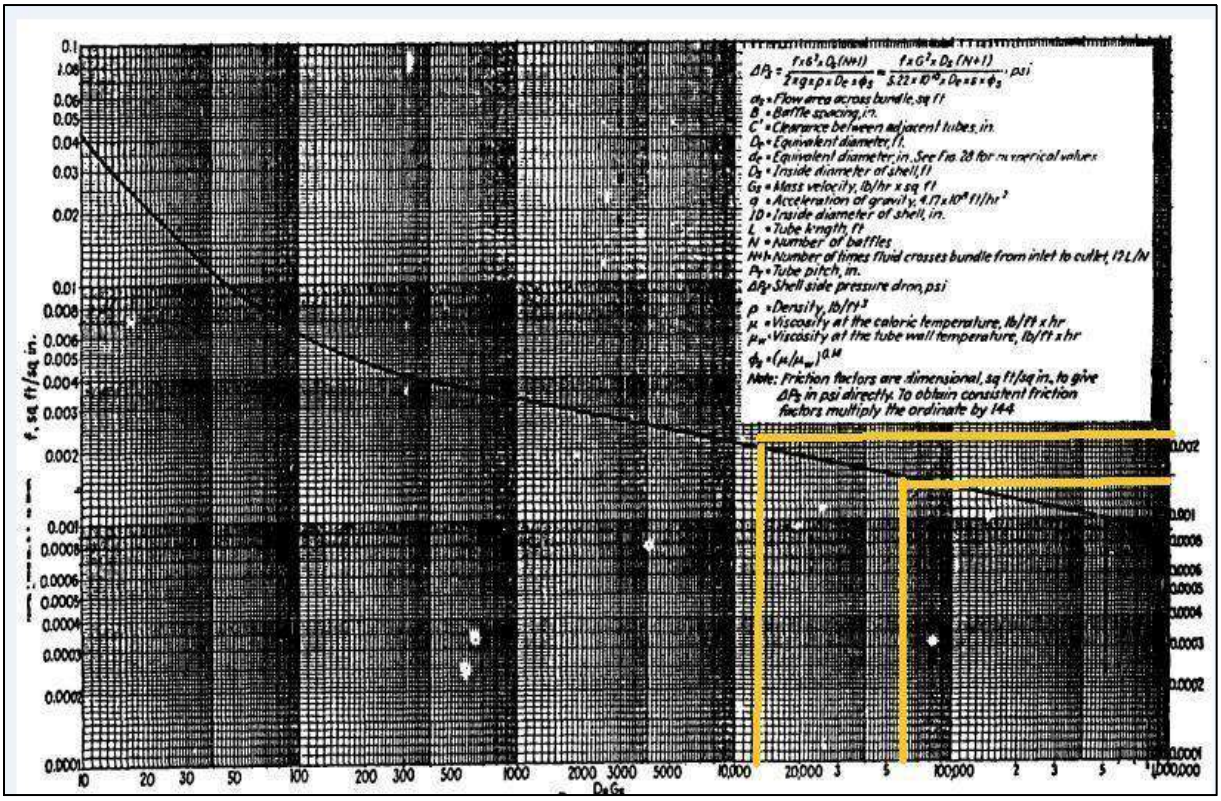
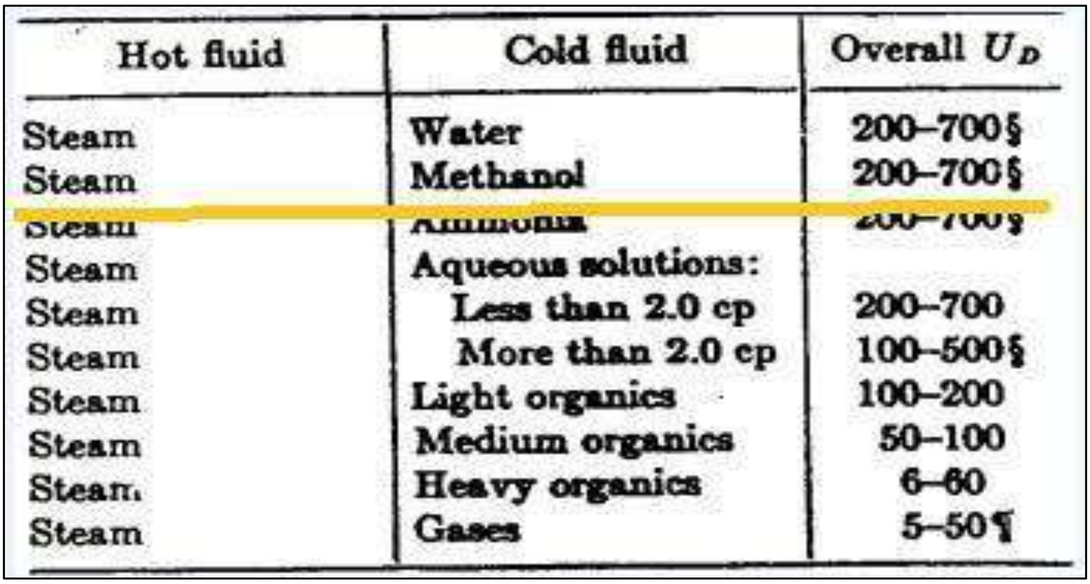


Figure A- 3: Reynolds Number

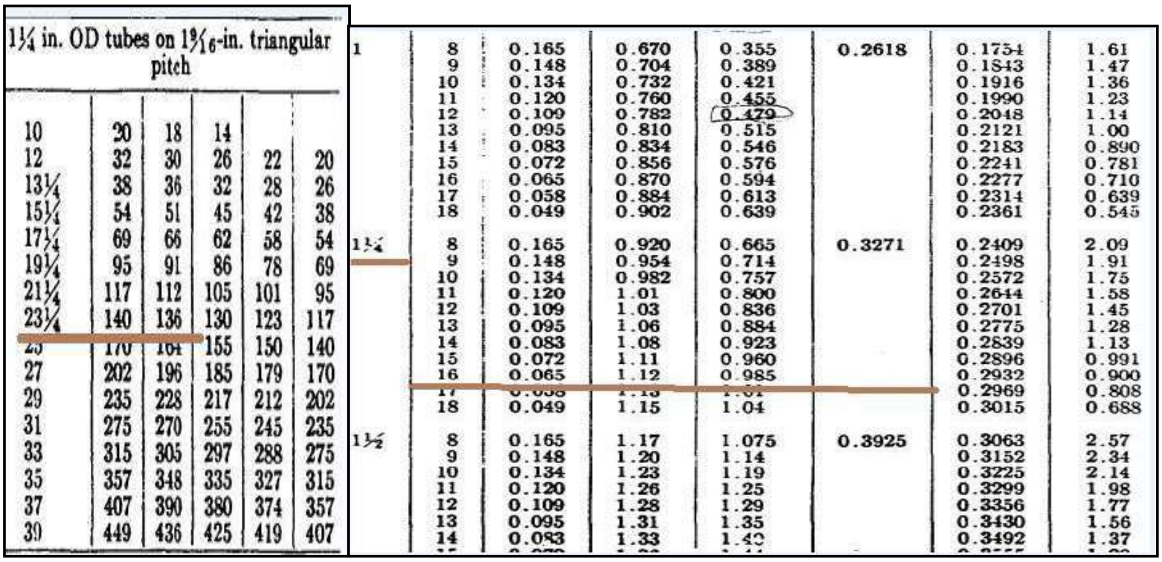
Table:

Table A-1: Design Coefficient



Hot fluid	Cold fluid	Overall U_D
Steam	Water	200–700§
Steam	Methanol	200–700§
Steam	Ammonia	200–700§
Steam	Aqueous solutions:	
Steam	Less than 2.0 cp	200–700
Steam	More than 2.0 cp	100–500§
Steam	Light organics	100–200
Steam	Medium organics	50–100
Steam	Heavy organics	6–60
Steam	Gases	5–50¶

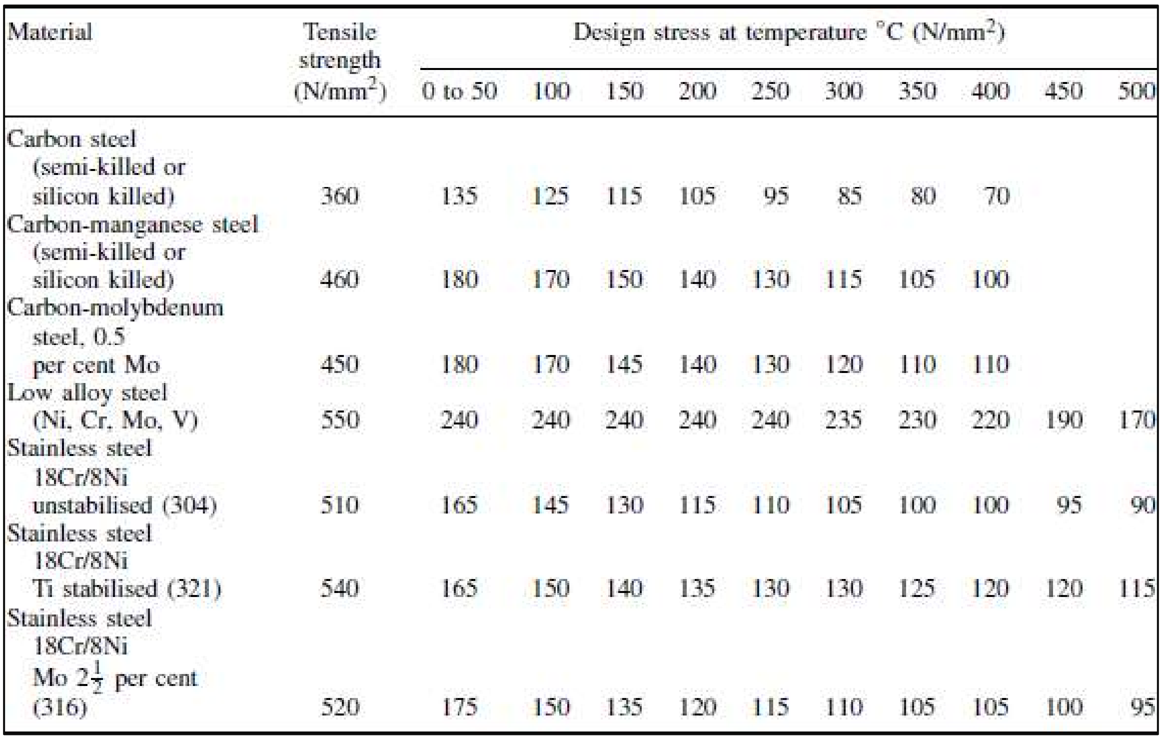
Table A-2: OD of Tubes in Triangular Pitch



1¼ in. OD tubes on 1 9/16-in. triangular pitch					
10	20	18	14		
12	32	30	26	22	20
13¼	38	36	32	28	26
15¼	54	51	45	42	38
17¼	69	66	62	58	54
19¼	95	91	86	78	69
21¼	117	112	105	101	95
23¼	140	136	130	123	117
25	170	164	155	150	140
27	202	196	185	179	170
29	235	228	217	212	202
31	275	270	255	245	235
33	315	305	297	288	275
35	357	348	335	327	315
37	407	390	380	374	357
39	449	436	425	419	407

1	8	0.165	0.670	0.355	0.2618	0.1754	1.61
	9	0.148	0.704	0.389		0.1843	1.47
	10	0.134	0.732	0.421		0.1916	1.36
	11	0.120	0.760	0.455		0.1990	1.23
	12	0.109	0.782	0.479		0.2048	1.14
	13	0.095	0.810	0.515		0.2121	1.00
	14	0.083	0.834	0.546		0.2183	0.890
	15	0.072	0.856	0.576		0.2241	0.781
	16	0.065	0.870	0.594		0.2277	0.710
	17	0.058	0.884	0.613		0.2314	0.639
	18	0.049	0.902	0.639		0.2361	0.545
1¼	8	0.165	0.920	0.665	0.3271	0.2409	2.09
	9	0.148	0.954	0.714		0.2498	1.91
	10	0.134	0.982	0.757		0.2572	1.75
	11	0.120	1.01	0.800		0.2644	1.58
	12	0.109	1.03	0.836		0.2701	1.45
	13	0.095	1.06	0.884		0.2775	1.28
	14	0.083	1.08	0.923		0.2839	1.13
	15	0.072	1.11	0.960		0.2896	0.991
	16	0.065	1.12	0.985		0.2932	0.900
	17	0.058	1.13	1.01		0.2969	0.808
	18	0.049	1.15	1.04		0.3015	0.688
1½	8	0.165	1.17	1.075	0.3925	0.3063	2.57
	9	0.148	1.20	1.14		0.3152	2.34
	10	0.134	1.23	1.19		0.3225	2.14
	11	0.120	1.26	1.25		0.3299	1.98
	12	0.109	1.28	1.29		0.3356	1.77
	13	0.095	1.31	1.35		0.3430	1.56
	14	0.083	1.33	1.40		0.3492	1.37

Table A.3: Design Stresses



Material	Tensile strength (N/mm^2)	Design stress at temperature °C (N/mm^2)									
		0 to 50	100	150	200	250	300	350	400	450	500
Carbon steel (semi-killed or silicon killed)	360	135	125	115	105	95	85	80	70		
Carbon-manganese steel (semi-killed or silicon killed)	460	180	170	150	140	130	115	105	100		
Carbon-molybdenum steel, 0.5 per cent Mo	450	180	170	145	140	130	120	110	110		
Low alloy steel (Ni, Cr, Mo, V)	550	240	240	240	240	240	235	230	220	190	170
Stainless steel 18Cr/8Ni unstabilised (304)	510	165	145	130	115	110	105	100	100	95	90
Stainless steel 18Cr/8Ni Ti stabilised (321)	540	165	150	140	135	130	130	125	120	120	115
Stainless steel 18Cr/8Ni Mo $2\frac{1}{2}$ per cent (316)	520	175	150	135	120	115	110	105	105	100	95

APPENDIX B

Pumps

Figures:

Figure B.1: Pump Selection Chart

Tables:

Table B.1: Location of Process Equipment

Table B.2: Pressure Drop Process Equipment

Table B.3: Pump Characteristics

Table B.4: Characteristics of Compressor and Pump Drivers

Table B.5: Standard Electric Motor Sizes

Figures:

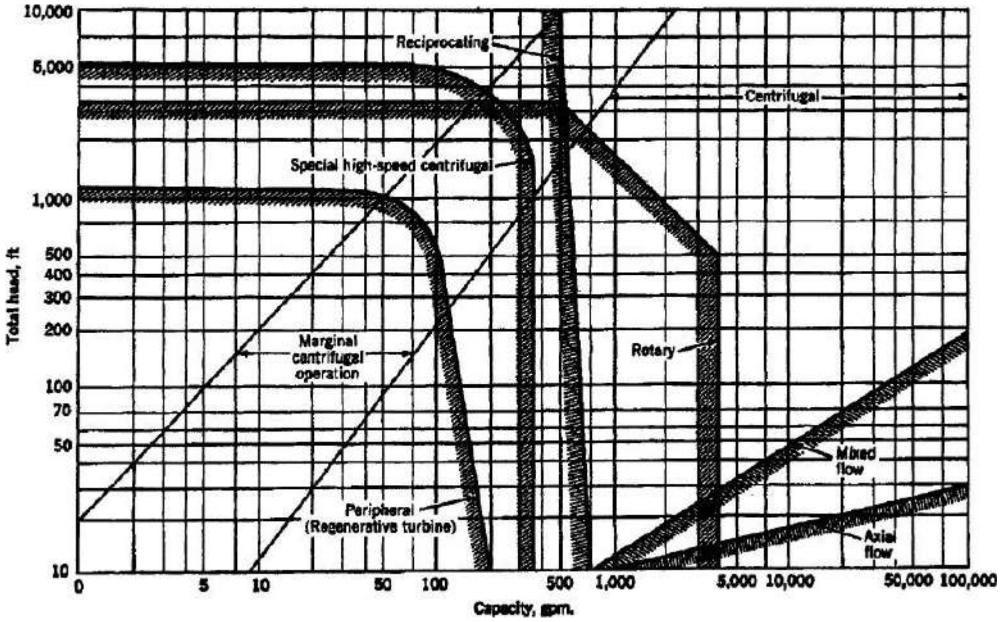
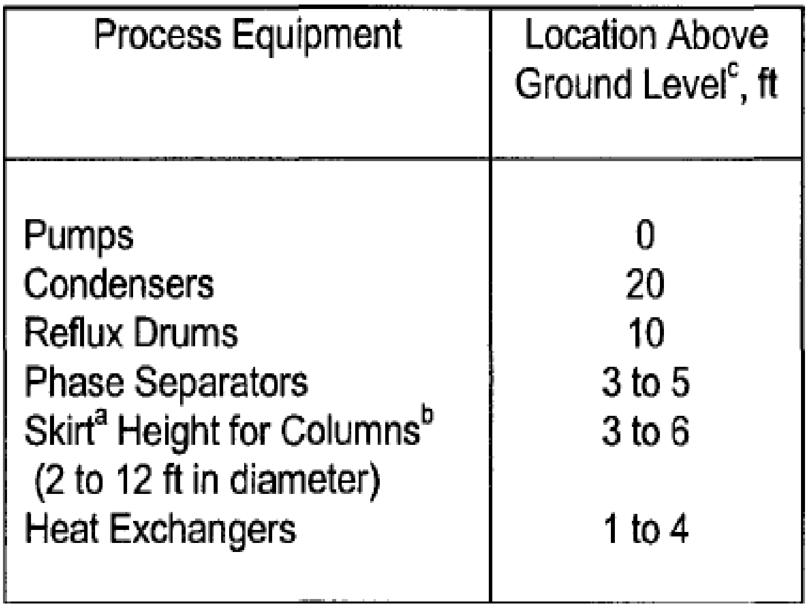


Figure B.1: Pump Selection Chart

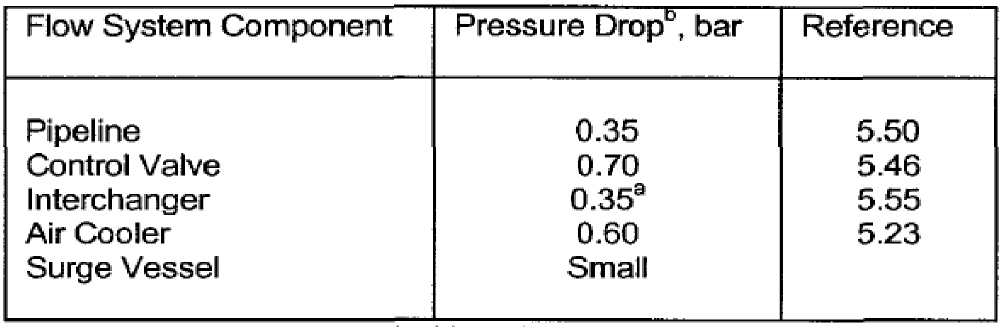
Tables:

Table B.1: Location of Process Equipment



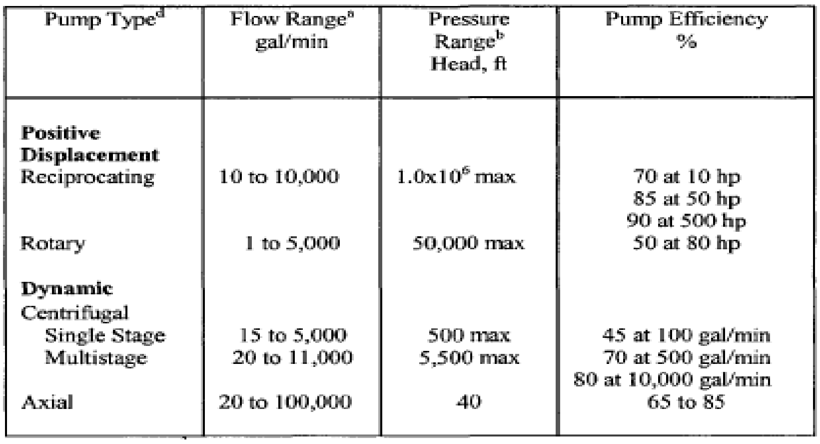
Process Equipment	Location Above Ground Level[c], ft
Pumps	0
Condensers	20
Reflux Drums	10
Phase Separators	3 to 5
Skirt[a] Height for Columns[b] (2 to 12 ft in diameter)	3 to 6
Heat Exchangers	1 to 4

Table B.2: Pressure Drop Process Equipment



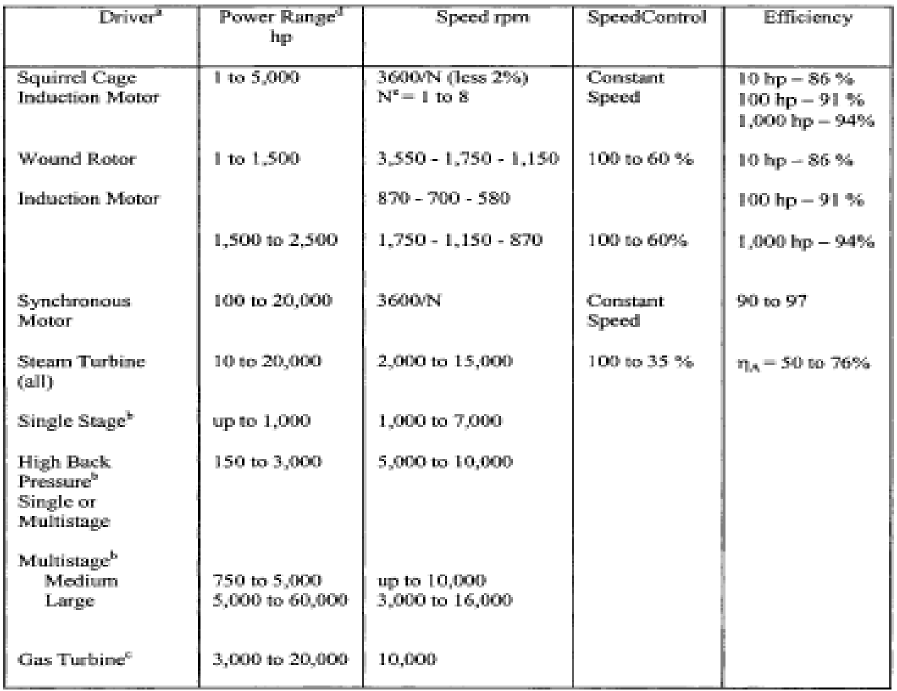
Flow System Component	Pressure Drop^b, bar	Reference
Pipeline	0.35	5.50
Control Valve	0.70	5.46
Interchanger	0.35^a	5.55
Air Cooler	0.60	5.23
Surge Vessel	Small	

Table B.3: Pump Characteristics



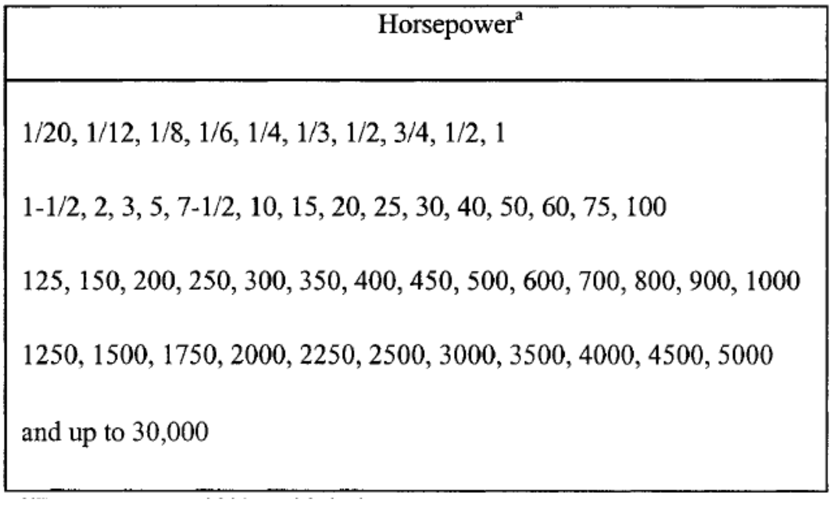
Pump Type^d	Flow Range^a gal/min	Pressure Range^b Head, ft	Pump Efficiency %
Positive Displacement			
Reciprocating	10 to 10,000	1.0×10^6 max	70 at 10 hp 85 at 50 hp 90 at 500 hp
Rotary	1 to 5,000	50,000 max	50 at 80 hp
Dynamic			
Centrifugal			
Single Stage	15 to 5,000	500 max	45 at 100 gal/min
Multistage	20 to 11,000	5,500 max	70 at 500 gal/min 80 at 10,000 gal/min
Axial	20 to 100,000	40	65 to 85

Table B.4: Characteristics of Compressor and Pump Drivers



Driver^a	Power Range^d hp	Speed rpm	SpeedControl	Efficiency
Squirrel Cage Induction Motor	1 to 5,000	3600/N (less 2%) N^a = 1 to 8	Constant Speed	10 hp – 86 % 100 hp – 91 % 1,000 hp – 94%
Wound Rotor	1 to 1,500	3,550 - 1,750 - 1,150	100 to 60 %	10 hp – 86 %
Induction Motor		870 - 700 - 580		100 hp – 91 %
	1,500 to 2,500	1,750 - 1,150 - 870	100 to 60%	1,000 hp – 94%
Synchronous Motor	100 to 20,000	3600/N	Constant Speed	90 to 97
Steam Turbine (all)	10 to 20,000	2,000 to 15,000	100 to 35 %	η_A = 50 to 76%
Single Stage^b	up to 1,000	1,000 to 7,000		
High Back Pressure^b Single or Multistage	150 to 3,000	5,000 to 10,000		
Multistage^b				
Medium	750 to 5,000	up to 10,000		
Large	5,000 to 60,000	3,000 to 16,000		
Gas Turbine^c	3,000 to 20,000	10,000		

Table B.5: Standard Electric Motor Sizes



Horsepower[a]
1/20, 1/12, 1/8, 1/6, 1/4, 1/3, 1/2, 3/4, 1/2, 1
1-1/2, 2, 3, 5, 7-1/2, 10, 15, 20, 25, 30, 40, 50, 60, 75, 100
125, 150, 200, 250, 300, 350, 400, 450, 500, 600, 700, 800, 900, 1000
1250, 1500, 1750, 2000, 2250, 2500, 3000, 3500, 4000, 4500, 5000
and up to 30,000

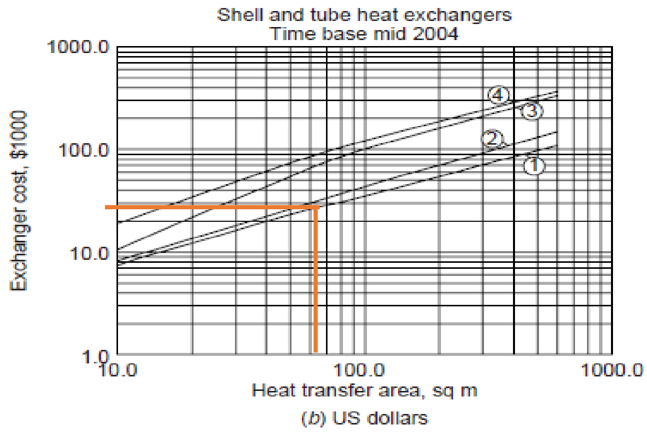
APPENDIX C

Equipment Cost

Figures:

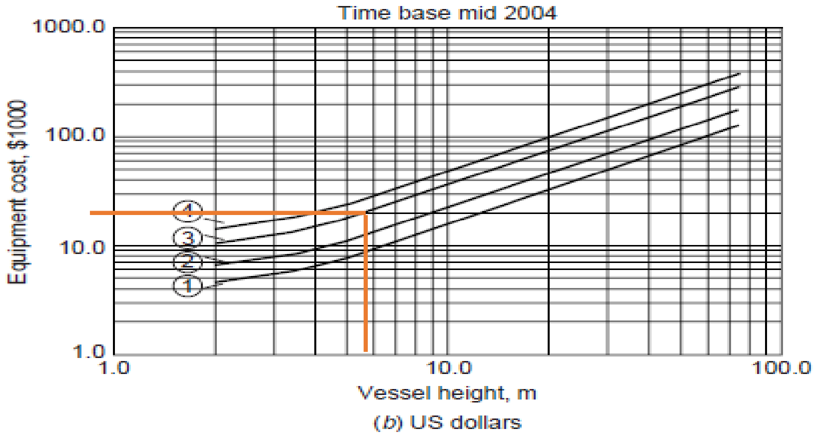
Tables:

Figures:



Materials		Pressure factors		Type factors	
Shell	Tubes				
① Carbon steel	Carbon steel	1–10 bar	× 1.0	Floating head	× 1.0
② C.S.	Brass	10–20	× 1.1	Fixed tube sheet	× 0.8
③ C.S.	Stainless steel	20–30	× 1.25	U tube	× 0.85
④ S.S.	S.S.	30–50	× 1.3	Kettle	× 1.3
		50–70	× 1.5		

Figure C-1: Heat Exchanger Cost



Diameter, m

①—0.5 ③—2.0
②—1.0 ④—3.0

Material factors		Pressure factors	
C.S.	× 1.0	1–5 bar	× 1.0
S.S.	× 2.0	5–10	× 1.1
Monel	× 3.4	10–20	× 1.2
S.S. clad	× 1.5	20–30	× 1.4
Monel clad	× 2.1	30–40	× 1.6
		40–50	× 1.8
		50–60	× 2.2

Figure C- 2: Reactor Cost

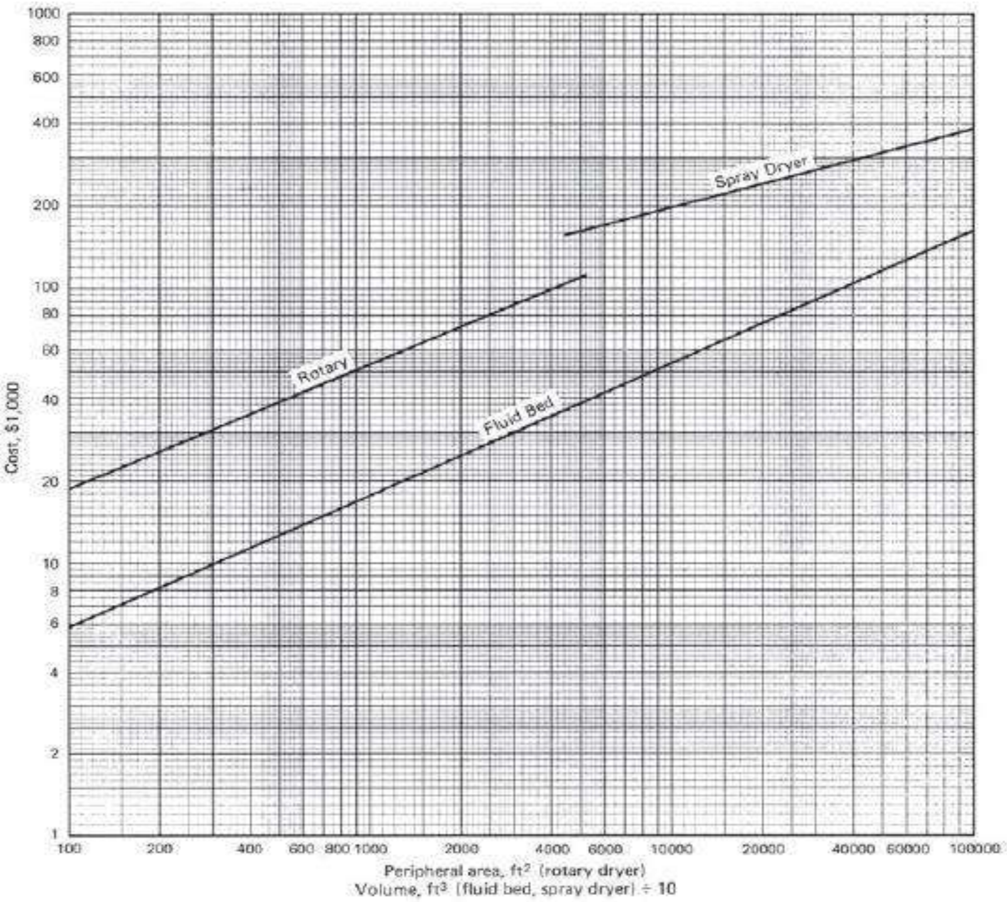
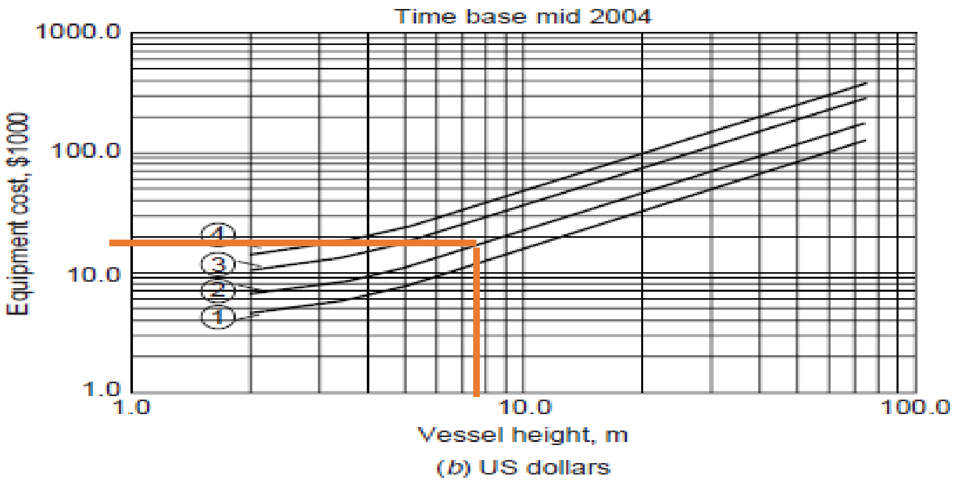


Figure C.3: Cost Data of Dryers



Diameter, m	
①—0.5	③—2.0
②—1.0	④—3.0

Material factors	
C.S.	× 1.0
S.S.	× 2.0
Monel	× 3.4
S.S. clad	× 1.5
Monel clad	× 2.1

Pressure factors	
1–5 bar	× 1.0
5–10	× 1.1
10–20	× 1.2
20–30	× 1.4
30–40	× 1.6
40–50	× 1.8
50–60	× 2.2

Figure C-4: Distillation Cost

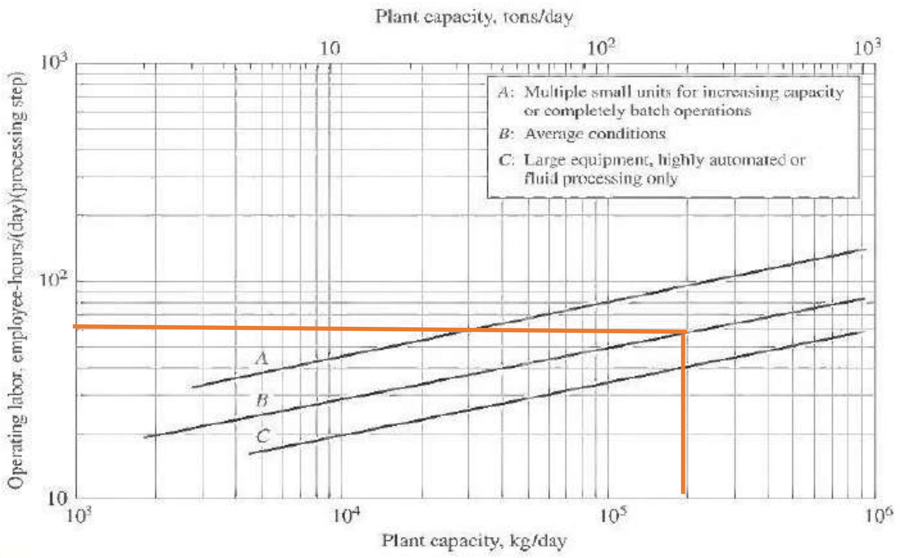


Figure C-5: Operating Labor

Tables:

Table C- 1: Pump Cost

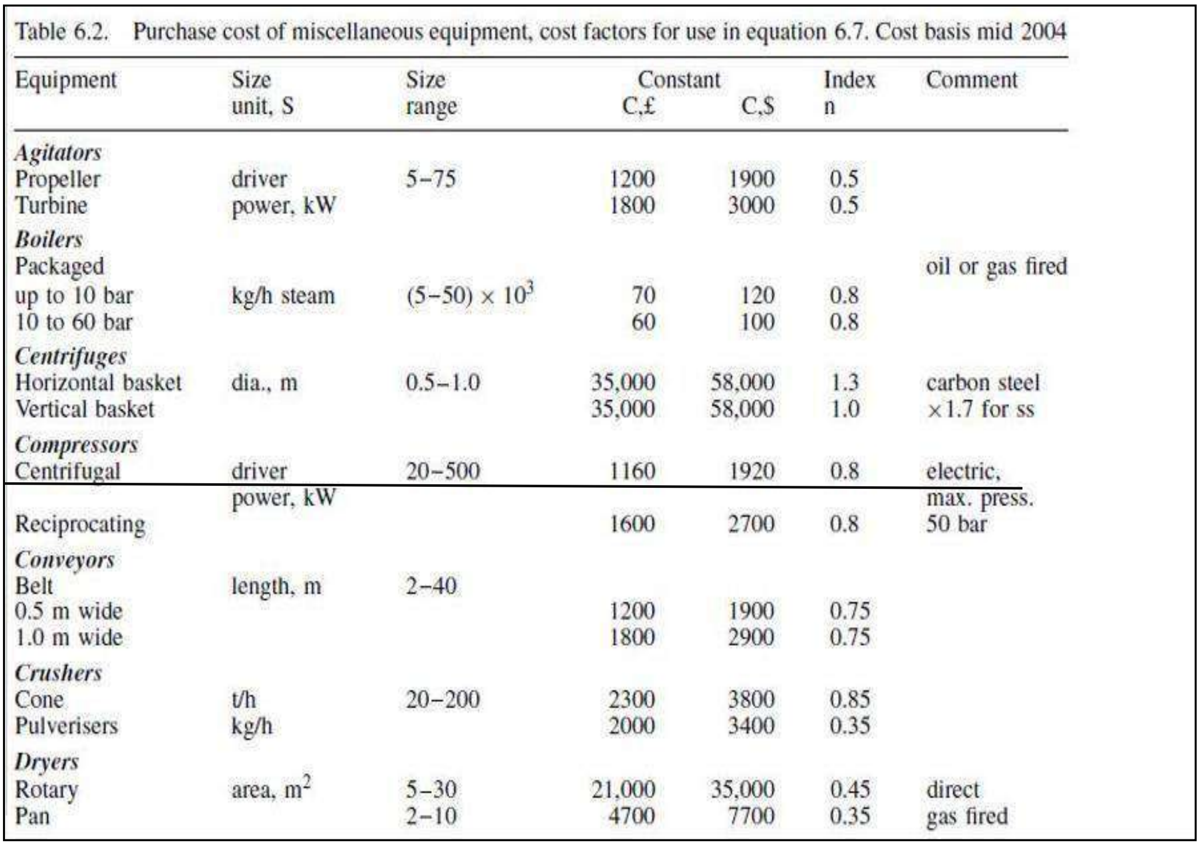
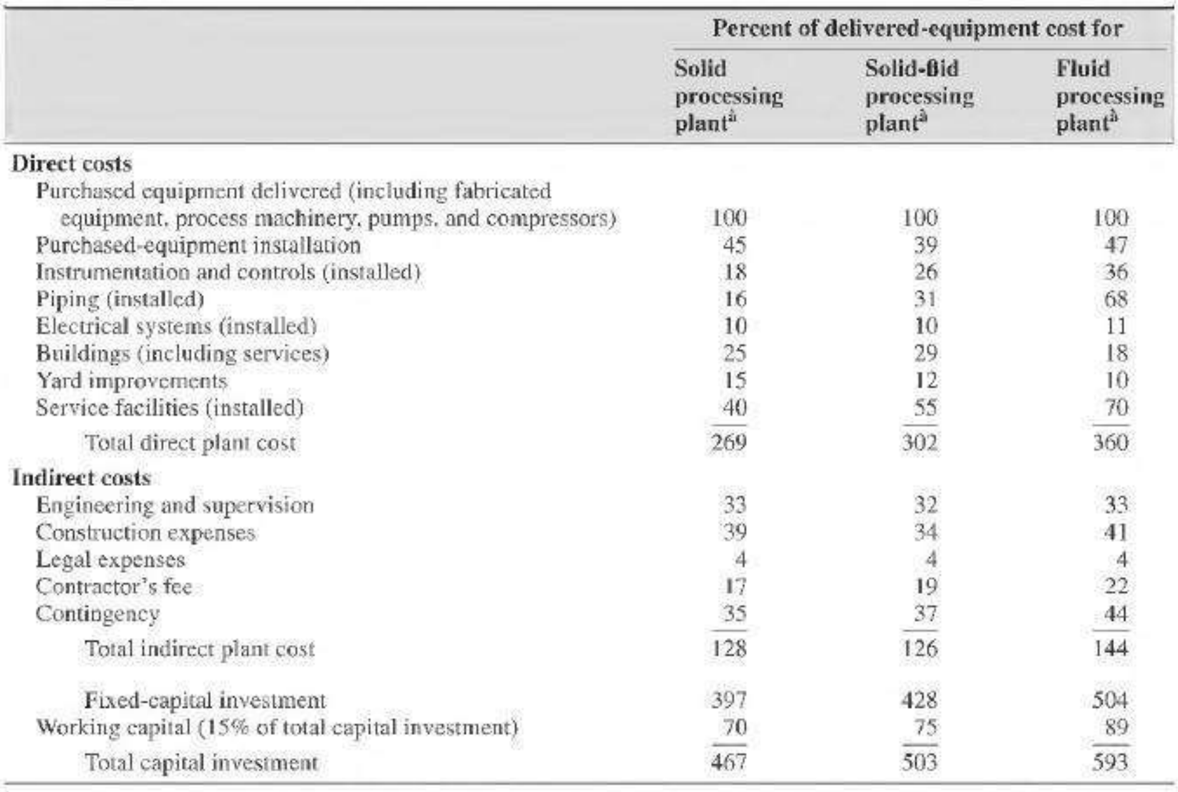


Table 6.2. Purchase cost of miscellaneous equipment, cost factors for use in equation 6.7. Cost basis mid 2004

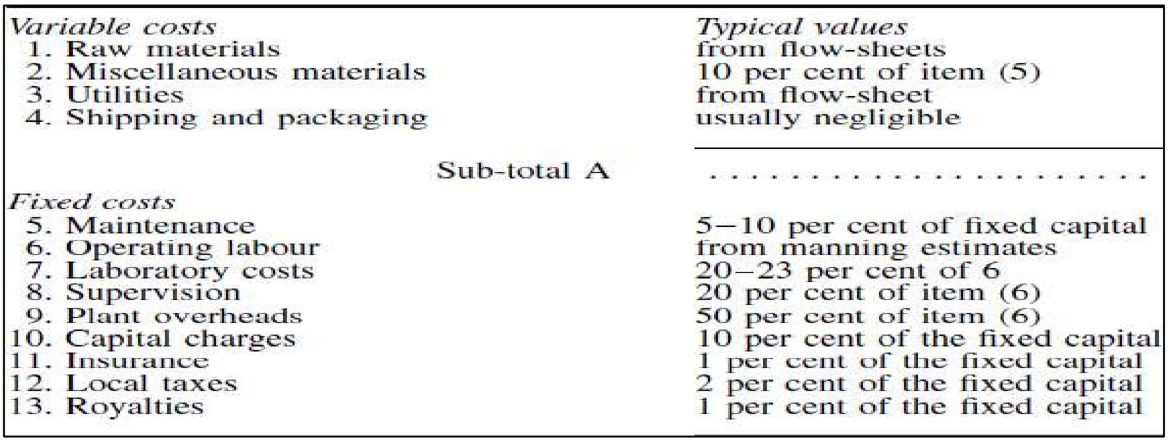
Equipment	Size unit, S	Size range	Constant C,£	C,$	Index n	Comment
Agitators						
Propeller	driver	5–75	1200	1900	0.5	
Turbine	power, kW		1800	3000	0.5	
Boilers						
Packaged						oil or gas fired
up to 10 bar	kg/h steam	$(5-50) \times 10^3$	70	120	0.8	
10 to 60 bar			60	100	0.8	
Centrifuges						
Horizontal basket	dia., m	0.5–1.0	35,000	58,000	1.3	carbon steel
Vertical basket			35,000	58,000	1.0	×1.7 for ss
Compressors						
Centrifugal	driver	20–500	1160	1920	0.8	electric,
	power, kW					max. press.
Reciprocating			1600	2700	0.8	50 bar
Conveyors						
Belt	length, m	2–40				
0.5 m wide			1200	1900	0.75	
1.0 m wide			1800	2900	0.75	
Crushers						
Cone	t/h	20–200	2300	3800	0.85	
Pulverisers	kg/h		2000	3400	0.35	
Dryers						
Rotary	area, m^2	5–30	21,000	35,000	0.45	direct
Pan		2–10	4700	7700	0.35	gas fired

Table C- 2: Direct & Indirect Cost



	Percent of delivered-equipment cost for		
	Solid processing plant[a]	Solid-fluid processing plant[a]	Fluid processing plant[a]
Direct costs			
Purchased equipment delivered (including fabricated equipment, process machinery, pumps, and compressors)	100	100	100
Purchased-equipment installation	45	39	47
Instrumentation and controls (installed)	18	26	36
Piping (installed)	16	31	68
Electrical systems (installed)	10	10	11
Buildings (including services)	25	29	18
Yard improvements	15	12	10
Service facilities (installed)	40	55	70
Total direct plant cost	269	302	360
Indirect costs			
Engineering and supervision	33	32	33
Construction expenses	39	34	41
Legal expenses	4	4	4
Contractor's fee	17	19	22
Contingency	35	37	44
Total indirect plant cost	128	126	144
Fixed-capital investment	397	428	504
Working capital (15% of total capital investment)	70	75	89
Total capital investment	467	503	593

Table C- 3: Variable & Fixed Cost



Variable costs	*Typical values*
1. Raw materials	from flow-sheets
2. Miscellaneous materials	10 per cent of item (5)
3. Utilities	from flow-sheet
4. Shipping and packaging	usually negligible
Sub-total A	. . . .
Fixed costs	
5. Maintenance	5–10 per cent of fixed capital
6. Operating labour	from manning estimates
7. Laboratory costs	20–23 per cent of 6
8. Supervision	20 per cent of item (6)
9. Plant overheads	50 per cent of item (6)
10. Capital charges	10 per cent of the fixed capital
11. Insurance	1 per cent of the fixed capital
12. Local taxes	2 per cent of the fixed capital
13. Royalties	1 per cent of the fixed capital

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CONFERENCE PAPER

Production of Biodiesel from Algae to Overcome Energy Crises

Laiba Ashraf[a], Muhammad Umar Mushtaq[a,b], Usama Ali[a], Muhammad Uzair Mudassar[a], Gulraiz Ali[a]

[a] Department of Chemical Engineering, Wah Engineering College, University of Wah, Quaid Avenue, 47040 Wah Cant.
[b] Department of Chemical Engineering, School of Chemical and Material Engineering (SCME), National University of Science and Technology (NUST), Islamabad.

ABSTRACT Financial development of the world is genuinely founded on petroleum derivative parts which are obliged now not best through confined accessibility anyway also create high scopes of contamination. The world is going through energy crises and environmental issues in this century because of elevated industrialization and overuse of ordinary assets for strength which includes fossil fuels. Since diesel is getting utilized immensely in modern business, horticulture and different areas. Thusly, the creation and the usage of biodiesel from oil seeds plants have been getting recharged interest in current years inside Pakistan to win over the negative marks of oil from oil seed crops. Making biodiesel from microalgae gives many advantages over the above resources in form of higher oil productivity and algal biomass and the need for non-arable land for its development. This papercomprises the general summary and arrangement of the development of biodiesel from green growth in Pakistan. The data relating to the microalgae exploration will help partners and legislative associations working inside the sustainable power zone to consider its development on a major scale, involving wastewater as a feedstock to deliver biodiesel to satisfy the objective set through the public authority of Pakistan of utilizing 10% mixed biodiesel continuously 2025 in Pakistan.

INDEX TERMS: Algae, Transesterification, Energy crises.

ACHIEVEMENT RELATED TO FYDP

Ref No: PEC/PPDC/22/ 338

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