PRODUCTION OF 12 MCMD OF BIOMETHANE FROM SUGARCANE BAGASSE

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Acknowledgement

We would like to take this opportunity to express our heartfelt gratitude and appreciation to all those who have contributed to the successful completion of my final year project.

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"Alhamdulillah."

Abstract

Sugarcane bagasse is an abundantly available agricultural waste having high potential that is still underutilized and mostly burnt as fuel. The rate at which we are consuming natural gas will cause its reserves to be exhaust by 2030 unless we explore more reserves . An estimate reports that only 19% of gas reserves are remaining. Replacing natural gas with biomethane is one of the best motivation for the project to make our environment clean as it is clean burning fuel or to overcome natural gas shortage near future . The process of hydrolysis is used for bagasse utilization in improved ways and then anaerobic digestion of bagasse is used for biogas production due to its economic viability and environmental sustainability. In the current project, utilization of biowaste(sugarcane bagasse) to biofuel(biomethane) with complete process was designed with optimized process conditions for each process stage to make this project technically feasible/sustainable. In this research work all the technical aspects with the economic evaluation of the production process have been discussed . All indicators of economic analysis (Net Present Worth, IRR etc.) show the Biomethane from sugarcane bagasse is economically viable (with 23 % rate of return) and payback period of 5 years to produce value added product (biomethane) by achieving SDGS goal 7 (affordable and clean energy) and SDGs goal 13 (climate action).

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CHAPTER # 1

INTRODUCTION

1-Introduction

Pakistan's economy still heavily relies on agriculture. Energy is the main limiting element and responsible for the decline in developing economies because it is the second-largest sector of the nation. Careful projections indicate that Pakistan's energy needs are projected to increase thrice by 2050 as a result of the energy shortfall, notwithstanding the lackluster energy sources. It is essential to investigate renewable and alternative energy sources. Biomethane is a unique source of renewable biomass energy[1]**.**

1.1 Introduction to Product:

Biomethane is a naturally occurring gas that is created when organic matter, such as dead animal and plant matter, manure, sewage, organic waste, etc., is digested in a process known as anaerobic digestion. It shares a chemical composition with natural gas, another fossil fuel that is created from dead plants and animals and is kept underground.

1.1.1 Biomethane:

Another name for biomethane is "renewable natural gas". It is a source of methane that is nearly pure and is created either by "upgrading" biogas. The decomposition of organic matter in the absence of oxygen results in the production of biogas, a mixture of methane (CH_4) and carbon dioxide (CO_2). Anaerobic digestion is what causes this. A 100 percent renewable energy source is biogas. Purified biogas is converted into biomethane, which is also referred to as a renewable energy source. It is created from "fresh" organic material, making it a renewable energy source that can be produced anywhere in the world. Biomethane is a green form of energy due to its many advantages for the environment If organic material, from which biomethane is formed, were simply allowed to decay naturally, the gas would be released into the atmosphere, and other gases created during the decomposition process, such as nitrous dioxide, for example, further contribute to the greenhouse effect. The creation of biomethane prevents the emission of a significant amount of methane and other hazardous gases into the atmosphere. This is because the synthesis of it prevents organic matter that is degrading from being exposed to the air, which allows methane and other gases to escape into the atmosphere.

With regard to fossil fuels in particular, biomethane has a lot of potential as a substitute energy source. Despite the fact that its usefulness has been known for quite some time, the production of biomethane only recently began due to the threat of global climate change, rising natural gas prices, and high electricity prices associated with other fossil fuels[2].

1.1.2 Raw material (Sugar cane Bagasse):

The portion of sugarcane biomass left behind after washing, preparing, and extracting sugarcane juice is known as sugarcane bagasse. A plentiful source of biomass lignocellulose was given by sugarcane bagasse.

Pakistan is the world’s fifth largest producer of sugarcane, grown on approximately 1.3 million hectares. The Punjab province accounts for 67 percent of sugarcane production, Sindh 25 percent, Khyber Pakhtunkhwa (KPK) 8 percent and Baluchistan less than one percent. Marketing year (MY) (Oct/Sep) 2022/23 sugarcane production is forecast at 89.5 MMT, a marginal increase over the previous year. Producers have already completed planting the cane that will be harvested in the fall of 2022, and reports indicate a slight increase in planted are[3].

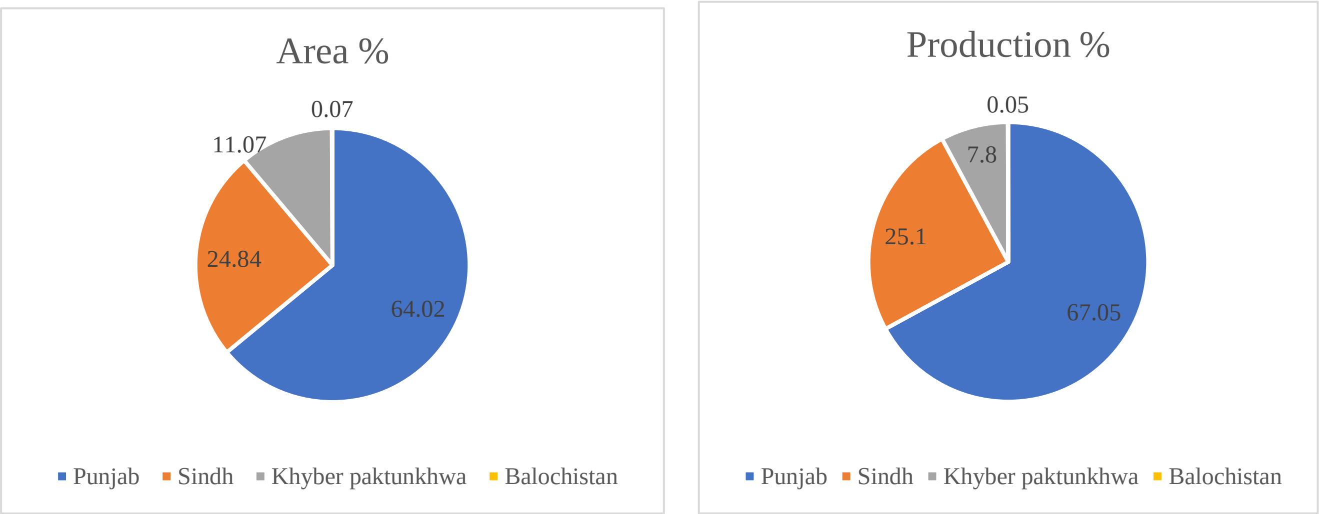


Fig no 1.1 : Provincial share of sugarcane production and acreage in Pakistan [3]

1.1.3 Composition of Bagasse:

Raw bagasse is a combination of cellulose, lignin, and hemicellulose.[4]

Table 1.1: Composition of Bagasse

Component	Percentage %
Cellulose	44
Hemi cellulose	27
Lignin	13
Ash	4

1.2 Physical Properties and Thermodynamic Data:

Main component of biomethane is methane similarly natural gas has methane as its main constituent. Some properties of biomethane are given below in the table.

Table 1.2: Physical and Thermodynamic Properties [5,6]

Properties	Biomethane
Molecular Weight	16.04 g/mol
Melting point	−182.5 °C
Boiling point	-162°C
Flash point	−188 °C
Autoignition temperature	537°C
Critical Temperature	-82.5ºC
Critical Pressure	4.6 MPa
Viscosity	11.2μPa.s
Specific Heat Capacity at 25°C	0.035 kJ/(mol.K)
Thermal Conductivity at 25°C	34.5 mW/(mK)
Internal Energy at 25°C	12.1 kJ/mol
Enthalpy at 25°C	14.6 kJ/mol
Density at 25°C:	0.64 kg/m³
Lower Heating Value	36 MJ/m^3
Higher Heating Value	39 MJ/m^3
Wobbe Index	50 MJ/m^3
Specific gravity	0.60
Methane number	100
Flammable limit vol%	4-16
Physical State	Gaseous

1.3 Reactions of the Product:

Methane will react in different ways for the formation of synthetic gas. Reactions of methane are given blow [7].

Reaction of Methane with carbon dioxide:

$$CH_4 + CO_2 \longrightarrow 2CO+2H_2 \qquad (1.1)$$

Reaction of Methane with oxygen:

$$CH_4 + O_2 \longrightarrow 2CO+4H_2 \qquad (1.2)$$

Reaction of Methane with water:

$$CH_4 + H_2O \longrightarrow 2CO+3H_2 \qquad (1.3)$$

1.4 Application of Biomethane:

Biomethane has diverse ,flexible spectrum of applications as described below:

1.4.1 Transportation fuel :

Biomethane (BM) as vehicle fuel is highly popular because biomethane is released from storage methods like compressed biomethane has high pressure, then it can be directly use in vehicle engines without requirement of complex or costly gas compression and injection systems. It can be used in existing CNG vehicle fleets without further modifications due to similar properties as natural gas. Currently biomethane mainly provided to transport sector through gas grids, CBM tanks, bottled BM or as Liquified Biomethane (LBM).

1.4.2 Cooking & Heating fuel:

Asian countries such as India and Pakistan are heavily used bottled (small cylinders) biomethane as cooking fuel in domestic and commercial applications. Also there is high potential to use movable bottled BM to utilize in heating applications in small scale consumers and use it as supplement to match peaking heating demand which heating applications depend on fossil fuels.

1.4.3 Industrial applications:

Generally biogas has number of obstacle to use in industrial applications due to their lower energy concentration and corrosive properties. However upgraded biomethane has removed those obstacles and it can use on any applications which run on CNG or LNG or other petroleum product as a fuel. Stored BM can use for meeting demand of peaking and intermittent industrial heating applications. In addition to that, upgraded biomethane has carbon and hydrogen as their elements, hence BM can use as raw material for iron core reduction process, syngas production, production of short olefins and production of methanol.

1.4.4 Electricity provision:

Due to high energy concentration in upgraded biomethane, it can use for generating electricity from gas engines or combined heat and power (CHP) units or internal combustion engine coupled with a generator. Produced electricity can be fed in to the power grid or use within the industry who is producing electricity [8].

1.5 Handling, Storage and Safety of Biomethane:

There are different methods available for storing biomethane after its upgrading process.

1.5.1 Gas grid storage:

This method of storing biomethane is most suitable for a country where it has better coverage of existing natural gas grids throughout the country. Also this method has low investment cost, high energy efficiency and some environmental benefits (such as encourage to use biomethane powered vehicles) compared with other methods.

1-5-2 Underground reservoir:

Underground reservoirs including salt caverns, aquifers, and depleted gas and oil reserves can all be used to store biomethane. This storage method has largest potential of storage capacity (>300 billion cubic meters throughout the world) than other energy storing methods like water storage, electricity or compressed air storages. In this method, salt caverns has high injection/ withdrawal ratio and high turnover ratio compared with other two options. Depleted gas and oil reservoirs also provide good option for storing biomethane due to their high tightness of the geological structure, existing infrastructure for injecting/ withdrawal of gas and require low investment cost.

1.5.3 Compressed tank:

During this method, biomethane producers are filled their product has in large pressurized gas containers and then distribute to centralized gas filling stations or industrial consumers by a medium of transportation. Compressed biomethane (CBM) tanks may be in shape of cylindrical, spherical or pipe tanks.

1.5.4 Liquefaction

Liquefied biomethane (LBM) is produced by cooling biomethane approximately up to 111 K when maintain its pressure around the atmospheric pressure level. LBM has about 1/600th volume of biomethane at nominal atmospheric conditions and hence the energy concentration of LBM is higher than biomethane in gaseous state. LBM is non-explosive and non-toxic, hence this method is improved safety measures of its end users [8].

1.5.5 Safety of biomethane:

Fuel and vehicle systems has associated hazards and risks in different parts of their life cycles.

- Transport of methane powered systems are regulated, monitored and widely considered safe .
- Methane is a non-poisonous, odorless, gas with a higher ignition temperature than gasoline and diesel and a low density which means that methane will rapidly rise from ground levels and be diluted if a leak occurs outdoors.
- In enclosed spaces such a vehicle workshops adequate gas detection systems should be installed which can detect hazardous biomethane concentrations in air which may not be sufficiently odorized for humans to smell.
- Some countries are experienced with the use of methane as a transport fuel, other countries have less experience. This can result in driver hesitancy in fuel switching. Moreover chemical mercaptan is added for detection weather it is leaked for safety purpose.

1.6 Shipping of Biomethane:

While biomethane distribution involves extra technological difficulties, it is a viable solution to many of the infrastructural problems related to the distribution of biomethane. Tankers are used to transport bulk LBM. Usually, class 8 vehicles are tractors pulling 10,000-gallon tankers. It is carried at low pressures (e.g., 20 to 150 psi), but particular handling is needed because it is a cryogenic liquid, with a nominal temperature of -260 ^{0}F [8].

1.7 Biomethane production and consumption data of world:

3.5 Mtoe (Million tons of oil equivalent) of biomethane are now generated worldwide. The majority of production occurs in Europe and North America, with some nations, like Denmark and Sweden, having biogas/biomethane percentages of over 10% of total gas sales.

- Although biomethane only makes up around 0.1% of the natural gas used today, more and more government regulations are promoting its usage in decarbonizing transportation and adding it to gas networks.
- For instance, the United Kingdom, the Netherlands, Germany, and Italy have all introduced policies that favour the use of biomethane in transportation. Brazil's Renovation programmer is to lower the carbon intensity of fuels used in the transportation sector by

10% by the year 2028. Subnational laws, like those governing low-carbon gasoline in California and British Columbia, are also beginning to take shape.

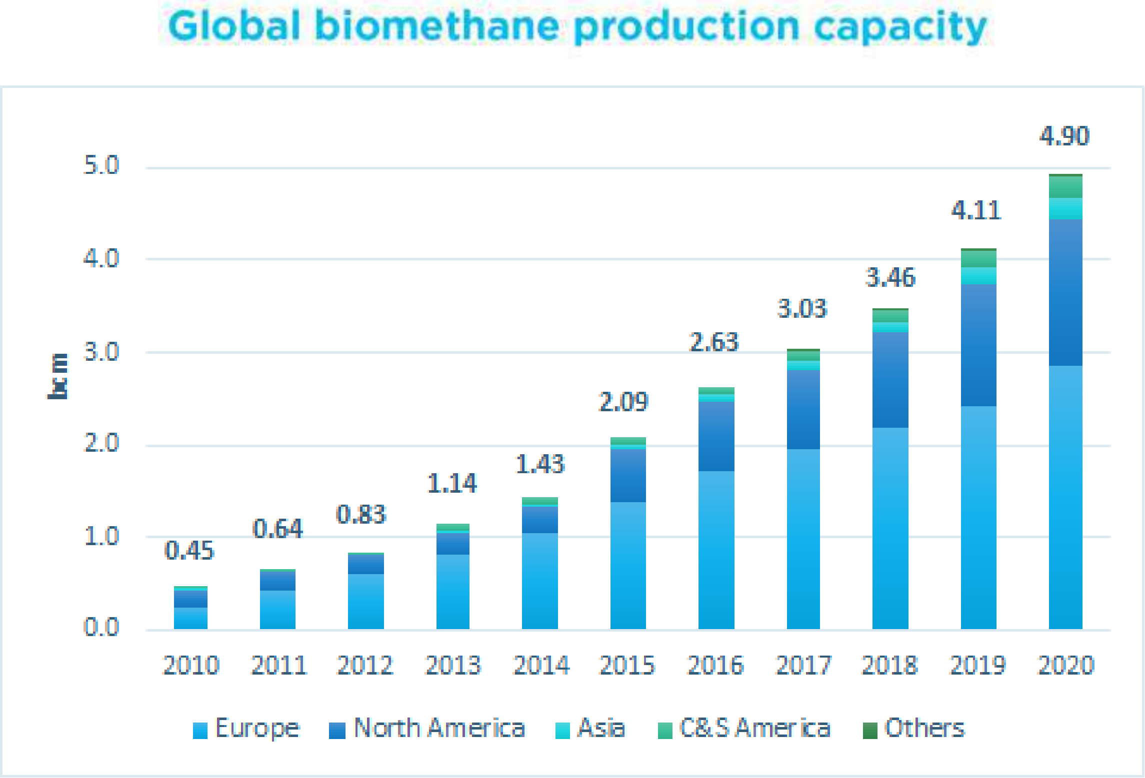


Fig no 1.2: Production of Biomethane worldwide

- The proportion of produced biogas that is upgraded varies significantly by region; it is 15% in North America and over 35% in South America; Only approximately 10% of biogas gets upgraded in Europe, the region that produces the most biogas and biomethane (although the percentages are substantially higher in nations like Denmark and Sweden); the figure is 2% in Asia. Combine to create a second stream of methane from hydrogen.
- The number of operational plants (biogas upgrading facilities) is anticipated to reach 1000 by the end of 2020 due to the growing demand in biomethane.
- About 60% of the facilities that are now operational or under construction inject biomethane into the gas distribution system, with another 20% serving as automobile fuel. Methane is produced from the remaining material for a number of regional purposes.
- The primary factor of demand growth is biomethane use as a transportation fuel. Biomethane usage in the sector increased 40% from 2018 to 1.5 bcm globally in 2019.
- There are currently 20 countries in Europe that produce biomethane. The sector has developed quickly as evidenced by the fact that the number of biomethane facilities has doubled over the last five years. France, Denmark, the Netherlands, Italy, and the United Kingdom have been driving forces behind recent expansion.

- In the Nordic countries, biomethane already makes up a sizable portion of the gas grids (20–30%). By 2030, it is projected to increase by an average of 8% at the European level, or about 35 bcm.

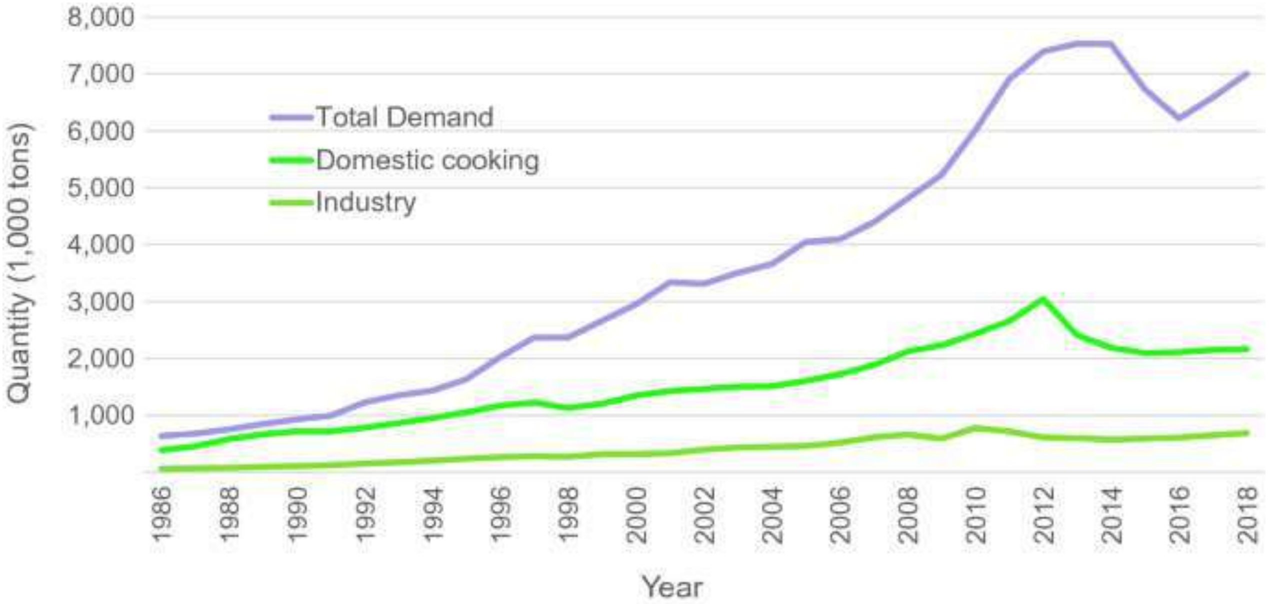


Fig no 1.3: Consumption of Biomethane worldwide

1.8 Market Assessment:

The Global Biomethane Market is anticipated to reach $3.38 billion by 2026, rising at a CAGR(Compound Annual Growth Rate) of 8.67% from its projected value of $2.23 billion in 2021.

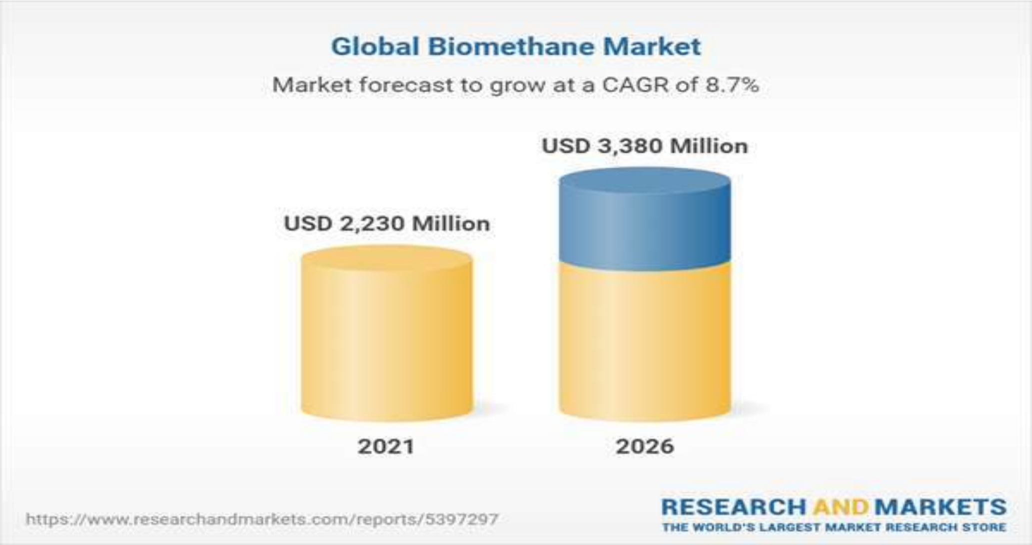


Fig no 1.4 : Global biomethane market.

The biomethane market is primarily being driven by rising automobile biomethane use, rising demand for bio-based fuel for power plants, and expanding industrialization. The need for the global biomethane market is also being driven by escalating environmental concerns, supportive administrative policies, and rising energy generating needs. The industry is also expanding as a result of an increasing number of nations using biomethane as a transportation fuel. Cost-setting and high primary financing, however, are impeding market expansion [9].

1.9 Future Trends :

Governments and organizations are pledging to cut carbon emissions to tackle climate change, which is driving up demand for renewable energy sources. Fossil fuels can be replaced with biomethane, which is renewable and low in carbon. In addition, by keeping organic waste out of landfills and lowering methane emissions, the creation of biomethane can aid in waste management.

- Increased Production: As more nations and companies show an interest in lowering their carbon emissions, biomethane output is predicted to rise.
- Improved technology: As technology advances, biomethane production should become more economical and efficient.
- Integrating renewable energy sources: To provide a sustainable supply of energy, biomethane may be combined with other renewable energy sources like solar and wind.
- Expansion of biomethane plants: More government and private sector investment is anticipated to drive biomethane plant expansion in the upcoming years.
- Infrastructure development for biomethane: To facilitate the use and transportation of biomethane, more infrastructure, like as pipelines and refueling facilities, is anticipated to be built.
- An increase in the number of vehicles using biomethane as fuel is predicted, especially in the transportation industry as nations seek to lessen their dependency on fossil fuels.
- Government support: In order to promote the use of biomethane, governments are anticipated to provide additional policy support, including financial incentives.
- Biomethane plants are very friendly plants because of no waste produced as such produced by other plants and there is great problem of disposing that waste.so that by product of biogas is used as fertilizer and further processing of biogas to biomethane will give off CO_2 which is transported to food (beverages industries) and to green houses.
- Biomethane is complete replacement of natural gas it has great potential to overcome natural gas shortage by directly injection into natural gas grides without any modification to the system.

CHAPTER # 2

PROCESS SELECTION

2-Process Selection

Biomethane can be produced by following three manufacturing methods.

1. Landfill Sites
2. Waste water treatment plants
3. Bio digestion Plants

2.1 Landfills:

A place where waste is dumped is referred to as a landfill site, tip, rubbish dump, garbage dump, or dumping ground. Organic waste, such as food scraps, yard debris, junk wood, and waste paper, makes up the majority of landfill content. Methane, a strong greenhouse gas, is produced during their decomposition and is contained in the biogas. The use of landfill gas for power production is a very attractive option in tropical sanitary landfills mainly in developing countries, where the waste composition, water content, and the climate conditions are favorable to a fast depletion of waste organic matter and a robust short term biogas production response. Organic waste is digested in landfill in the absences of oxygen producing biogas with CH4 as main constituent [10].

Reactions:

$$4CH_3COOH \longrightarrow 4CO_2 + 4CH_4 \qquad (2.1)$$

$$CO_2 + 4H_2 \longrightarrow 4CH_4 + 2H_2O \qquad (2.2)$$

$$4CH_3OH + 6H_2 \longrightarrow 3CH_4 + 2H_2O \qquad (2.3)$$

Flow Diagram:

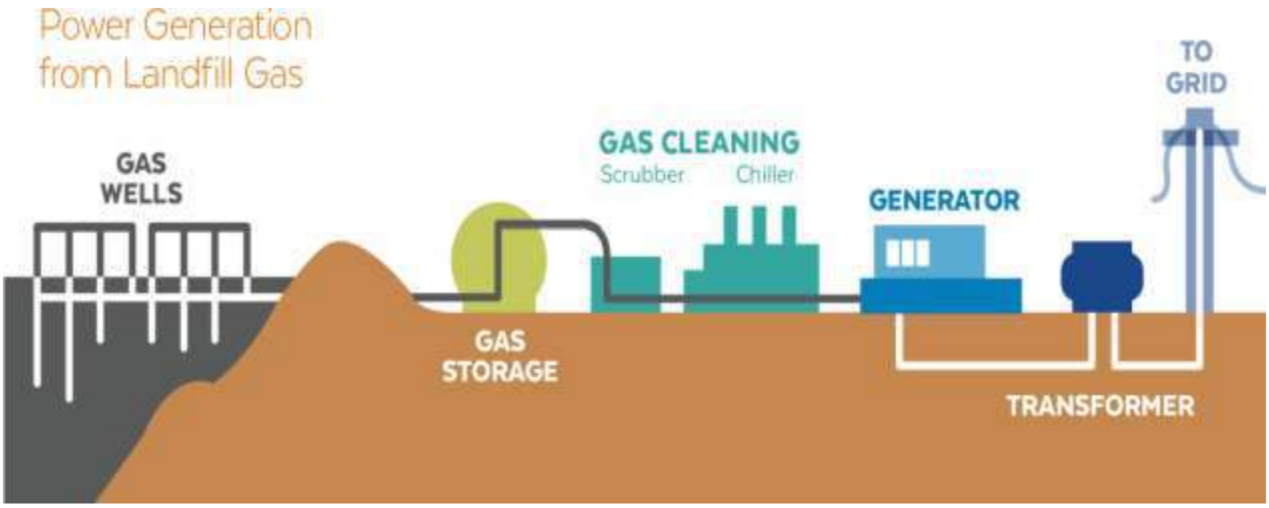


Fig no 2.1 : Landfill gas to Biomethane for Power Generation

2.2 Waste Water Treatment Plant:

Wastewater treatment plants (WWTPs) create sewage sludge as part of the purification of water. The wastewater's rich in nutrients and organic matter removed particles are contained in the sludge, leaving the water clean for release into the environment. Sewage sludge production is increasing quickly as a result of expanding industry and population centers that are more well served by wastewater treatment facilities. The sludge is pumped into anaerobic continuously stirred tank reactors (CSTR), which typically operate at mesophilic temperatures (35 to 39 °C), where digestion occurs [11].

Reactions:

$$CH_3COOH \longrightarrow CH_4 + CO_2 \tag{2.4}$$

$$CO_2 + 4\,H_2 \longrightarrow CH_4 + 2\,H_2O \tag{2.5}$$

$$2CH_3CH_2OH + CO_2 \longrightarrow CH_4 + 2\,CH_3COOH \tag{2.6}$$

Block Flow Diagram:

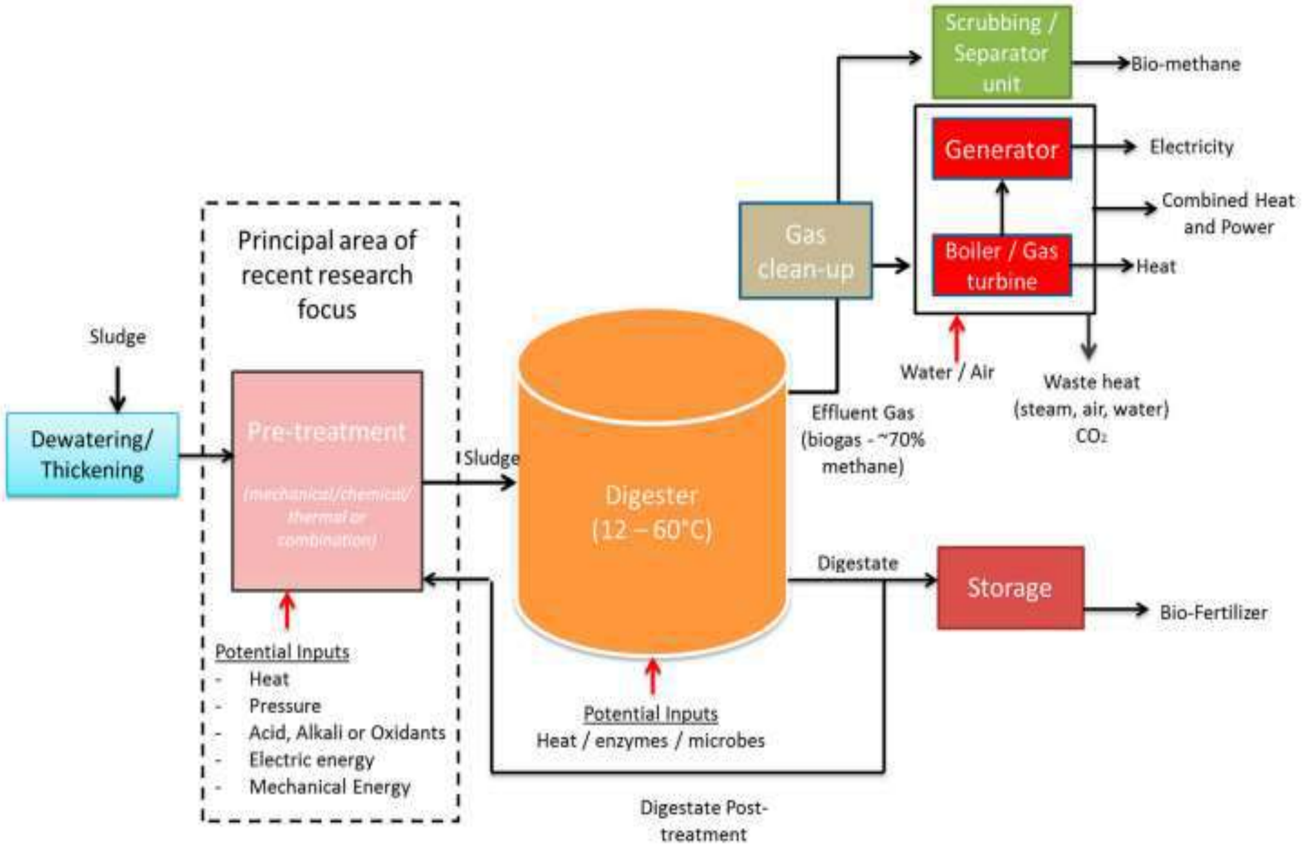


Fig no 2.2: Schematic representation of the anaerobic digestion of sludge

2.3 Anaerobic Digestion Plants:

Anaerobic digestion depends on the effective conversion of organic matter into biogas, which has methane CH_4 as its primary combustible component. The creation of bioenergy through anaerobic digestion is seen as a workable waste management treatment method and a promising alternative to reducing climate change. The fact that these systems are adaptive to the climatic conditions of most countries and do not require time-consuming and expensive maintenance procedures is just one of their many noteworthy benefits. The net energy production rate of this method is positive, and the CH_4 gas that results from the process has a propensity to displace fossil fuels. Anaerobic digestion systems don't actually harm the environment or human health when used appropriately.. Anaerobic digestion relies on efficient conversion of organic matter into a valuable product known as biogas, with methane CH_4 as its main combustible constituent [12].

Main Reaction:

$$C_6H_{12}O_6 \longrightarrow 3CO_2 + 3CH_4 \qquad (2.7)$$

The biological conversion of organic matter occurs in three steps

- The process begins with the conversion of substances with larger molecular masses into substances that can be used as a source of energy and cell carbon. The first step's chemicals are transformed by bacteria into recognizable lower-molecular-mass intermediate molecules in the second process, known as acidogenesis.
- A group of bacteria called acetogens use the lower-chain volatile fatty acids generated during acidogenesis to make acetate (acetic acid) and carbon dioxide.
- Methanogenesis, the third phase, entails the bacterial breakdown of the intermediate substances into less complex byproducts like methane and carbon dioxide [13].

$$C_6H_{11}O_5 + H_2O \longrightarrow C_6H_{12}O_6 \qquad (2.8)$$

$$C_6H_{12}O_6 + H_2O \longrightarrow 2CH_3COOH + 4H_2 + 2CO_2 \qquad (2.9)$$

$$2CH_3COOH \longrightarrow 2CH_4 + 2CO_2 \qquad (2.10)$$

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O \qquad (2.11)$$

Process Flow Diagram:

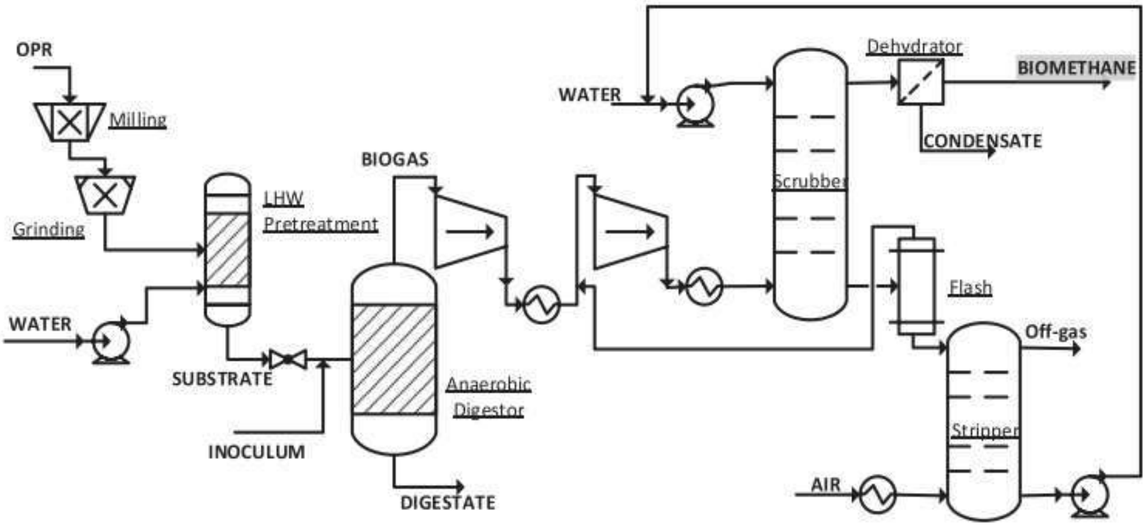


Fig no 2.3: Process Flow Diagram of Biomass to Biomethane

2.4 Process Comparison:

Table 2.1: Comparison of process [14,15]

Raw Material	**Primary gas**	**Temperature**	**Product CH_4 composition%**	**Merits /Demerits**
1. Municipal Solid waste(organic waste)	Landfill gas	30-70ºC	45 to 55%	• Higher Green house gases emission • Raw material is of heterogenous nature. • Contains siloxanes
2. Sludge(organic matter)	Sewage gas	35-40ºC	55 to 65%	• Less Green house gases emission • Raw material is of heterogenous nature. • Contains siloxanes
3. Biomass (Bagasse)	Bio gas	35-60ºC	60 to 70%	• Less Green house gases emission. • Raw material is widely available in homogenous form. • No siloxanes

2.5 Process Selection:

We have selected Bio digestion plants using biomass for biogas production because;

- Wastewater sewage sludge requires expensive pre, inter, post treatment processes.
- Landfills do not have gas capture in operation and are potentially dangerous, because the methane-rich biogas may mix with oxygen in the air making an explosive gas.
- Bio digestion plants are referred to as no waste plant as it byproduct is used as fertilizer.
- It has highest methane content as compared to other methods.
- It will reduce greenhouse gasses emission and is cost effective.
- Moreover methane produced from digestion plants does not contain siloxanes.

2.6 Process Description:

The three steps involved in production of biomethane are as follows:

1. Pre-Treatment
    - Washing
    - Drying
    - Grinding
    - Liquid Hot Water treatment
2. Reactions
    - Biogas production
3. Post-Treatment
    - Scrubbing
    - Stripping
    - Dehydration

2.6.1 Pre-Treatment Section:

Physical Pre-treatment:

In pretreatment sugarcane waste bagasse is entered for washing to remove dirt and sticky juice after washing it is moved to drying section to remove moisture for grinding .Basically rotary drying is used for removal of moisture. Bagasse has moisture content of 40 to 50% after drying it is left with 10% moisture. It is then moved to grinder for which hammer mill is selected initially bagasse has size of 25 mm after grinding operation 2mm is achieved. This will also reduce crystallinity and helps in uniformity of particles. Then grinded bagasse is moved to liquid hot water treatment vessel.

2.6.2 Physiochemical Pre-treatment:

In liquid hot water treatment vessel bagasse and press mud which is used as inoculum is treated with hot water at high temperature and pressure to keep water in liquid state at 10 bar , 170°C this will lead to swelling of bagasse and as a result lignin is removed as well as some part of lignin is already dislocated or disrupted because of grinding operation. Hemicellulose is polymer that will solubilized in water and cellulose become more accessible for enzymatic attack and undergo hydrolysis reaction and glucose is formed.

2.6.3 Reaction:

Anaerobic Digestion:

Anaerobic Digestion is process which is done in the absence of oxygen so glucose from liquid hot water treatment vessel is moved to digestor for further conversion to biogas. Digestion process occurs in stages first stage is acidogenesis which utilizes acidogenic bacteria resulting in formation of acetic acid , hydrogen and carbon dioxide. Last stages is methanogenesis where methanogens use the intermediate products of the preceding stages and convert them methane and carbon dioxide. Now mixture of gases named biogas is formed is ready to moved to post treatment section. Temperature is 55°C inside the digestor. Waste or byproduct of digestion is digestate which is moved to centrifuge decanter for solid and liquid separation which is further used as fertilizer.

2.6.4 Post-Treatment:

Scrubbing:

Biogas from digestor is pressurized and injected to absorption column from bottom and water used as solvent which is injected into column from top to make counter current flow for efficient absorption of unwanted gas CO_2 in to water. Our desired product is CH_4 moreover CO_2 is 26 times more soluble in water at 25°C than CH_4.Absorption column will operate at high pressure and low temperature of 10 bar and 30°C.As a result CH_4 separated from other gases is obtained from top with 90% composition and is entered to dehydrator for removal of water .From bottom water with absorbed gas CO_2 is moved to flash column.

Dehydration:

Methane obtained from top of absorption column has some amount of water in it which must be removed before any application. Dehydrator consist of Silica gel which will absorb water and biomethane composition reached 97% which is ready for further applications.

Separation:

Bottom stream of absorption column consist of absorbed gases like CO_2 and very less amount of CH_4 to recover this methane it is injected into column where pressure is reduced from 10 bar to 3 bar. Partial pressure of methane is only 10% of total pressure maintained in flash column due to this pressure difference only methane will moved out and from the top of column it is recycled to biogas stream. Moreover water with 90% of CO_2 and is moved to stripper for regeneration of water.

Stripping:

Water with absorbed CO_2 is moved to stripper for separation of CO_2 and water. Water is basically regenerated which is used in the scrubbing process. Air is injected into column from bottom and water is injected from top. It will operate at high temperature and low pressure and a result high concentration of CO_2 in water in combination with low pressure will decrease partial pressure as well solubility of CO_2 and it will desorb from water. Water is regenerated and reused.

2.7 Capacity Selection:

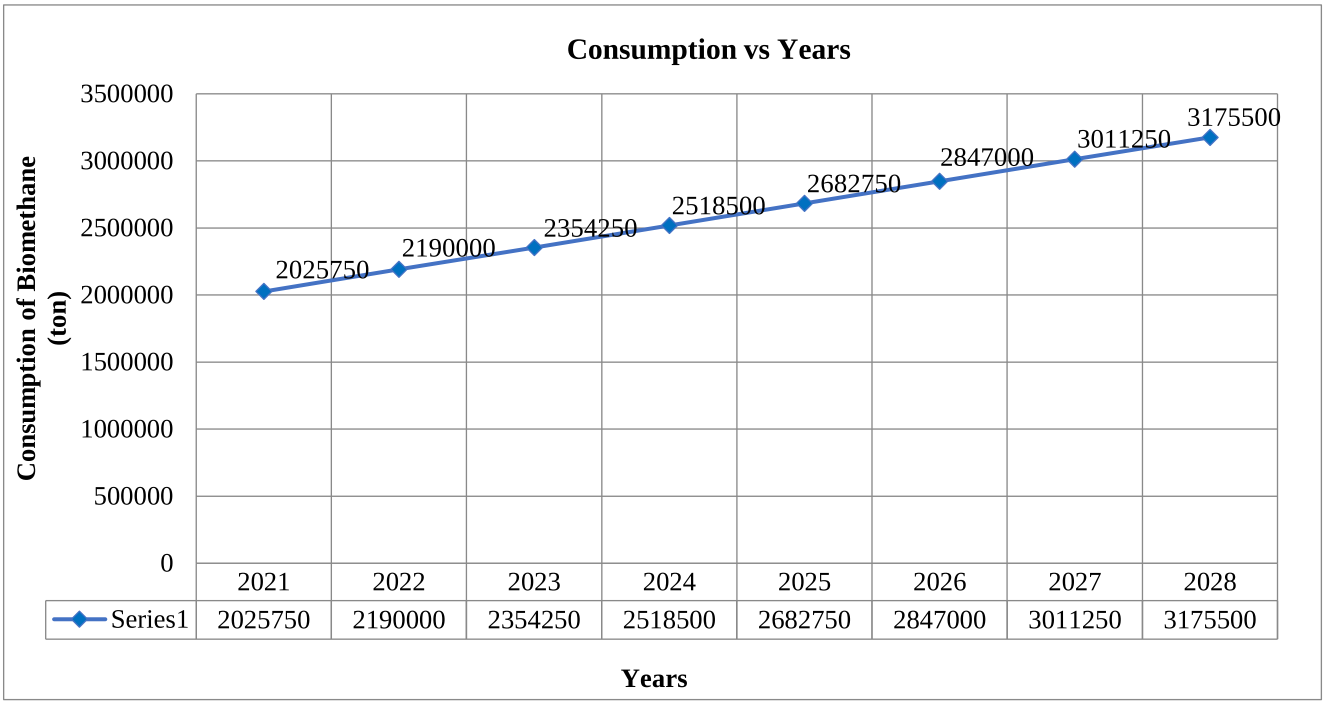
According to Pakistan Economic Survey performed by Finance Division Government of Pakistan [16].

Consumption data of Natural Gas of year 2022 = 439 million cubic feet per day.

Biomethane potential from bagasse = 62%

Biomethane consumption of year 2022 = 272 million cubic feet per day.

= 8 million cubic meter per day.

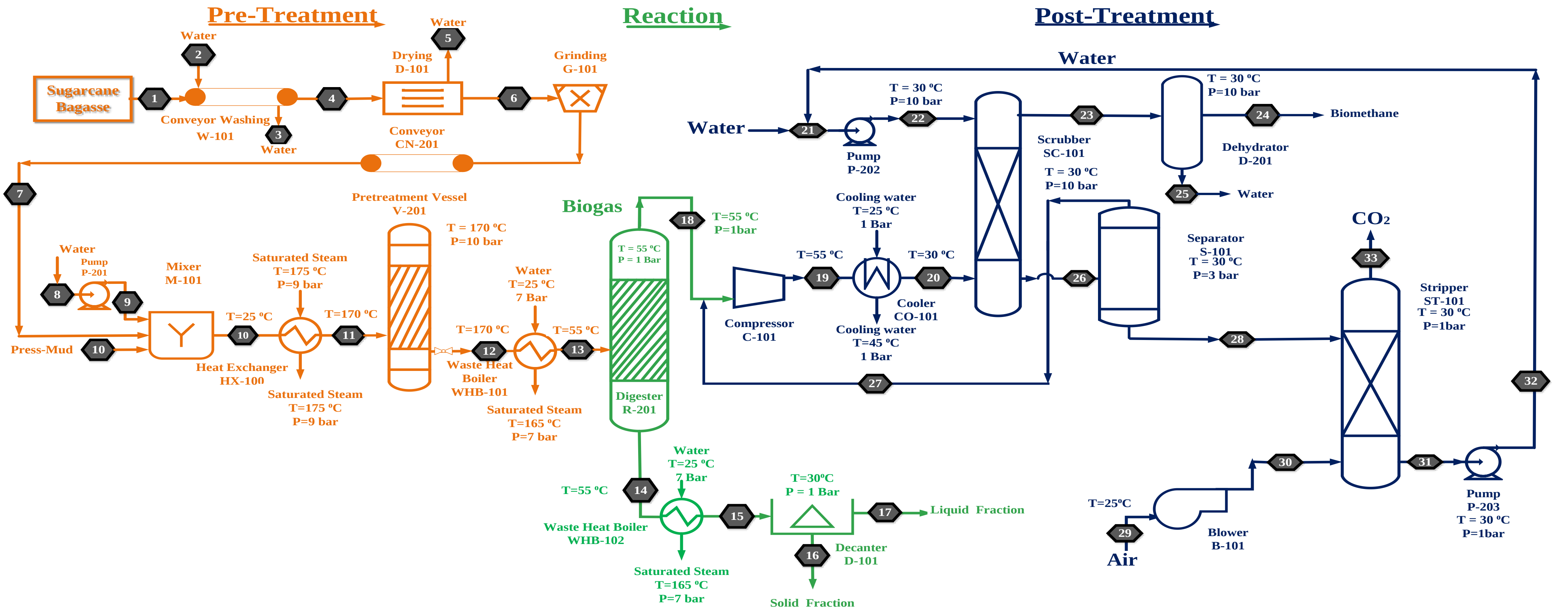


	2021	2022	2023	2024	2025	2026	2027	2028
Series1	2025750	2190000	2354250	2518500	2682750	2847000	3011250	3175500

From graph consumption data of year 2028 is = 3 million ton per year

Capacity of plant is 6500 tons per day which is equal to 12 million cubic meter per day

2.8 Process Flow Diagram:



Conveyor washing	Drying	Grinder	Pretreatment Vessel	Digestor	Decanter	Scrubber	Dehydrator	Separator	Stripper	Heat Exchanger	Compressor	Pump
W-101	D-101	G-102	V-201	R-201	D-301	SC-301	D-201	F-401	ST-501	HX,201-205	C-201,202	P,201-203

CHAPTER # 3

MATERIAL BALANCE

3-Material Balance:

Mass balance is the calculation of the amounts of materials that enter and leave any system or process based on the principle of the law of conservation of mass, which states that matter is neither created nor destroyed in the process and the total mass remains unchanged. By accounting for materials entering and leaving a system, the independent equations that involve of the unknown of compositions and mass flow rates of streams enter and leave the system or process can be solved. According to the following generic equation, mass balance in a system can be expressed:

General Material Balance Equation:

Input of Mass to the system – Output of Mass from the system + Generation of Mass in the system – Consumption of Mass in the system = Accumulation of Mass in the system

Assumption:

The plant is running at a steady state condition so accumulation becomes zero

Input – Output + Generation – Consumption = 0

Basis:

1 hr of operation

Operating Time:

The operating time of plant is 300 days.

Plant Capacity:

12 million cubic meter per day

Yield:

60%

Production rate:

$$\frac{3\times10^9\ \text{m}^3}{\text{year}}\ \bigg|\ \frac{0.65\ \text{kg}}{\text{m}^3}\ \bigg|\ \frac{1\ \text{year}}{300\ \text{day}}\ \bigg|\ \frac{1\ \text{day}}{24\ \text{hours}}$$

= 270833 kg/hr

So, the production rate of biomethane for the working days of 300 is 270833 kg/hr

Reactants rate:

$$\text{Yield} = \frac{product}{reactant}$$

$$\text{Reactant} = \frac{270833}{0.60}$$

Reactant supplied flow rate = 451388 $\frac{kg}{hr}$

3.1 LHW Pre-treatment Reactor (R-201):

Liquid hot water pretreatment mainly utilizes hot water instead of steam at temperatures 170°C and Pressure 10 bar. In this process, cellulose undergoes the hydrolysis reaction and as a result glucose is formed.

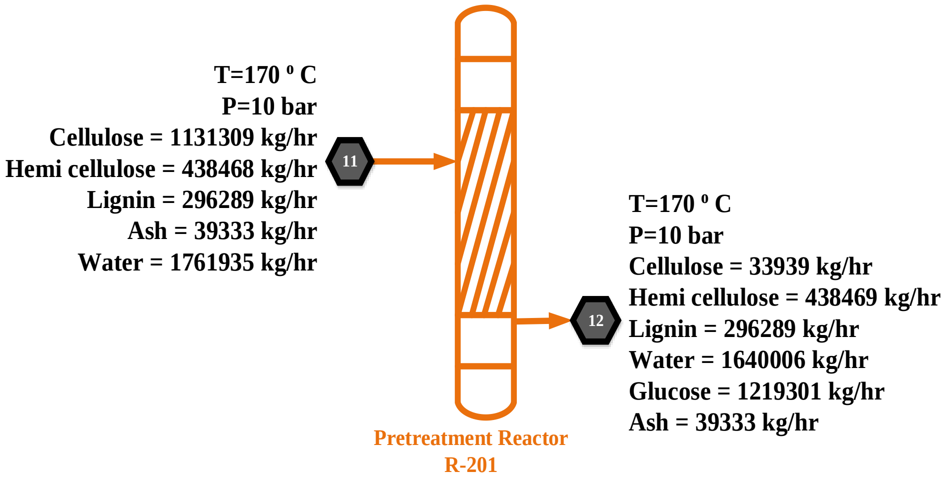


Fig no 3.1: Pre-Treatment Reactor (R-201)

Reaction:

$$C_6H_{10}O_5 + H_2O \longrightarrow C_6H_{12}O_6 \qquad \text{Conversion} = 97\% \qquad (3.1)$$

Table 3-1: Flow Rates of Input streams

	Input(kg/hr)				
	Stream 11				
Component	Bagasse	1966649	Press Mud	451388	Water
Cellulose	55%	1081657	11%	49652	-
Hemi-Cellulose	20%	393329	10%	45138	-
Lignin	13%	255664	9%	40624	-
Water	10%	196664	70%	315971	1249299
Ash	2%	39332	-	-	-
	1966649		451388		1291400
Total	**3667336**				

Amount of Cellulose present = 1131309 kg/hr

Amount of Cellulose reacted = 1131309 × 0.97 kg/hr

= 1097370 kg/hr

Amount of Cellulose unreacted = 1131309 -1097370 kg/hr

= 33939 kg/hr

Moles of Cellulose reacted = 6773 kmol/hr

Amount of Water reacted = 121930 kg/hr

Amount of Water unreacted = 1640005 kg/hr

Amount Glucose Formed = 1219300 kg/hr

Table 3.2: Material Balance around Pretreatment Reactor (R-201)

	Input(kg/hr)					**Output(kg/hr)**
	Stream 11					**Stream 12**
Component	Bagasse	1966649	Press Mud	451388	Water	-
Cellulose	55%	1081657	11%	49652	-	33939
Hemi-Cellulose	20%	393329	10%	45138	-	438468
Lignin	13%	255664	9%	40624	-	296289
Water	10%	196664	70%	315971	1249299	1640005
Glucose	-	-	-	-	-	1219300
Ash	2%	39332	-	-	-	39333
	1966649		451388		1249299	-
Total	**3667336**					**3667336**

3.2 Anaerobic Reactor (R-202):

Anaerobic digesters undergo processes without oxygen that produce biogas, with CH4 as the primary component.

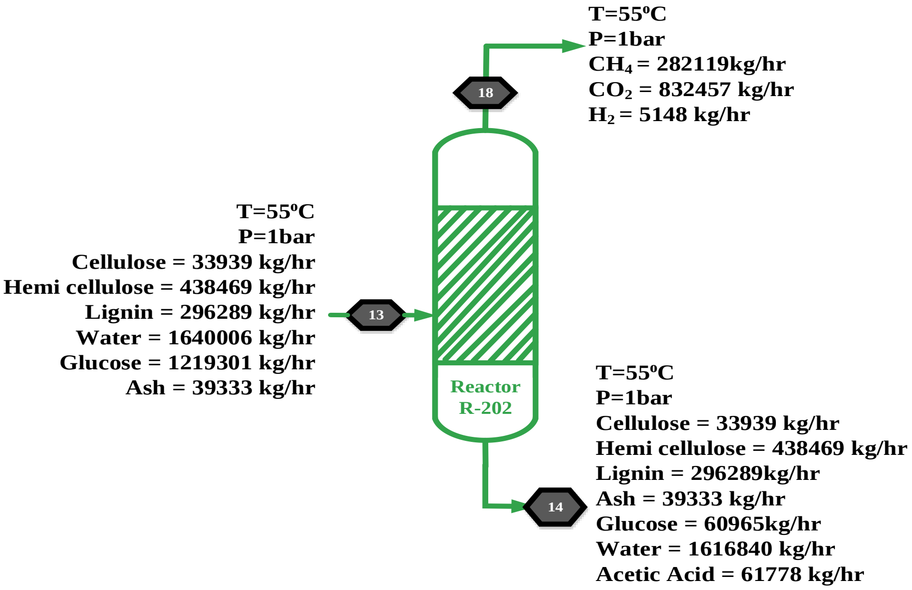


Fig no 3.2 : Anaerobic Reactor (R-202)

The principal reaction sequences in these key steps are:

Reactions:

$C_6H_{12}O_6 + 2H_2O \longrightarrow 2CH_3COOH + 2CO_2 + 4H_2$ Conversion = 95% (3.2)

$4H_2 + CO_2 \longrightarrow 2H_2O + CH_4$ Conversion = 45% (3.3)

$2CH_3COOH \longrightarrow 2CH_4 + 2CO_2$ Conversion = 92% (3.4)

Table 3.3: Flow Rates of Input streams

Input(kg/hr)	
Components	**Stream 13**
Cellulose	33939
Hemi Cellulose	438468
Lignin	296289
Water	1640005
Glucose	1219300
Ash	39332
Total	**3667336**

For Reaction 1:

$$C_6H_{12}O_6 + 2H_2O \longrightarrow 2CH_3COOH + 2CO_2 + 4H_2 \tag{3.5}$$

Amount of Glucose present = 1219300 kg/hr

Conversion = 95%

Amount of Glucose Reacted= 1219300 × 0.95

= 1158335 kg/hr

Amount of Glucose unreacted = 1219300- 1158335

= 60965 kg/hr

Moles of Glucose reacted = 6435 kmol/hr

Amount of water reacted = 231667 kg/hr

Amount of water unreacted = 1640005 - 231667 kg/hr

= 1408338 kg/hr

Amount of Acetic Acid Formed=772223 kg/hr

Amount of Carbon dioxide Formed = 566297 kg/hr

Amount of Hydrogen Formed = 51481 kg/hr

For Reaction 2:

$$4H_2 + CO_2 \longrightarrow 2H_2O + CH_4 \tag{3.6}$$

Conversion = 45%

Amount of Carbon dioxide reacted=566297 × 0.45

= 254833 kg/hr

Amount of Carbon dioxide unreacted = 566297 - 254833

= 311463 kg/hr

Moles of Carbon dioxide reacted = 5791 kmol/hr

Amount of Hydrogen reacted = 46333 kg/hr

Amount of Hydrogen unreacted = 51481-46333 kg/hr

=5148 kg/hr

Amount of Water Formed = 208500 kg/hr

Amount of CH_4 Formed = 92666 kg/hr

For Reaction 3:

$$2CH_3COOH \longrightarrow 2CH_4 + 2CO_2 \qquad (3.7)$$

Conversion: 92%

Amount of CH_3COOH reacted = 772223 × 0.92 kg/hr

= 710445 kg/hr

Amount of CH_3COOH unreacted= 772223 - 710445 kg/hr

= 61777 kg/hr

Moles of CH_3COOH reacted = 5920 kmol/hr

Amount of CH_4 Formed = 189452 kg/hr

Amount of CO_2 Formed = 520993 kg/hr

Total CH_4 = 282119 kg/hr

Total CO_2= 832457 kg/hr

Table 3.4: Material Balance around Anaerobic Reactor (R-202):

	Input(kg/hr)	**Output(kg/hr)**	
Components	**Stream 13**	**Stream 14**	**Stream 18**
Cellulose	33939	33939	
Hemi Cellulose	438468	438468	
Lignin	296289	296289	
Water	1640005	1616839	
Glucose	1219300	60965	
Ash	39332	39332	
H_2			5148
CH_4			282119
CO_2			832457
CH_3COOH		61777	
		2547612	1119724
Total	**3667336**	**3667336**	

3.3 Decanter Centrifuge (D-101):

Decanter Centrifuge is used for separation of solid and liquid , as liquid fraction is light and is separated from top right while solid fraction is separated from bottom of decanter.

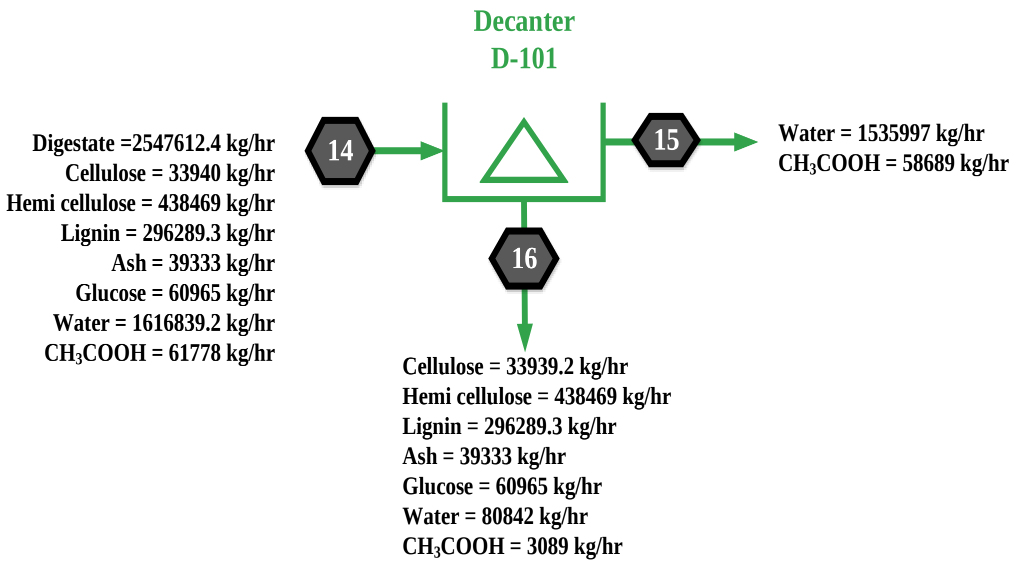


Fig no 3.3 : Decanter Centrifuge (D-101)

Efficiency of Decanter = 95%

Table 3.5: Flow Rates of Input streams

Input(kg/hr)	
Components	**Stream 14**
Cellulose	33939
Hemi Cellulose	438468
Lignin	296289
Glucose	60965
Ash	39332
CH_3COOH	61777
Water	1616839
Total	**2547612**

Table 3.6 Material Balance around Decanter Centrifuge (D-101)

	Input(kg/hr)	**Output(kg/hr)**	
Components	**Stream 14**	**Stream 15**	**Steam 16**
Cellulose	33939	-	33939
Hemi Cellulose	438468	-	438468
Lignin	296289	-	296289
Glucose	60965	-	60965
Ash	39332	-	39332
CH_3COOH	61777	58689	3088
Water	1616839	1535997	80841
	-	1594686	952926
Total	**2547612**	**2547612**	

3.4 Scrubber (SC-101):

Biogas from Anaerobic reactor is injected into scrubber from bottom where Carbon dioxide is removed from biogas using water as a solvent so that biogas is upgraded to biomethane.

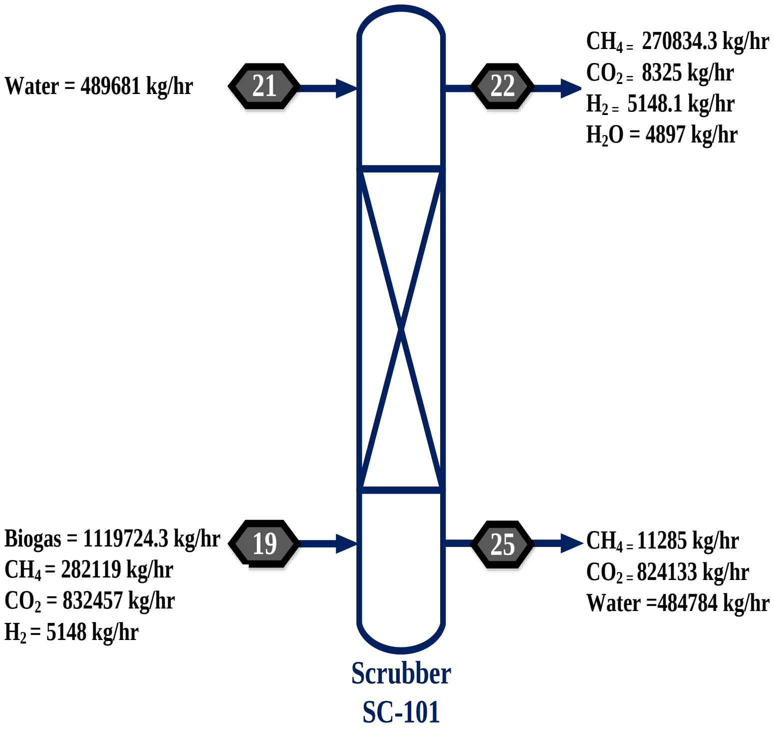


Fig no 3.4 : Scrubber (SC-101)

Table 3.7: Flow Rates of Input streams

	Input(kg/hr)	
Component	**Stream 19**	**Stream 21**
CH_4	28119	
CO_2	832457	
H_2	5148	
H_2O	4896	489680
Total	**1609405**	

Solubility of gases CO_2 and CH_4 at 30C⁰ [20]

CH_4 =0.024 kg/L

CO_2= 1.7 kg/L

Top Composition

CH_4 = 96%

CO_2 = 1%

H_2O =1%

Bottom Composition

CH_4 = 4%

CO_2 = 99%

H_2O = 99%

Solvent Water Flowrate

Density of water = 1000 kg/m3 = 1 kg/L

Water required for CO_2 = $\frac{Flow\ rate}{Solubility}$ × Density of solvent

$$= \frac{832457\ kg/hr}{1.7\ kg/L} \times 1\ \text{kg/L}$$

Water required = 489680 kg/hr

Table 3.8 Material balance around Scrubber(Sc -101):

	Inputs (kg/hr)		**Outputs (kg/hr)**	
Component	**Stream 19**	**Stream 21**	**Stream 22**	**Stream 25**
CH_4	28119	-	270834	11284
CO_2	832457	-	824	824132
H_2	5148	-	5148	-
H_2O	-	28119.06464	4896	484783
	-		289203	1320201
Total	**1609405**		**1609405**	

3.5 Separator (S-101):

In the separation unit methane gas is separated out on the bases of pressure reduction as well as on difference of solubility of gases present in mixture of feed stream.

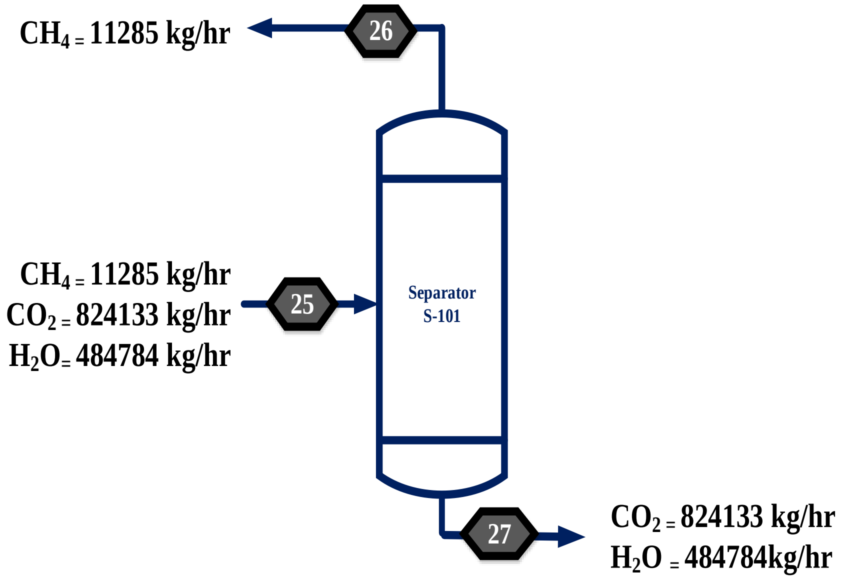


Fig no 3.5 : Separator (S-101)

Table 3.9: Flow Rates of Input streams

Inputs (kg/hr)	
Component	**Stream 25**
CH_4	11284
CO_2	824132
H_2O	48783
Total	**1320201**

Methane removed = 99.9%

Table 3.10 Material balance around Separator(S -101):

	Input (kg/hr)		Output (kg/hr)
Component	**Stream 25**	**Stream 26**	**Stream 27**
CH_4	11284	11284	
CO_2	824132		824132
H_2O	484783		484783
		11284	1308916
Total	**1320201**	**1320201**	

3.6 Stripper (ST-101):

In stripper air is used to remove carbon dioxide from by product stream it will regenerate solvent (water) used in scrubbing process.

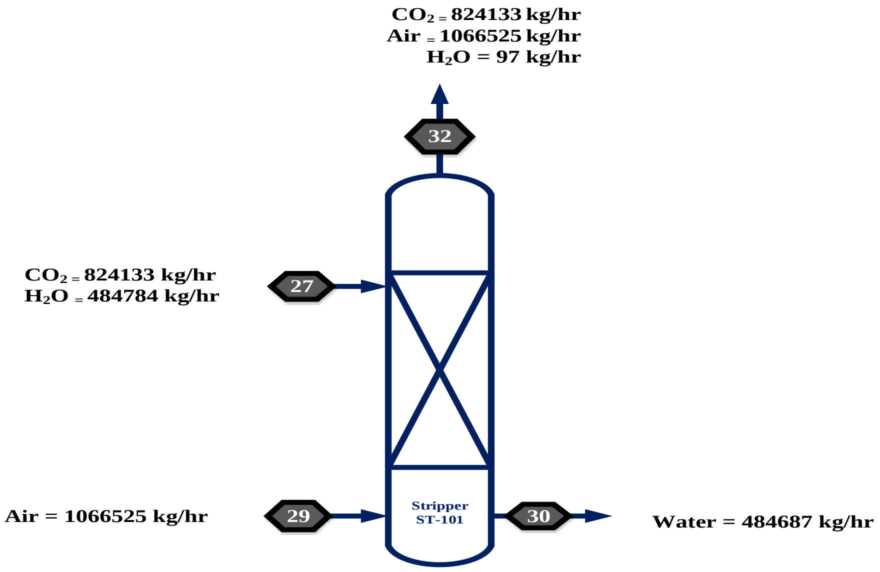


Fig no 3.6: Stripper (ST-101)

Table 3.11:Flow Rates of Input streams

Input(kg/hr)		
Component	**Stream 27**	**Stream 29**
CO_2	824132	-
H_2O	484783	-
Air	-	1066524
	1308916	1066524
Total	**2375440**	

<u>Air Required:</u>

Water = 484783 kg/hr

Air : Water

2.2 : 1

1066524 : 484783

kg/hr : kg/hr

Table 3.12: Material Balance around Stripper (ST-101)

	Input(kg/hr)		**Output(kg/hr)**	
Component	**Stream 27**	**Stream 29**	**Stream 32**	**Stream 30**
CO_2	824132.		824132	
H_2O	484783		97	484686
Air		1066524	1066525	
	1308916	1066524	1890754	484686
Total	**2375440**		**2375440**	

3.7 Dehydrator (D-201):

The purpose of dehydrator is just to remove the moisture content from the biomethane.

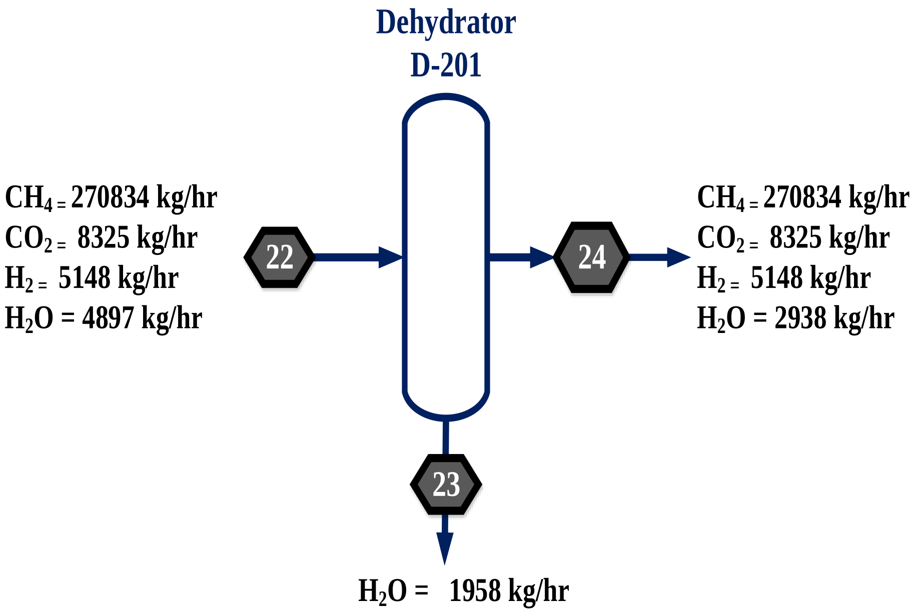


Fig no 3.7: Dehydrator (D-201)

Table 3.13: Flow Rates of Input streams

Input	
Component	**Stream 22 (kg/hr)**
CH_4	270834
CO_2	8325
H_2	5148
H_2O	4896
Total	**289203**

Dehydrator consists of Silica Gel which has 40% tendency of adsorbing water as product stream has very less amount of water in it which is useful in other application.

Table 3.14:Material Balance around Dehydrator (D-201)

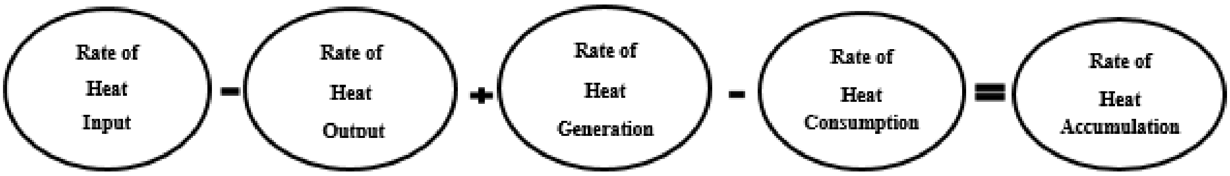
	Input (kg/hr)	**Output (kg/hr)**		**Fraction**
Component	**Stream 22**	**Stream 23**	**Stream 24**	**Mass Fractions**
CH_4	270834		270834	0.94
CO_2	8325		8325	0.03
H_2	5148		5148	0.02
H_2O	4897	1959	2938	0.01
	289203	1959	287245	1
Total	**289203**	**289203**		1

CHAPTER # 4

ENERGY BALANCE

4-Energy Balance

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:



4.1 Heat Exchanger (HX-100):

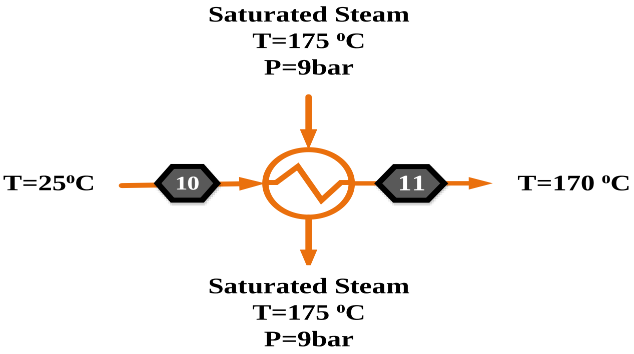


Fig no 4.1 Heat Exchanger (HX-100)

Table 4.1:Specific Heat Capacities

Component	Mass Flow rate (kg/hr)	Specific Heat Capacity (kJ/kg.K) at 370 K
Cellulose	1131309	0.5
Hemi cellulose	438468	0.7
Lignin	296289	0.3
Water	1761935	4.16
Ash	39332	0.2

Temperatures:

Inlet Temperature =T_{in} = 25 ⁰C

Outlet Temperature=T_{out} = 170 ⁰C

Average Temperature = T_{avg} = 97 ⁰C

Difference of Temperature = ΔT = 145 ⁰C

Heat Balance:

$Q = (\Sigma \dot{m} \times Cp) \times \Delta T$

$Q = =((1131309\times0.5)+(438468\times0.7)+(1761935\times4.16)+(296289\times0.3)+(39332\times0.2))\times145$

Q = 1203353 MJ/hr

Utility Steam Requirement:

Pressure = P = 9 bar

Temperature =T = 175 ⁰C

Heat of vaporization =λ = 2030 kJ/kg

$Q = \dot{m}\,\lambda$

$\dot{m}$ = 1203352796 /2030

$\dot{m}$ = 592784 kg/hr

mass flow rate of utility = 6×10^5 kg/hr

Table 4.2:Energy Balance around Heat Exchanger (HX-100)

Component	Mass Flow rate (kg/hr)	Specific Heat Capacity (kJ/kg.K) at 370 K	Heat Duty
Cellulose	1131309	0.5	1203353 MJ/hr
Hemi cellulose	438468	0.7	
Lignin	296289	0.3	
Water	1761935	4.16	
Ash	39332	0.2	

4.2 LHW Pre-treatment Reactor (R-201):

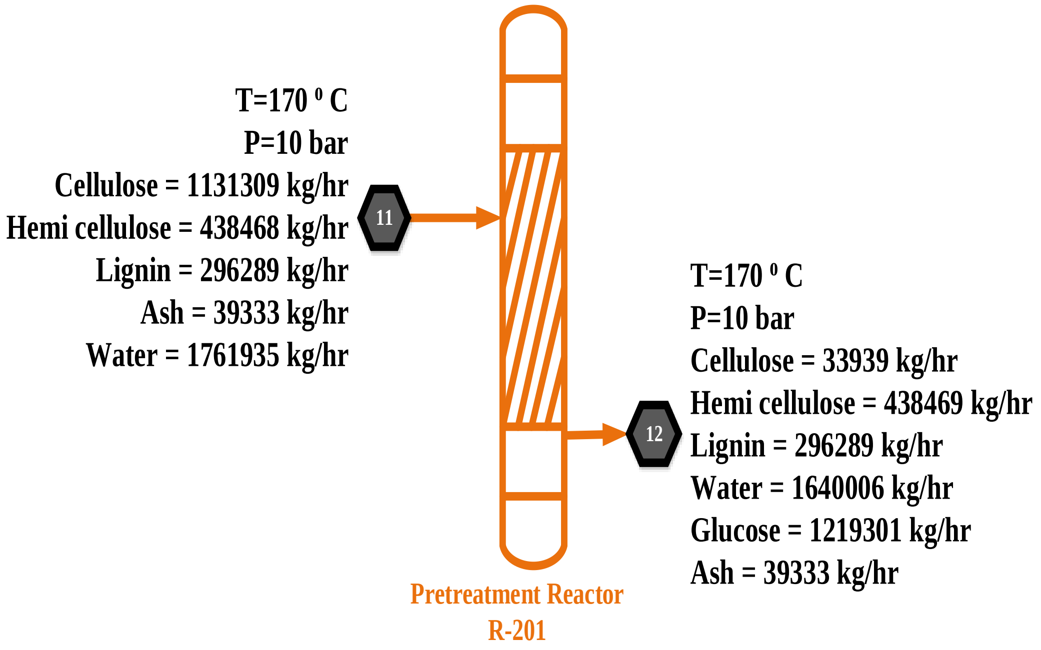


Fig no 4.2: Pre-Treatment Reactor (R-201)

Reaction:

$$C_6H_{10}O_5 + H_2O \longrightarrow C_6H_{12}O_6 \qquad \text{Conversion} = 97\% \qquad (4.1)$$

Table 4.3:Specific Heat Capacities

Component	Mass Flow Rate (kg/hr)	Specific Heat Capacity (kJ/kg.K) at 370K
Cellulose	1131309	0.5
Hemi cellulose	438468	0.7
Lignin	296289	0.3
Water	1761935	4.16
Ash	39332	0.2
Glucose	1219300	1.3

Temperatures:

Inlet Temperature $=T_{in} = 25\ ^oC$

Outlet Temperature$=T_{out} = 170\ ^oC$

Average Temperature $= T_{avg} = 97\ ^oC$

Difference of Temperature $= \Delta T = 145\ ^oC$

Table 4.4:Heat of Formation at 25⁰C

Component	Heat of Formation($\Delta\hat{H}_f^0$) (KJ/mol)
Cellulose	-950
Water	-285.8
Glucose	-1260

Heat of reaction:

At 25 ⁰C

$$\Delta\hat{H}_{r,\,298K} = \Sigma\,\hat{H}_{f\,Product} - \Sigma\,\hat{H}_{f\,Reactants} \qquad (4.2)$$

$$\Delta\hat{H}_{r,\,298K} = ((-1260)-(-950-285.8))$$

$$\Delta\hat{H}_{r,\,298K} = -24.2\ \text{kJ/mol}$$

$$\Delta\hat{H}_{r,\,298K} = -24200\ \text{kJ/kmol}$$

Heat of reaction:

At 443 ⁰C

$$\Delta\hat{H}_{r,\,443} = \Delta\hat{H}_{r,298K} + \int_{298}^{443}[(n\text{Cp})\text{P} - (\text{nCp})\text{R}]\text{dT} \qquad (4.3)$$

$$= -24200 + (81\times(298-443)+75\times(298-443)+294\times(443-298))$$

$$= -12872.6\ \text{kJ/kmol}$$

$$= -87186119.8\ \text{kJ/hr}$$

Heat Balance:

$Q = (\Sigma\dot{m}\times Cp)\times\Delta T$

Q input

$Q=((1131309\times0.5\times145)+(438468\times0.7\times145)+(1761935\times4.16\times145)+(296289\times0.3\times145)$
$+(39332\times0.2\times145))$

$Q = 1203352$ MJ/hr

Q Output

Q=((33939×0.5×145)+(438468×0.7×145)+(1640005×4.16×145)+(296289×0.3×145)

+(39332×0.2×145)+(1219300×1.3×145))

Q = 1280083 MJ/hr

For Exothermic Reaction:

For exothermic reaction overall energy balance equation is written as;

Rate of heat Q $_{in}$ - Rate of heat Q $_{out}$ + Heat of reaction(- ΔHr) - Heat Q $_{removed}$ = 0 (4.4)

Heat Removed = Input Heat – Output Heat + $\Delta Hr,_{443K}$

= 1203352 MJ/hr - 1280083×10^4 MJ/hr + 87186 MJ/hr

= 10455 MJ/hr

Rate of heat Q $_{in}$ + Heat of reaction (-ΔHr) = Rate of heat Q $_{out}$ + Heat Q $_{removed}$ (4.5)

1203352 MJ/hr + 87186 MJ/hr = 1280083 MJ/hr + 10455 MJ/hr

1290538MJ/hr = 1290538MJ/hr

Cooling Water Requirement:

As rection is exothermic so there is a need of cooling media to maintain temperature of reactor so we have to calculate the amount of water.

Temperature Difference = ΔT = 20 ºC

Specific Heat Capacity = Cp = 4.16 kJ/kg.K

$Q = \dot{m}\times Cp\times \Delta T$

$\dot{m} = \frac{Q}{Cp\times \Delta T}$

$\dot{m} = \frac{10455570}{4.16\times 20}$

ṁ = 12566 kg/hr

Mass flow rate of cooling water = 12566 kg/hr

Table 4.4: Energy Balance around Pretreatment Reactor (R-201)

Component	**Mass Flow Rate (kg/hr)**	**Specific Heat Capacity (kJ/kg.K) at 370K**	**Q Input (MJ/hr)**	**Q out (MJ/hr)**
Cellulose	1131309	0.5	82020	2461
Hemi cellulose	438468	0.7	44505	44505
Lignin	296289	0.3	12888	12888
Water	1761935	4.16	1062799	989251
Ash	39332	0.2	1140	1140
Glucose	1219300	1.3	-	229838
Q removed	-	-	-	10455
Heat of reaction	-	-	87186	-
Total			**1290538**	**1290538**

4.3 Waste Heat Boiler (WHB-101):

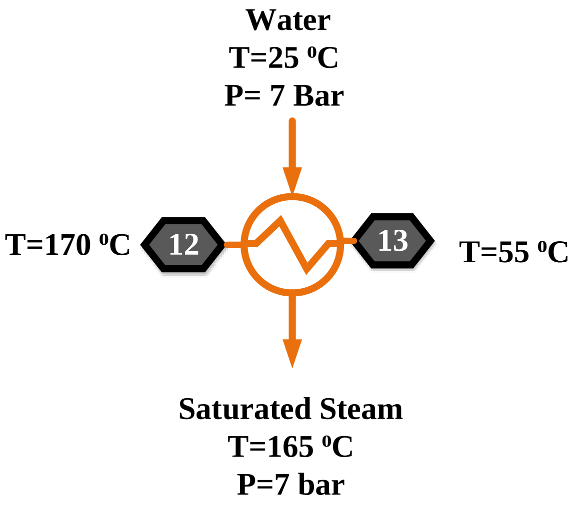


Fig no 4.3 Waste Heat Boiler (WHB-101)

Table 4.5:Specific Heat Capacities

Component	Mass Flow rate (kg/hr)	Specific Heat Capacity (kJ/kg.K) at 345K
Cellulose	33939	0.58
Hemi cellulose	438468	0.8
Lignin	296289	0.4
Water	1640005	4.16
Ash	39332	0.2
Glucose	1219300	1.4

Temperatures:

Inlet Temperature =T_{in} = 170 ºC

Outlet Temperature=T_{out} = 55 ºC

Average Temperature = T_{avg} = 112 ºC

Difference of Temperature = ΔT = 115 ºC

Heat Balance:

$Q = (\Sigma \dot{m} \times Cp) \times \Delta T$

$Q = ((33939 \times 0.58)+(438468 \times 0.8)+(1640005 \times 4.16)+(296289 \times 0.4)+(39332 \times 0.2)+(1219300 \times 1.4)) \times 145$

Q = 187844 MJ/hr

Utility Cooling Water Requirement:

Temperature difference = ΔT = 140 ºC

Heat of vaporization =λ = 2064 kJ/kg

$Q = \dot{m} \times Cp \times \Delta T + \dot{m} \times \lambda$

$187844334 = \dot{m} (4.16 \times 140 + 2064)$

$\dot{m}$ = 70981 kg/hr

mass flow rate of utility = 70981 kg/hr

Table 4.6:Energy Balance around Waste Heat Boiler (HX-101)

Component	Mass Flow rate (kg/hr)	Specific Heat Capacity (kJ/kg.K) at 370 K	Heat Duty
Cellulose	33939	0.5	187844 MJ/hr
Hemi cellulose	438468	0.8	
Lignin	296289	0.4	
Water	1640005	4.16	
Ash	39332	0.2	
Glucose	1219300	1.4	

4.4 Anaerobic Reactor (R-202):

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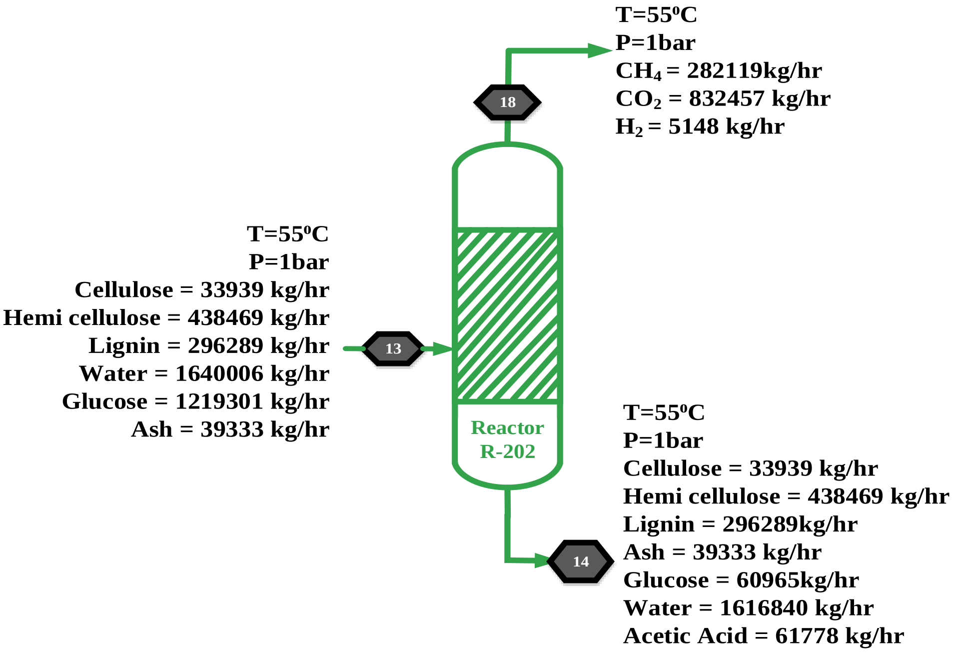

Fig no 4.4 : Anaerobic Reactor (R-202)

The principal reaction sequences in these key steps are:

Reactions:

$C_6H_{12}O_6 + 2H_2O \longrightarrow 2CH_3COOH + 2CO_2 + 4H_2$ Conversion = 95%

$4H_2 + CO_2 \longrightarrow 2H_2O + CH_4$ Conversion = 45%

$2CH_3COOH \longrightarrow 2CH_4 + 2CO_2$ Conversion = 92%

Table 4.7:Specific Heat Capacities

Component	Mass Flow rate (kg/hr)	Specific Heat Capacity (kJ/kg.k) at 313 K
Cellulose	1131309	0.25
Hemi cellulose	438468	0.5
Lignin	296289	0.2
Water	1761935	4.16
Ash	39332	0.1
Glucose	1219300	1.13
Acetic Acid	61777	2.12
H_2	5148	14.4
CH_4	282119	2.25
CO_2	832457	1

Temperatures:

Inlet Temperature =T_{in} = 55 ^oC

Outlet Temperature=T_{out} = 55^oC

Reference Temperature = T_{ref} = 25 ^oC

Average Temperature = T_{avg} = 40 ^oC

Difference of Temperature = ΔT = 30 ^oC

Table 4.8:Heat of Formation at 25^oC

Components	Heat of Formation ($\Delta \hat{H}_f^0$) (kJ/mol)
Glucose	-1260
water	-285.8
Acetic Acid	-486.18
Methane	-74.85
Carbon dioxide	-393.5
Hydrogen	0

Heat of reaction

At 298k:

For First Reaction:

$$\Delta\hat{H}_{r,\,298K} = \Sigma\,\hat{H}_{f\,Product} - \Sigma\,\hat{H}_{f\,Reactants}$$

$\Delta\hat{H}_{r,\,298K}$ = (2×(-486.16)-2×(393.5))-(-1260-2×(285.8))

$\Delta\hat{H}_{r,\,298K}$ = 72.2 kJ/mol

$\Delta H_{r,\,298K}$ = 72240 kJ/kmol

For Second Reaction:

$\Delta\hat{H}_{r,\,298K}$=2×(-285.8)-(74.85)+(393.5)

$\Delta\hat{H}_{r,\,298K}$ = - 252 kJ/mol

$\Delta H_{r,\,298K}$ = - 252950 kJ/kmol

For Third Reaction:

$\Delta\hat{H}_{r,\,298K}$=(2×(-74.8)-2×(393.5)-(2×(-486.18))

$\Delta\hat{H}_{r,\,298K}$ = 35.76 kJ/mol

$\Delta H_{r,\,298K}$ = 35760 kJ/kmol

Heat of reaction:

At 328 ^{o}C

$$\Delta\hat{H}_{r,\,443} = \Delta\hat{H}_{r,298K} + \int_{298}^{328} [(n\mathrm{Cp})\mathrm{P} - (\mathrm{nCp})\mathrm{R}]\mathrm{dT}$$

For First Reaction:

$\Delta\hat{H}_{r,\,328K}$ = 72240 +(2×127×(328-298)+2×44×(328-298)+4×28.8×(328-298)+40.5×(298-328)+2×74.8×(298-328))

$\Delta\hat{H}_{r,\,328K}$ = 80300.2 kJ/kmol

$\Delta\hat{H}_{r,\,328K}$ = 516731787 kJ/hr

For Second Reaction:

$\Delta\hat{H}_{r,\,328K}$ = - 252950+(2×74.8× (328-298)+44× (328-298)+4×28.8× (298-328)+36×(298-328))

$\Delta\hat{H}_{r,\,328K}$ = -252153.2 kJ/kmol

$\Delta\hat{H}_{r,\,328K}$ = -1460219181 kJ/hr

For Third Reaction:

$\Delta\hat{H}_{r,\,328K}$ = 35760+(2×36× (328-298)+2×44× (328-298)+2×127.2× (298-328))

$\Delta\hat{H}_{r,\,328K}$ = 32928 kJ/kmol

$\Delta\hat{H}_{r,\,328K}$ = 194933760 kJ/hr

<u>Total Heat of rection:</u>

Heat of reaction = 516731787 kJ/hr +(-1460219181 kJ/hr)+ 194933760 kJ/hr

= -748553634 kJ/hr

<u>Heat Balance:</u>

Q = (Σṁ×Cp)×ΔT

Q input:

Q=((33939×0.25×30)+(438468×0.5×30)+(1640005×4.16×30)+(296289×0.2×30)

+(39332×0.1×30)+(1219300×1.13×30)

Q = 254734 MJ/hr

Q Output:

Q=((33939×0.25×30)+(438468×0.5×30)+(1616839×4.16×30)+(296289×0.2×30)

+(39332×0.1×30)+(60695×1.13×30))+(832457×1×30))+(282119×2.25×30))

+(5148×14.4×30)

Q = 262736 MJ/hr

For Exothermic Reaction:

Rate of heat Q_{in} - Rate of heat Q_{out} + Heat of reaction(- ΔHr) - Heat $Q_{removed}$ = 0

Heat Removed = Input Heat – Output Heat + $\Delta Hr_{,328K}$

= 254734 MJ/hr – 262736 MJ/hr + 748554MJ/hr

= 740552 MJ/hr

Rate of heat Q in + Heat of reaction (-ΔHr) = Rate of heat Q out + Heat Q removed

254734MJ/hr + 748554 MJ/hr = 262736MJ/hr + 740552MJ/hr

1003288 MJ/hr = 1003288 MJ/hr

Cooling Water Requirement:

Temperature Difference = $\Delta T = 20\ ^oC$

Specific Heat Capacity = Cp = 4.16 kJ/kg.K

$Q = \dot{m} \times Cp \times \Delta T$

$$\dot{m} = \frac{Q}{Cp \times \Delta T}$$

$$\dot{m} = \frac{740551764}{4.16 \times 293}$$

Mass flow rate of cooling water = 607567 kg/hr

Table 4.9:Energy Balance around Anaerobic Reactor (R-202)

Component	Mass Flow rate (kg/hr)	Specific Heat Capacity (kJ/kg.k) at 313 K	Q Input (MJ/hr)	Q out (MJ/hr)
Cellulose	1131309	0.25	254	254
Hemi cellulose	438468	0.5	6577	6577
Lignin	296289	0.2	1778	1778
Water	1761935	4.16	204673	201781
Ash	39332	0.1	118	118
Glucose	1219300	1.13	41334	2058
Acetic Acid	61777	2.12	-	3929
H_2	5148	14.4	-	2224
CH_4	282119	2.25	-	19043
CO_2	832457	1	-	24974
Q removed	-	-	-	740552
Heat of reaction	-	-	748554	-
Total			1003288	1003288

4.5 Waste Heat Boiler (WHB-102):

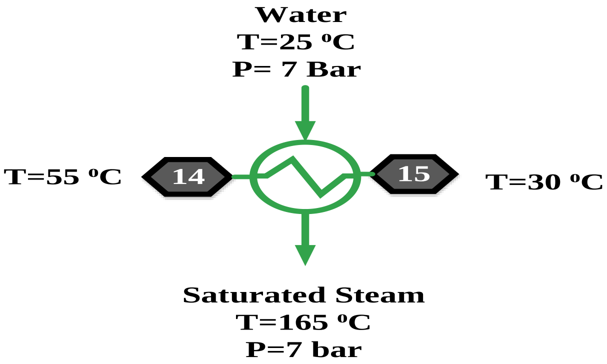

Fig no 4.5 Waste Heat Boiler (WHB-102)

Table 4.10:Specific Heat Capacities

Component	Mass Flow rate (kg/hr)	Specific Heat Capacity (kJ/kg.K) at 315K
Cellulose	33939	0.25
Hemi cellulose	438468	0.5
Lignin	296289	0.2
Water	1616839	4.16
Ash	39332	0.1
Glucose	60965	2.12

Temperatures:

Inlet Temperature =T_{in} = 55 ºC

Outlet Temperature=T_{out} = 30 ºC

Average Temperature = T_{avg} = 42 ºC

Difference of Temperature = ΔT = 25 ºC

Heat Balance:

$Q = (\Sigma \dot{m} \times Cp) \times \Delta T$

$Q = ((33939\times0.25)+(438468\times0.5)+(1616839\times4.16)+(296289\times0.2)+(39332\times0.1)+(60965\times2.12))$

$\times 25$

Q = 167660 MJ/hr

Utility Cooling Water Requirement:

Temperature Difference = ΔT = 140 ºC

Heat of vaporization = λ = 2064 kJ/kg

$Q = \dot{m}\times Cp\times \Delta T + \dot{m}\times \lambda$

$167660488 = \dot{m}\,(4.16\times 140 + 2064)$

$\dot{m}$ = 63354 kg/hr

mass flow rate of utility = 63354 kg/hr

Table 4.11:Energy Balance around Waste Heat Boiler (HX-102)

Component	Mass Flow rate (kg/hr)	Specific Heat Capacity (kJ/kg.K) at 315 K	Heat Duty
Cellulose	33939	0.25	167660 MJ/hr
Hemi cellulose	438468	0.5	
Lignin	296289	0.2	
Water	1616839	4.16	
Ash	39332	0.1	
Glucose	60965	2.12	

4.6 Heat Exchanger (HX-101):

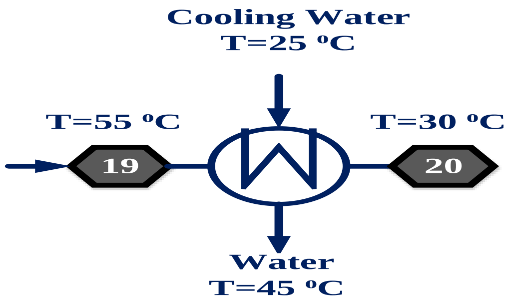

Fig no 4.6 Heat Exchanger (HX-101)

Table 4.12:Specific Heat Capacities

Component	Mass Flow rate (kg/hr)	Specific Heat Capacity (kJ/kg.K) at 315 K
CO_2	282119	1.04
CH_4	832457	2.3
H_2	5148	14.5

Temperatures:

Inlet Temperature =T_{in} = 55 ºC

Outlet Temperature=T_{out} = 30 ºC

Average Temperature = T_{avg} = 42 ºC

Difference of Temperature = ΔT = 25 ºC

Heat Balance:

$Q = (\Sigma \dot{m} \times Cp) \times \Delta T$

$Q = =((282119 \times 1.04)+(832457 \times 2.3)+(5148 \times 14.5)) \times 25$

Q = 351 MJ/hr

Utility Steam Requirement:

Temperature difference =ΔT = 20 ºC

$Q = \dot{m} \times Cp \times \Delta T$

$\dot{m} = 351521 / 4.16 \times 20$

$\dot{m}$ = 4225 kg/hr

mass flow rate of utility = 4225 kg/hr

Table 4.13:Energy Balance around Heat Exchanger (HX-101)

Component	Mass Flow rate (kg/hr)	Specific Heat Capacity (kJ/kg.K) at 315 K	Heat Duty
CO_2	282119	1.04	351 MJ/hr
CH_4	832457	2.3	
H_2	5148	14.5	

CHAPTER # 5

PROCESS EQUIPMENT DESIGN

5-Equipment Design

5.1 Heat Exchanger (HX-100):

Spiral Plate Heat Exchanger:

A spiral plate heat exchanger (SPHE) is a type of heat exchanger that consists of two plates, typically made of stainless steel, that are coiled around a central core to form a spiral-shaped channel. The two plates are welded together to form a continuous channel that allows two fluids to flow in opposite directions, without mixing, while exchanging heat.. Overall, SPHEs offer a number of advantages over traditional heat exchangers, including high heat transfer rates, low pressure drops, and compact design. They are also easy to clean and maintain, making them a popular choice in a wide range of industrial applications. We are selecting spiral plate heat exchanger because of slurry flow through the exchanger and spiral plate heat exchanger are used for slurry and the fluid which has high viscosity and also our slurry has high viscosity.

SPHEs are used in a wide range of industrial applications that involve heat transfer between two fluids, such as heating, cooling, condensation, and evaporation. Some of the most common industrial applications of SPHEs include:

1. Chemical processing: SPHEs are widely used in the chemical processing industry to transfer heat between two fluids, such as cooling water and process fluids. They are particularly useful in applications where one fluid is corrosive or fouling, as the spiral design allows for easy cleaning and maintenance.
2. Food and beverage processing: SPHEs are commonly used in the food and beverage industry to heat or cool liquids, such as milk, juice, and beer. They are also used in the processing of viscous fluids, such as tomato sauce, where the spiral design helps to prevent clogging and fouling.
3. HVAC systems: SPHEs are used in heating, ventilation, and air conditioning (HVAC) systems to transfer heat between two fluids, such as hot water and air. They are particularly useful in applications where space is limited, as the spiral design allows for a large heat transfer area in a compact unit.
4. Power generation: SPHEs are used in power generation systems to cool the working fluid in steam turbines, as well as to preheat the feedwater before it enters the boiler.

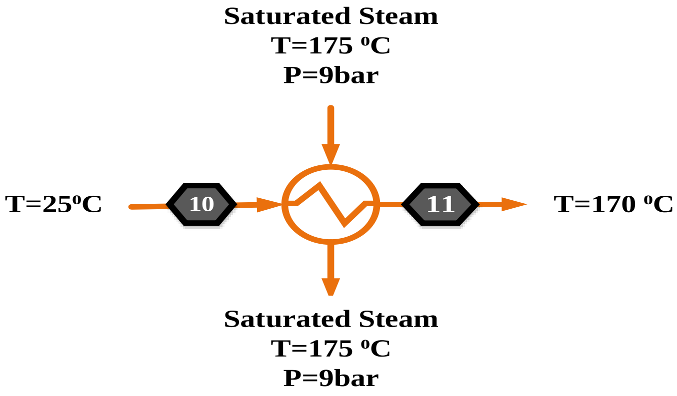

Fig no 5.1 Heat Exchanger (HX-100)

Design Calculations:

Temperatures:

Inlet Temperature $=T_{in} = 25$ ºC

Outlet Temperature$=T_{out} = 170$ ºC

Average Temperature = $T_{avg} = 97$ ºC

Difference of Temperature = $\Delta T = 145$ ºC

Hot fluid (Lean solvent)	T_1(hot inlet)	175	°C	T_2 (hot outlet)	175	°C	T_{avg}	175	°C
Temperature differences	Δt_2 , Δt_h	5	°C	Δt_1, Δt_c	150	°C	Bulk mean Temperature		
Cold fluid (Rich solvent)	t_2 (cold outlet)	170	°C	t_1 (cold inlet)	25	°C	t_{avg}	97.5	°C

LMTD:

$$\mathbf{LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln\left(\frac{\Delta t_2}{\Delta t_1}\right)}$$

$$\mathrm{LMTD} = \frac{5 - 150}{\ln\left(\frac{5}{150}\right)} = 43°\mathrm{C} = 316\mathrm{K}$$

Area:

U_D=3975 W/m^2 °K

Allowable dirt factor R_d =0.003 on both sides

$$\mathrm{A} = \frac{\dot{\mathrm{Q}}}{(\mathrm{U}_D)(\mathrm{LMTD})}$$

$$\mathrm{A} = \frac{(334265000\ \mathrm{W})}{\left(3975\,\frac{\mathrm{W}}{\mathrm{m}^2\ °\mathrm{K}}\right)(316\ °\mathrm{K})}$$

$$\mathrm{A} = 266\ \mathrm{m}^2$$

Dimensions of Spiral Plate:

Specifications	**mm**	**m**
No of turns of Spiral	10	
Channel Spacing (d_h=d_c)	8	0.008
Pitch	20	0.02
Core Diameter (d_s)	150	0.15
Start diameter of inner spiral	170	0.17
Start diameter of outer spiral	192	0.192
Spiral thickness (t)	2	0.002
Length of spiral	8364	8.364
Spiral outer diameter	485	0.485
Width of plate	300	0.3
$Ds = \sqrt{(1.28 * L(dc + dh + 2t) + c^2)}$	485	0.485

Thermal Calculations	
Hot Side Calculation	**Cold Side Calculation**
Equivalent diameter	
$\text{D}_{eh} = \frac{2 \times d_h \times H)}{d_h \times H} = \frac{2 \times 0.008 \times 0.3048}{0.008 + 0.3048}$ $\text{D}_{eh} = 0.01547\text{m}$	$\text{D}_{ec} = \frac{2 \times d_c \times H)}{d_c + H} = \frac{2 \times 0.008 \times 0.3048}{0.008 + 0.3048}$ $\text{D}_{ec} = 0.01547\text{m}$
Mass Flux	
$\text{G} = \frac{m_h}{\text{A}_c} = \frac{m_h}{H \times d_h} = \frac{162 \text{ kg/s}}{0.008 \times 0.3048}$ $\text{G} = 66437 \frac{\text{kg}}{sec\ \text{m}^2}$	$\text{G} = \frac{m_c}{\text{A}_c} = \frac{m_c}{H \times d_c} = \frac{1018\text{kg/s}}{0.008 \times 0.3048}$ $\text{G} = 417486 \frac{\text{kg}}{sec\ \text{m}^2}$
Reynold Number	
$R_e = \frac{\text{Deh} \times \text{G}_a}{\mu_h}$ $= \frac{(0.01547 \text{ m}) \times (66437 \frac{\text{kg}}{sec\ \ \text{m}^2})}{0.000149 \frac{\text{kg}}{\text{m.sec}}}$ $R_e = 6897855$	$R_e = \frac{\text{Dec} \times \text{G}_a}{\mu_c}$ $= \frac{(0.01547 \text{ m}) \times (417486 \frac{\text{kg}}{sec\ \ \text{m}^2})}{1.4 \frac{\text{kg}}{\text{m.sec}}}$ $R_e = 4613$
Critical Reynold Number	
$R_e = 20000 \frac{D_{eh}^{0.32}}{D_s^{0.32}}$ $=20000\times\frac{0.01547^{0.32}}{0.485^{0.32}}=6640$	$R_e = 20000 \frac{D_{ec}^{0.32}}{D_s^{0.32}}$ $=20000\times\frac{0.01547^{0.32}}{0.485^{0.32}}=6640$
$P_r = \left(\frac{\boldsymbol{C_{ph}}\ \mu_h}{\boldsymbol{K_h}}\right)^{0.33}$	$P_r = \left(\frac{\boldsymbol{C_{pc}}\ \mu_c}{\boldsymbol{K_c}}\right)^{0.33}$

$$P_r = \frac{2773.04\,\frac{KJ}{Kg.K}\times 0.000149\,\frac{\text{kg}}{\text{m.sec}}}{34.58\,\frac{W}{m.K}}$$

$$\text{P}_r = 0.012$$

$$P_r = \frac{3.8\,\frac{KJ}{Kg.K}\times 1.4\,\frac{\text{kg}}{\text{m.sec}}}{0.6\,\frac{W}{m.K}}$$

$$\text{P}_r = 8$$

Heat Transfer Coefficient

$$h_h = \left(1 + 3.54 \times \frac{\text{D}_{eh}}{D_s}\right) \times 0.023 \times G \times R_e^{-0.2} \times P_r^{-0.67}$$

$$= \left(1 + 3.54 \times \frac{0.01547}{0.485}\right) \times 0.023 \times 2773.04 \times 66437 \times 6897855^{-0.2} \times 0.012^{-0.67}$$

$$= 3915270\,\frac{W}{m^2.K}$$

$$h_c = \left(1 + 3.54 \times \frac{\text{D}_{ec}}{D_s}\right) \times 0.023 \times C_{pc} \times G \times R_e^{-0.2} \times P_r^{-0.67}$$

$$= \left(1 + 3.54 \times \frac{0.01547}{0.485}\right) \times 0.023 \times 3.8 \times 417486 \times 4613^{-0.2} \times 8^{-0.67} = 1865\,\frac{W}{m^2.K}$$

Overall Heat Transfer Coefficient (U)

$$\frac{1}{h_h} = \frac{1}{3915270} = 0.0000003\,, \frac{1}{h_c} = \frac{1}{1865} = 0.0005$$

Stainless steel conductivity (k)=16.26 $\frac{W}{m^2.K}$, t = 2 mm = 0.002 m , $\frac{t}{K} = 0.000123$

$$\frac{1}{5000} = 0.00006661$$

$$U = \frac{1}{\frac{1}{h_h} + \frac{1}{h_c} + \frac{t}{k} + 0.00006 + 0.00006} = 1282\,\frac{W}{m^2.k}$$

Heat transfer area required (A)

$$A_2 = \frac{\dot{\text{Q}}}{(\text{U}_D)(\text{LMTD})} = 825\text{m}^2\,,$$

Excess Area

$$= \frac{A_2 - A}{A_2} = \frac{825 - 266}{825} = 0.67m^2$$

Number of turns of spiral (N)

$$N = \frac{-\left(d - \frac{d_{h,c}}{2}\right) + \sqrt{\left(d - \frac{d_{h,c}}{2}\right)^2 + \left(\frac{4 \times d_{h,c} \times L}{\pi}\right)}}{2 \times d_{h,c}} = 10$$

$$d_{h,c} = 0.0079m$$

$$d = 0.17m$$

$$L = 8.364m$$

<table>
<tr><th colspan="2">Hydraulic Calculations</th></tr>
<tr><th>Hot Fluid (Gases)</th><th>Cold Fluid (Water)</th></tr>
<tr><td>Pressure Drop
$\Delta \mathrm{P}_a = \{\left(\mathbf{0.0789} \times \left(\frac{L}{\rho_h}\right)\right) \times \left(\frac{m_h}{H * d_h}\right) \times \left\{\frac{[1.3(\mu_h^{0.33})]}{(d_h + 0.032)}\right\} * (\frac{H}{m})_h^{0.33} + \mathbf{1.5} + \frac{16}{L}\} = 2143 Pascal$</td><td>$\Delta \mathrm{P}_a = \{\left(\mathbf{0.0789} \times \left(\frac{L}{\rho_c}\right)\right) \times \left(\frac{m_c}{H * d_c}\right) \times \left\{\frac{[1.3(\mu_c^{0.33})]}{(d_c + 0.032)}\right\} \times (\frac{H}{m})_c^{0.33} + \mathbf{1.5} + \frac{16}{L}\}$=529bar
$= 5290 Pascal$</td></tr>
</table>

<table>
<tr><th colspan="3">Specification Sheet</th></tr>
<tr><th colspan="3">Identification</th></tr>
<tr><td>Item</td><td colspan="2">Heat Exchanger</td></tr>
<tr><td>Item no</td><td colspan="2">HX-100</td></tr>
<tr><td>Operation</td><td colspan="2">Continuous</td></tr>
<tr><td>Type</td><td colspan="2">Spiral Plate Heat Exchanger</td></tr>
<tr><th colspan="3">Function: To heat the Process Stream</th></tr>
<tr><td>Heat Duty</td><td colspan="2">334265000 W</td></tr>
<tr><td>Area</td><td colspan="2">$A = 266m^2$</td></tr>
<tr><td>Number of turns</td><td colspan="2">10</td></tr>
<tr><td>Heat transfer area</td><td colspan="2">$266m^2$</td></tr>
<tr><td>Excess Area</td><td colspan="2">$0.67m^2$</td></tr>
<tr><th>Fluid Allocation</th><th>Cold Fluid</th><th>Hot Fluid</th></tr>
<tr><td>Fluid Name</td><td>**Slurry**</td><td>**Saturated Steam**</td></tr>
<tr><td>Fluid Quantity(Total)</td><td>1018kg/s</td><td>162 kg/s</td></tr>
<tr><td>Temperature (In/Out)</td><td>25 to 170 °C</td><td>175°C</td></tr>
<tr><td>Pressure</td><td>1 bar</td><td>9 bar</td></tr>
<tr><td>Viscosity</td><td>1.4kg/m.s</td><td>0.000149kg/m.s</td></tr>
<tr><td>Thermal Conductivity</td><td>0.6W/m.°K</td><td>34.58W/m.°K</td></tr>
<tr><td>Pressure Drop</td><td>2143Pascal</td><td>5290Pascal</td></tr>
</table>

5.2 LHW Pre-treatment Reactor (R-201):

A reactor is a vessel used in processing plants to create desired products through chemical reactions.

Types of Reactor:

Reactor types Reactors come in two main categories.

- Tubular reactors.
- Stirred-tank reactor.

A Continuous Stirred Tank Reactor (CSTR) is a kind of reaction vessel in which reagents, reactants, and frequently solvents flow into the reactor while the product(s) of the reaction simultaneously exit the vessel. In this sense, the tank reactor is regarded as an effective tool for continuous chemical processing. A continuous-stirred tank reactor (CSTR) has a continuous material input and output. There are no dead zones or bypasses, and the CSTR is functioning at its peak. Perplexing may or may not be involved. The ideal CSTR maintains a consistent composition and temperature throughout the tank.

Choice of Continuous stirred tank reactors (CSTR):

A CSTR is preferred usually under the following circumstances:

- Reaction in the liquid phase.
- Extreme agitation is necessary.
- Large residence time.
- Better temperature control.
- Easy cleaning.
- The reactor outlet reacts quickly to modifications in the reactor feed stream. This quality makes automated reactor control easier.
- Compared to tubular reactors, CSTRs are substantially more affordable per unit volume due to the simplicity of their construction.

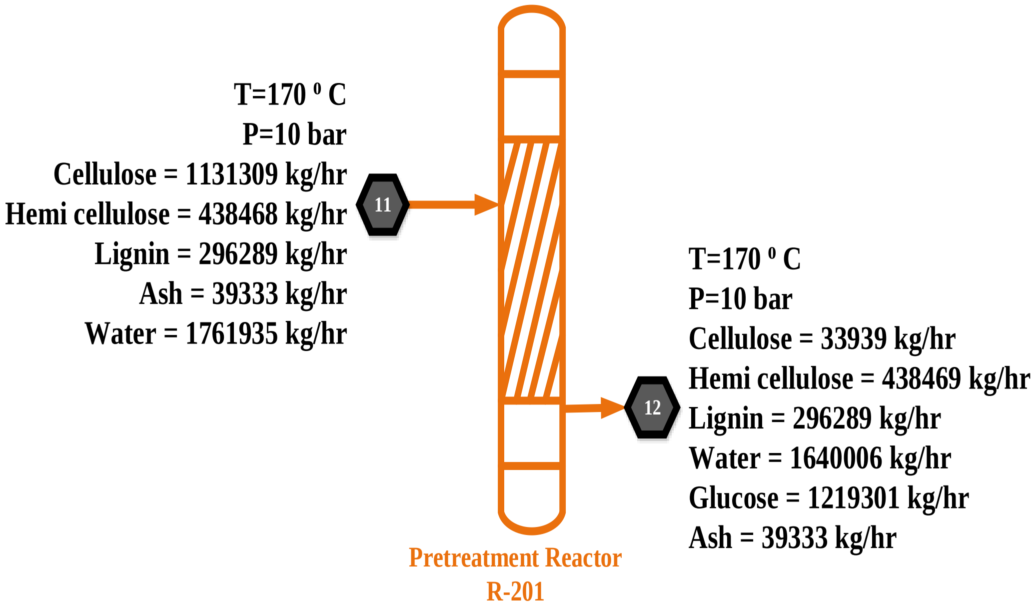

Fig no 5.2: Pre-Treatment Reactor (R-201)

Design Calculations:

Reaction:

$$C_6H_{10}O_5 + H_2O \xrightarrow{\qquad\qquad} C_6H_{12}O_6 \qquad (5.1)$$

Operating Pressure= 10 bar

Operating Temperature =170 °C

Design Equation for CSTR:

$$\frac{V}{FA0} = \frac{XA}{-rA}$$

Where;

A is limiting reactant= $C_6H_{10}O_5$

Molar initial flow rate F_{A0} = 6940 k mol/hr

Volumetric flow rate V_0 = 452 m^3/hr

Initial concentration of key component= Initial molar flow rate / Volumetric flow rate

$$C_{Ao} = \frac{FAo}{V0}$$

$$C_{Ao} = 15 \text{ Kmol/m}^3$$

Final Concentration:

$$C_A = C_{Ao}\,(1-X_A)$$

$$C_A = 0.45\ \text{Kmol/m}^3$$

Rate Equation for the reaction:

$$-r_A = kCA^{\,n}$$

Where,

n = 1 (First order reaction)

k= 0.5×10^5 day $^{-1}$ = 2083 hr^{-1}

Volume of reactor:

Putting all values in Design equation:

$$V = \frac{0.97\times6940}{2083\times(0.45)}$$

$$V = 7.1\ \text{m}^3$$

5 % Safety Allowance Volume of reactor = 8 m^3

This 8 m^3 is divided into 4m^3 of equal volume reactors.

Diameter of reactor:

$$L/D = 1.5$$

$$L = 1.5\,D$$

$$V = \frac{\pi}{4}\,D^2L$$

$$4 = 1.17\,D^3$$

$$D = 1.5\ \text{m}$$

Length of reactor:

$$L/D = 1.5$$

$$L = 2.3\ \text{m}$$

5.2.1 Design of Agitator:

An agitator is a mechanical device that helps shake or churn a liquid or mixture of liquids. The major three agitator kinds are as follows.

1. Paddle
2. Propeller
3. Turbine

Paddle:

The most basic agitators are those with blades in the shape of paddles. Due to their limited capabilities, they are mostly used for laminar flow fluids with low shearing needs. They feature an equal number of forward and backward paddles and can move ingredients from one end of the boat to the other.

Propeller:

Low viscosity materials are perfect for propeller agitators. The completion of tasks like homogenization, suspension, and dispersion is made simple by the use of propeller-type agitators operating at medium to high speeds. Because they prevent solid particles from accumulating, axial flow agitators are ideal for solid-in-liquid suspensions.

Turbine:

Turbine agitators are frequently used to emulsify and disperse fluids at very high speeds. Turbine agitators have excellent mixing performance over a wide range of viscosities. An axial input and a radial output are features of turbine agitators. During work, they combine rotation and centrifugal force.

Selection:

- The selected impeller is vertical flat blade turbine.
- Turbine is type of radial flow impeller used for low to moderate viscous fluid.
- For mixing radial flow impeller is best choice.
- Less power requirement.
- Promote heat transfer between the liquid and a coil or jacket
- High mass transfer between phases

The shape factors for correlations of agitator performance:

Da / Dt = 1/3 Da=0.5m

L/Da = 1/4 L= 0.13m

H / Dt = 1 H=1.5 m

J / Dt = 1/12 J=0.1m

E/Dt = 1/3 E =0.5m

W/Da = 1/5 W = 0.1m

Where,

Da= Diameter of impeller

Dt= Tank diameter

H= Depth of liquid in tank

J= Width of baffles

L= length of impeller blade

E= Height of impeller above vessel flow

W= Impeller width

Reynolds number

$$\text{Re} = \frac{D_a^2 \times N \times \rho}{\mu} = 98250$$

Power Calculations:

Power number =Np = 4.5

P = Np $N^3 \rho Da^5$

From here,

Power = P = 747 W = 1 hp

5.2.2 Design of Cooling Jacket:

In order to maintain a continuous heat exchange between the fluid flowing through it and the vessel walls, a jacket must be located outside the vessel. A jacketed vessel is a container designed to control the temperature of its contents. It uses a cooling or heating "jacket" surrounding the vessel, through which a cooling or heating fluid is cycled. There are three primary categories of jackets.

1. Spiral baffle Jacket

2. Dimple jacket

3. Half pipe coil Jacket

Jacket selection:

Factor to be consider when selecting the type of jacket use are listed below:

1- Cost-wise, the design can be graded from least expensive to most expensive.

- Simple no baffles
- Agitation nozzles
- Dimple Jacket
- Half-pipe jacket

2- If a high rate of heat transfer is necessary, choose a spirally baffled or half-pipe jacket.

3-Pressure As a general rule, the designs' pressure ratings are as follows:

- Jackets, 10 bar or higher.
- A dimple jacket capable of 40 bar.
- Up to 70 bar in the half-pipe. As a result, high pressure would need a half-pipe jacket.

So selected vessel is Spiral baffle Jacket due to following reasons;

- It is less costly.
- Higher Heat transfer rates are required.
- It is used for pressure up to 10 bar

Jacket Side Calculations:

Spacing between jacket and vessel = 175 mm

Pitch between spirals = 200 mm

Height of jacket = 2.2 m

$Number\ of\ spirals = \frac{Height\ of\ jacket}{Pitch\ between\ spirals}$ = 11

Cross sectional area of channel = spacing between jacket and vessel × pitch = $35\times10^{-3}m^2$

Hydraulic mean diameter = d_e = $\frac{4\times cross\ sectional\ area}{wetted\ parameter}$ = 187 mm

Velocity through channels = $\frac{flow\ rate}{density\times cross\ sectional\ area}$ = 0.9 m/s

Reynolds number = $\frac{\rho\times v\times D}{\mu}$ = 185878

Prandtl number = $\frac{C_p\times\mu}{k}$ = 6.2

Nusselt number $= C \times R_e^{0.8} \times P_r^{0.33}$ = 689

Where C = 0.023 for water (non Viscous)

Heat transfer coefficient jacket side:

$h_j = \frac{N_u\times k}{de}$ = 2210 W/m^2.K

Tank side calculations:

Reynolds number $= \frac{\rho\times v\times D}{\mu}$ =15750

Prandtl number $= \frac{C_p\times\mu}{k}$ = 3

Nusselt number $= C \times R_e^{0.8} \times P_r^{0.33} \times(\mu/\ \mu_w)^{0.14}$ = 159

Tank side heat transfer coefficient:

$h_t = \frac{N_u\times k}{d}$= 226 W/m^2.K

Overall heat transfer coefficient

$U_d = \frac{h_j\times h_t}{h_j+h_t}$ = 205 W/m^2.K

Area of Jacket = 14 m^2

Specification Sheet	
Identification	
Item	Reactor
Item no	R-102
Number Required	2
Operation	Continuous
Type	Continuous stirred tank reactor
Function : Hydrolysis of Cellulose	
Chemical Reaction $C_6H_{10}O_5 + H_2O \longrightarrow C_6H_{12}O_6$	
Reactor	
Length	2.3 m
Diameter	1.5 m
Volume	4 m^3
Impeller	
Speed	90 rev/min
Length	0.13 m
Diameter	0.5 m
Power	1 hp
Jacket	
Area	14 m^2
Heat Transfer Coefficient Jacket Side	2210 $W/m^2.K$
Heat Transfer Coefficient Tank Side	266 $W/m^2.K$
Overall heat Transfer Coefficient	205 $W/m^2.K$

5.3 Anaerobic Reactor (R-202):

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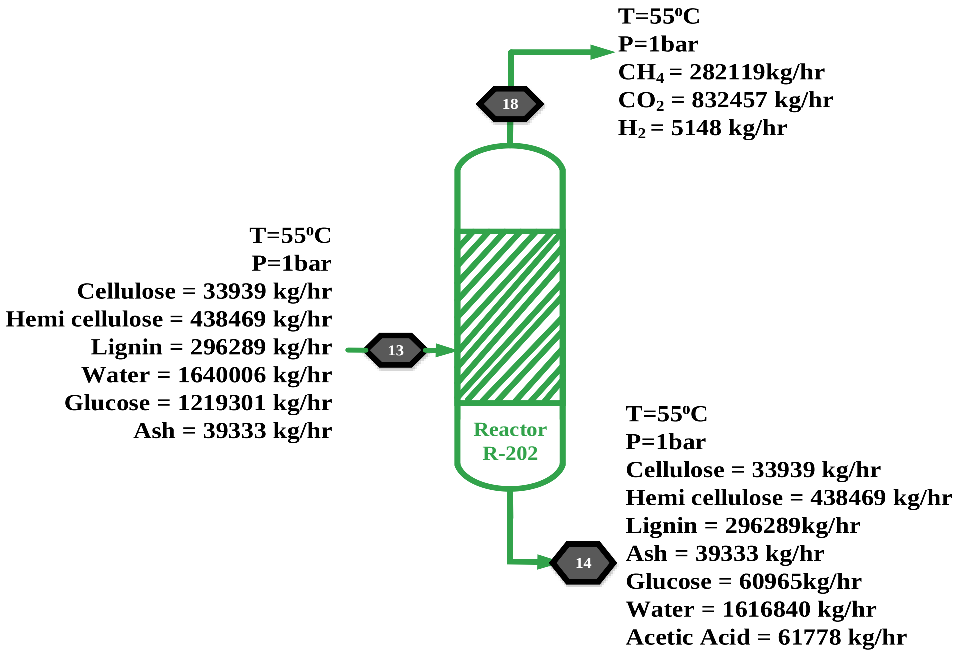


Fig no 5.3 : Anaerobic Reactor (R-202)

Design Calculations:

Reaction:

$$C_6H_{12}O_6 \longrightarrow 3CH_4 + 3CO_2 \qquad (5.2)$$

Operating Pressure= 1 bar

Operating Temperature =55 °C

Design Equation for CSTR:

$$\frac{V}{FA0} = \frac{XA}{-rA}$$

Where;

A is limiting reactant= $C_6H_{12}O_6$

Molar initial flow rate F_{A0} = 6773 k mol/hr

Volumetric flow rate $V_0 = 609\ m^3/hr$

Initial concentration of key component= Initial molar flow rate / Volumetric flow rate

$$C_{Ao} = \frac{FAo}{V0}$$

$$C_{Ao} = 11\ Kmol/m^3$$

Final Concentration:

$$C_A = C_{Ao}\,(1-X_A)$$

$$C_A = 0.55\ \text{Kmol/m}^3$$

Rate Equation for the reaction:

$$-r_A = kCA^{n}$$

Where,

n = 1 (First order reaction)

k= 6.1×10^4 day $^{-1}$ = 2541 hr^{-1}

Volume of reactor:

Putting all values in Design equation:

$$V = \frac{0.95 \times 6773}{2541 \times (0.55)}$$

$$V = 5\ \text{m}^3$$

20 % Safety Allowance Volume of reactor = 6 m^3

Time Required for growth of anaerobic microbes:

Rate of growth of biomass is given by;

$$r_x = \frac{dX}{dt} = \mu X$$

$$\frac{dX}{X} = \mu\, dt$$

Taking Integral on both sides;

$$\int_{X0}^{X} \frac{dX}{X} = \int_{0}^{t} dt$$

$X_0 = 6.3$ kmol/m^3

$X = 0.3$ kmol/m^3

Growth rate:

$$\ln\left(\frac{6.3}{0.3}\right) = \mu\ (0.18)$$

$$\mu = 17\ \text{day}^{-1}$$

Lag time :

$$\lambda = \frac{1}{\mu}$$

$$\lambda = \frac{1}{17} = 1.4 \text{ hr}$$

Total time required = space time + lag time

T = 0.007 + 1.4

T = 1.41 = 1.4 hr

Now to compensate the time 6 m^3 volume of reactor is dividing into $3m^3$ of two reactors to keep operation in continuous phase.

Diameter of reactor:

$$L/D = 1.5$$

$$L = 1.5\,D$$

$$V = \frac{\pi}{4} D^2 L$$

$$3 = 1.17\,D^3$$

$$D = 1.4 \text{ m}$$

Length of reactor:

$$L/D = 1.5$$

$$L = 2.1 \text{ m}$$

5.3.1 Design of Agitator:

The shape factors for correlations of agitator performance:

Da / Dt = 1/3 Da=0.3m

L/Da = 1/4 L= 0.08m

H / Dt = 1 H=1 m

J / Dt = 1/12 J=0.08m

E/Dt = 1/3 E =0.3m

W/Da = 1/5 W = 0.06m

Where,

Da= Diameter of impeller

Dt= Tank diameter

H= Depth of liquid in tank

J= Width of baffles

L= length of impeller blade

E= Height of impeller above vessel flow

W= Impeller width

Reynolds number

$$\mathrm{Re} = \frac{D_a^2 \times N \times \rho}{\mu} = 77142$$

Power Calculations:

Power number =Np = 4

$P = Np\ N^3\ \rho\ Da^5$

From here,

Power = P = 65 W = 0.09 hp

5.3.2 Design of Cooling Jacket:

Jacket Side Calculations:

Spacing between jacket and vessel = 175 mm

Pitch between spirals = 200 mm

Height of jacket = 1.4 m

$$Number\ of\ spirals = \frac{Height\ of\ jacket}{Pitch\ between\ spirals} = 7$$

Cross sectional area of channel = spacing between jacket and vessel × pitch = $35 \times 10^{-3} m^2$

$$\text{Hydraulic mean diameter} = d_e = \frac{4 \times cross\ sectional\ area}{wetted\ parameter} = 187\ \text{mm}$$

$$\text{Velocity through channels} = \frac{flow\ rate}{density \times cross\ sectional\ area} = 4\ \text{m/s}$$

Reynolds number = $\frac{\rho \times v \times D}{\mu}$ = 748000

Prandtl number $= \frac{C_p \times \mu}{k}$ = 7

Nusselt number $= C \times R_e^{0.8} \times P_r^{0.33}$ = 2186

Where C = 0.023 for water (non Viscous)

Heat transfer coefficient jacket side:

$h_j = \frac{N_u \times k}{de}$ = 7013 W/m^2.K

Tank side calculations:

Reynolds number $= \frac{\rho \times v \times D}{\mu}$ =11428

Prandtl number $= \frac{C_p \times \mu}{k}$ = 1.75

Nusselt number $= C \times R_e^{0.8} \times P_r^{0.33} \times(\mu/ \mu_w)^{0.14}$ = 55

Tank side heat transfer coefficient:

$h_t = \frac{N_u \times k}{d}$= 220 W/m^2.K

Overall heat transfer coefficient

$U_d = \frac{h_j \times h_t}{h_j + h_t}$ = 213 W/m^2.K

Area of Jacket = 12 m^2

Specification Sheet	
Identification	
Item	Reactor
Item no	R-102
Number Required	2
Operation	Continuous
Type	Continuous stirred tank reactor
Function : Digestion of Glucose	
Chemical Reaction $C_6H_{12}O_6 \longrightarrow 3CO_2 + 3CH_4$	
Reactor	
Length	2.1 m
Diameter	1.4 m
Volume	3 m^3
Impeller	
Speed	90 rev/min
Length	0.08 m
Diameter	0.3 m
Power	0.08 hp
Jacket	
Area	12 m^2
Heat Transfer Coefficient Jacket Side	7013 $W/m^2.K$
Heat Transfer Coefficient Tank Side	220 $W/m^2.K$
Overall heat Transfer Coefficient	213 $W/m^2.K$

5.4 Waste Heat Boiler (WHB-101):

A waste heat boiler turns heat produced as a byproduct of another process into steam instead of wasting it. Energy-generating turbines can be run on steam. The boiler can also be used to simply heat fluids like water or other substances. By recycling some of the energy used, a waste heat boiler, often referred to as a waste heat recovery boiler, can reduce a system's consumption of fossil fuels and operational expenses. A water tube boiler is a type of boiler that produces steam using tubes filled with water, also known as a water tube or water-tube boiler. A water tube boiler is a type of boiler that produces steam using tubes filled with water, also known as a water tube or water-tube boiler.

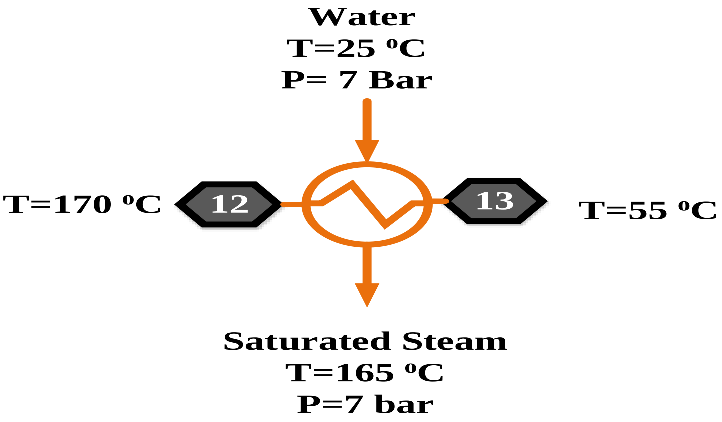


Fig no 5.4 Waste Heat Boiler (WHB-101)

Design Calculation:

Thermal Calculations:

Heat duty:

$$Q = 187844334\ \frac{kj}{hr} = 187844\ \frac{Mj}{hr}$$

Mass Flow Rate:

$$m = 70981\frac{kg}{hr}$$

Energy required producing steam:

The energy required for producing the steam is

$$Q_u = 187844334\ \frac{kj}{hr}$$

Taking heat loss as 2% approx.

Using the relation for energy required and heat loss

$Q_T = Q_u + 0.02Q_T$

Rearranging the above the equation and putting values

$Q_u = Q_T - 0.02Q_T$

$Q_T = 191677891 \frac{kj}{hr}$

Estimation of surface area:

So assuming $U_d = 2100 \frac{W}{m2.K}$

Log Mean Temperature Difference (LMTD):

$$\Delta T_{ln} = \frac{(T_1 - t_2) - (T_2 - t_1)}{l_n \left(\frac{T_1 - t_2}{T_2 - t_1}\right)}$$

Putting Values will give us

$$\Delta T_{ln} = \frac{(30) - (5)}{l_n \left(\frac{30}{5}\right)}$$

$\Delta T_{ln} = 13℃ = 286\ ^oK$

Correction Factor of LMTD:

$f_{LMTD} = 0.86$

After applying correction factor area will be

$$A = \frac{Q}{Ud\Delta T_{ln} f} = 91\ m^2$$

Tube Side Calculation:(Water)

Dimensions' for tube are taken as

$Length\ of\ tube = 16ft = 4.8m$

$Tube\ outer\ diameter = \frac{3}{4} in = 0.02\ m$

$Tube\ inner\ diameter = 0.652\ Inch = 0.016$

Number of tubes = $N_t = \frac{A}{\pi d_o L}$

$N_t = 315\ tubes$

Actual number of tubes N_t= 316

Bundle Diameter:

For triangular pitch;(1 shell 2 tube passes)

pt = 1.25 d_o

K_1 = 0.319 n_1=2.142

$$D_b \;= d_o\left(\frac{N_t}{k_1}\right)^{\frac{1}{n1}} = 0.47m$$

Total Flow Area:

$$Total\ flow\ area = (Tube\ per\ pass)(Total\ Crosssectional\ Area)$$

Tubes per pass can be calculated as

$$Tube\ per\ Passes = \frac{316}{2} = 158\ tubes$$

Total cross-sectional can be calculated as

$$Total\ crosssectional\ area = \ \frac{\pi d_o^2}{4} = 2.9 \times 10^{-4} m^2$$

Total Flow area = 0.05 m^2

Linear velocity:

Volumetric flow rate = $\frac{Mass\ flow\ rate}{density}$ = 67m^3/hr

Linear velocity = 0.4 m/s

Reynold Number:

$$\mathrm{Re} = \ \frac{\rho.\mathrm{v.do}}{\mu} = 23268$$

Prandtl number:

$$\mathrm{Pr} = \ \frac{\mathrm{Cp}.\mu}{\mathrm{k}} = 2.4$$

The L/D can be calculated as

$$\frac{L}{D_i} = \frac{4.8}{0.019} = 252$$

$j_H = 3\times10^{-3}$

For Tube side coefficient:

$$h_i \;= \frac{k}{d_i} j_H Re(Pr)^{0.33}\left(\frac{\mu}{\mu_w}\right)^{0.14}$$

h_i = 4200 W/m^2.K

Shell diameter:(Organic mixture)

Shell diameter can be calculated as

$$Shell\ diameter = Ds = Db + diametrical\ clearance$$

For U tube heat exchanger, diametrical clearance = $12 \times 10^{-3} m$

Putting values will give us

Ds = 0.48 m

Tube pitch can be calculated as

$$P_t = 1.25 d_o = 0.0238m$$

For Area of shell;

$$A_s = \left(\frac{\rho_t - d_o}{\rho_t}\right)(D_s)(L_B) = 0.05m^2$$

$$G_s = \frac{Massflow\ rate\ of}{Area\ of\ shell\ (As)} = 20374 \frac{\text{kg}}{m^2 s}$$

Equivalent diameter for triangular pitch:

$$\text{de} = \frac{4\left(\frac{Pt}{2}\times 0.87pt - \frac{1}{2}\pi\frac{do2}{4}\right)}{\pi(\frac{do}{2})} = 0.0134 \text{ m}$$

Reynolds number

$$\text{Re} = \frac{\text{Gs} \times \text{do}}{\mu} = 68252$$

Prandtl number

$$\text{Pr} = \frac{\text{Cp} \times \mu}{\text{k}} = 20$$

$J_H = 2.8\times10^{-3}$

For Shell side coefficient

$$h_o = \frac{k_f}{d_i} j_H Re(Pr)^{0.33} \times (\mu/\ \mu_w)^{0.14} = 15330 \frac{w}{m^2 K}$$

Overall Coefficient:

$$h_{id} = 3000 \frac{w}{m^2 °C} \quad , \quad h_{od} = 5000 \frac{w}{m^2 °C}$$

K_m (Stainless Steel) =16W/m˚C

$$\left(\frac{1}{U_o}\right) = \left(\frac{1}{h_o}\right) + \left(\frac{1}{h_{od}}\right) + \left(\frac{d_o}{2k_m}\right) + ln\left(\frac{d_o}{d_i}\right) + \left(\frac{d_o}{d_i}\right)\left(\frac{1}{h_{id}}\right) + \left(\frac{d_o}{d_i}\right)\left(\frac{1}{h_i}\right)$$

Putting values will gives:

$U_d = 2139$ W/m^2.k

Hydraulic Calculation:

Tube Side Pressure Drop:

$J_f = 4\times10^{-3}$

$$\Delta Pt = Np \times \left[8 \times Jf \times \frac{L}{di} + 2.5\right] \times \frac{\rho \times ut2}{2}$$

ΔPt = 0.26 psi

Shell Side Pressure Drop:

$J_f = 3\times10^{-2}$

$$\Delta Pt = 8jf \times \frac{Ds}{de} \times \frac{L}{Lb} \times \frac{\rho\times ut2}{2} \times \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

ΔPt = 5.5 psi

<table>
<tr><td colspan="2">Specification Sheet</td></tr>
<tr><td colspan="2">Identification</td></tr>
<tr><td>Item</td><td>Waste Heat Boiler</td></tr>
<tr><td>Item no</td><td>WHB-101</td></tr>
<tr><td>Number Required</td><td>1</td></tr>
<tr><td>Operation</td><td>Continuous</td></tr>
<tr><td>Type</td><td>1 2 Horizontal Heat Exchanger</td></tr>
<tr><td colspan="2">Function : Recovery of Excess Heat from Process Stream</td></tr>
<tr><td colspan="2">Heat Duty = 191677 MJ /hr</td></tr>
<tr><td colspan="2">Ud Assumed = 2100 W/m2.K</td></tr>
<tr><td colspan="2">Ud Calculated = 2139 W/m2.K</td></tr>
<tr><td colspan="2">Area = $91m^2$</td></tr>
</table>

<table>
<tr><td>Conditions</td><td>Shell Side</td><td>Tube Side</td></tr>
<tr><td>Pressure</td><td>1 bar</td><td>7 bar</td></tr>
<tr><td>Temperature</td><td>170 to 55 ºC</td><td>25 to 165 ºC</td></tr>
<tr><td>Passes</td><td>1</td><td>2</td></tr>
<tr><td>Pressure Drop</td><td>5.5 Psi</td><td>0.26 Psi</td></tr>
<tr><td colspan="3">No of Tubes = 316 BWG = 18 Pitch= 1 inch Triangular OD = ¾ inch</td></tr>
</table>

<table>
<tr><th colspan="6">Specification Sheet</th></tr>
<tr><th colspan="6">Identification</th></tr>
<tr><td colspan="3">Item</td><td colspan="3">Waste Heat Boiler</td></tr>
<tr><td colspan="3">Item no</td><td colspan="3">WHB-102</td></tr>
<tr><td colspan="3">Number Required</td><td colspan="3">1</td></tr>
<tr><td colspan="3">Operation</td><td colspan="3">Continuous</td></tr>
<tr><td colspan="3">Type</td><td colspan="3">1 2 Horizontal Heat Exchanger</td></tr>
<tr><td colspan="6">**Function : Recovery of Excess Heat from Process Stream**</td></tr>
<tr><td colspan="6">Heat Duty = 171082 MJ /hr</td></tr>
<tr><td colspan="6">Ud Assumed = 2100 W/m2.K</td></tr>
<tr><td colspan="6">Ud Calculated = 1973 W/m2.K</td></tr>
<tr><td colspan="6">Area = 76m^2</td></tr>
<tr><td colspan="2">Conditions</td><td colspan="2">Shell Side</td><td colspan="2">Tube Side</td></tr>
<tr><td colspan="2">Pressure</td><td colspan="2">1 bar</td><td colspan="2">7 bar</td></tr>
<tr><td colspan="2">Temperature</td><td colspan="2">55 to 30 ^{o}C</td><td colspan="2">25 to 165 ^{o}C</td></tr>
<tr><td colspan="2">Passes</td><td colspan="2">1</td><td colspan="2">2</td></tr>
<tr><td colspan="2">Pressure Drop</td><td colspan="2">7.5 Psi</td><td colspan="2">0.08 Psi</td></tr>
<tr><td colspan="6">No of Tubes = 262 BWG = 18 Pitch= 1 inch Triangular OD = ¾ inch</td></tr>
</table>

5.5 Heat Exchanger (HX-101):

Double Pipe Heat Exchanger:

A double pipe heat exchanger is a type of heat exchanger that consists of two pipes, one inside the other. The inner pipe carries the fluid to be heated or cooled, while the outer pipe carries the heating or cooling medium. The two fluids flow in opposite directions, allowing for efficient heat transfer. The main advantage of a double pipe heat exchanger is its simplicity and low cost compared to other types of heat exchangers. It is also easy to maintain and clean, making it ideal for applications that require frequent cleaning.

Application:

Some of the common industrial applications of double pipe heat exchangers include:

1. Heating and cooling of process fluids in chemical and pharmaceutical industries.
2. Heat recovery from waste streams in industrial processes.
3. Cooling of engine or turbine oil in power generation plants.
4. Heating and cooling of lubricating oils in machine tools.
5. Heating and cooling of food and beverage products in the food processing industry.
6. Heating and cooling of water in HVAC (heating, ventilation, and air conditioning) systems.
7. Heating and cooling of swimming pool water in recreational facilities.
8. Heating and cooling of water in geothermal systems.

Double pipe heat exchangers are commonly used in applications where the heat transfer rate is relatively low and the temperature difference between the two fluids is small. They are also preferred in applications where the fluids being handled are corrosive or fouling, as the inner pipe can be easily replaced or cleaned. We select double pipe heat exchanger because it is used for area lower than 200ft^2.Our area is 148ft^2 which is quite low area.

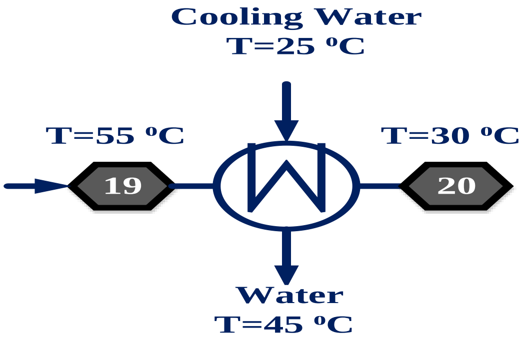


Fig no 5.5 Heat Exchanger (HX-101)

Design Calculations

Hot fluid: T_1, T_2, T_{avg}, T_c W, C, s or ρ, μ, k, ΔP, Rdi or Rdo

Cold fluid: t_1, t_2, t_{avg}, t_c w, c, s or ρ, μ, k, ΔP, Rdi or Rdo

Hot fluid (Lean solvent)	T_1(hot inlet)	55	°C	T_2 (hot outlet)	30	°C	T_{avg}	42.5	°C	T_c	111	°F
Temperature differences	Δt_2 , Δt_h	10	°C	Δt_1, Δt_c	5	°C	Bulk mean Temperature			Caloric Temperature		
Cold fluid (Rich solvent)	t_2 (cold outlet)	45	°C	t_1 (cold inlet)	25	°C	t_{avg}	35	°C	t_c	97	°F

LMTD

$$\text{LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln\left(\frac{\Delta t_2}{\Delta t_1}\right)}$$

$$\text{LMTD} = \frac{10 - 5}{\ln\left(\frac{10}{5}\right)} = 7°\text{C} = 45°\text{F}$$

Caloric Temperature:

Hot Fluid

$$\text{Tc} = \text{T}_2 + \text{Fc}\,(\text{T}_1 - \text{T}_2)$$

$$\text{Tc} = 86 + 0.55\,(131 - 86)$$

$$\text{Tc} = 111°\text{F}$$

Cold Fluid

$$\text{tc} = \text{t}_1 + \text{Fc}\,(\text{t}_2 - \text{t}_1)$$

$$\text{tc} = 77 + 0.55\,(113 - 77)$$

$$\text{tc} = 97°\text{F}$$

Properties

We have calculated both fluids properties at caloric temperatures

Property	**Hot fluid**			**Cold fluid**		
Specific Gravity	s	1.3	-	s	0.99756	-
Density	ρ_h	0.9	lb/ft^3	ρ_c	62.03	lb/ft^3
Viscosity	μ_c	0.036	lb/ft hr	μ_c	1.7	lb/ft hr
Specific Heat	C_h	0.34	Btu/lb°F	C_c	0.998	Btu/lb°F
Thermal conductivity	k_h	0.014	Btu/hr ft °F	k_c	0.36	Btu/hr ft °F

Heat Balance:

Q = 3331777 Btu/hr

U_D=50 Btu/hr ft^2 °F

Allowable dirt factor factor R_d =0.003 on both side

$$A = \frac{\dot{Q}}{(U_D)(\mathrm{LMTD})}$$

$$A = \frac{(333{,}177\ \mathrm{Btu/h})}{\left(50\frac{\mathrm{Btu}}{\mathrm{h\ ft^2\ °F}}\right)(45\ °\mathrm{F})}$$

$$A = 148\ \mathrm{ft}^2$$

As the Area is less than 200 ft^2 thus we are doing calculations of double pipe heat exchanger.

Inner Pipe		**Outer Pipe**	
Description	Feet	Description	Feet
Nominal; pipe size IPS,	1.83	Nominal; pipe size IPS,	2
D (inner dia)	1.771	D_2 (inner dia)	1.94
D_1 (outer dia)	1.83	External surface per feet length	6.283
D_e (equivalent dia) $De = \frac{D_2^2 - D_1^2}{D_1}$	0.23	Length of pipes (hair pin)	20
De' (equivalent dia for ΔP) De' =D_2-D_1	0.11	Heat transfer surface of hair pin	40

<table>
<tr><th colspan="2">Thermal Calculations</th></tr>
<tr><th>Annulus :water</th><th>Inner pipe :gas</th></tr>
<tr><td colspan="2">Flow Area</td></tr>
<tr><td>$a_a = \frac{\pi(D_2^2 - D_1^2)}{4} = \frac{\pi((1.94)^2 - (1.83)^2)}{4}$
$a_a = 0.3255\text{ft}^2$</td><td>$a_p = \frac{\pi D^2}{4} = \frac{\pi(1.771)^2}{4}$
$a_p = 2.5\ \text{ft}^2$</td></tr>
<tr><td colspan="2">Mass Velocity</td></tr>
<tr><td>$G_a = \frac{W}{a_a} = \frac{9315\ \text{lb/h}}{0.3255\text{ft}^2}$
$G_a = 28617\ \frac{\text{lb}}{h\ \text{ft}^2}$</td><td>$G_p = \frac{W}{a_p} = \frac{2468570\ \text{lb/h}}{2.5\ \text{ft}^2}$
$G_p = 987428\frac{\text{lb}}{h\ \text{ft}^2}$</td></tr>
<tr><td colspan="2">Reynold Number</td></tr>
<tr><td>$Re_a = \frac{\text{De}\ G_a}{\mu} = \frac{(0.23\ \text{ft})\ (28617\ \frac{\text{lb}}{h\ \text{ft}^2})}{1.7\frac{\text{lb}}{\text{ft h}}}$
$Re_a = 3872$</td><td>$Re_p = \frac{\text{D}\ G_p}{\mu} = \frac{(1.771\ \text{ft})\ (987428\ \frac{\text{lb}}{h\ \text{ft}^2})}{0.036\frac{\text{lb}}{\text{ft h}}}$
$Re_{\boldsymbol{p}} = 4857597$</td></tr>
<tr><td colspan="2">Prandtl Number</td></tr>
<tr><td>$(\boldsymbol{Pr_a})^{\frac{1}{3}} = \left(\frac{\mathbf{C}\ \mu}{\boldsymbol{k}}\right)^{\frac{1}{3}} = \left(\frac{(0.998\frac{\text{Btu}}{\text{lb}\ ^\circ\text{F}})(1.70\ \frac{\text{lb}}{\text{ft h}})}{(0.36\frac{\text{Btu}}{\text{h ft}\ ^\circ\text{F}})}\right)^{\frac{1}{3}}$
$(\boldsymbol{Pr_a})^{\frac{1}{3}} = 1.68$</td><td>$(\boldsymbol{Pr_p})^{\frac{1}{3}} = \left(\frac{\mathbf{c}\ \mu}{\boldsymbol{k}}\right)^{\frac{1}{3}}$
$= \left(\frac{(0.34\frac{\text{Btu}}{\text{lb}\ ^\circ\text{F}})(0.036\ \frac{\text{lb}}{\text{ft h}})}{(0.014\frac{\text{Btu}}{\text{h ft}\ ^\circ\text{F}})}\right)^{\frac{1}{3}}$
$(\boldsymbol{Pr_p})^{\frac{1}{3}} = 0.96$</td></tr>
<tr><td colspan="2">Nusselt Number</td></tr>
<tr><td>$\frac{\text{Nu}}{\Phi\text{a}} = 0.027(Re_a)^{0.8}(Pr_a)^{\frac{1}{3}}$
Where $\Phi\text{a} = \left(\frac{\mu}{\mu_w}\right)^{0.14}$
$\text{Nu}'_a = 0.027(3872)^{0.8}\ (1.68)^{\frac{1}{3}}$
$\text{Nu}'_a = 34$</td><td>$\text{Nu} = 0.027\left(Re_p\right)^{0.8}(Pr_p)^{\frac{1}{3}}\left(\frac{\mu}{\mu_w}\right)^{0.14}$
Where $\Phi\text{p} = \left(\frac{\mu}{\mu_w}\right)^{0.14} = 1$
$\text{Nu}_{\boldsymbol{p}} = 0.027\ (4857597)^{0.8}(0.96)^{\frac{1}{3}}\ (1)$
$\text{Nu}_{\boldsymbol{p}} = 5791$</td></tr>
<tr><td colspan="2">$\boldsymbol{\frac{h_o}{\Phi\text{a}}}$
$\frac{h_o}{\Phi\text{a}} = \frac{\text{Nu}'_a\text{k}}{\text{De}} = \frac{34\ \left(0.36\frac{\text{Btu}}{\text{h ft}\ ^\circ\text{F}}\right)}{0.23\ \text{ft}} = 53$</td></tr>
</table>

Pipe wall temperature & correction factor

$$t_w = t_c + \frac{\frac{h_o}{\Phi a}}{\frac{h_o}{\Phi a} + \frac{h_{io}}{\Phi a}}(T_c - t_c) \ = 97°\mathrm{F} + \frac{53}{53 + 82}(111 - 97)$$

$$t_w = 99°\mathrm{F}$$

$$\Phi a = \left(\frac{\mu}{\mu_w}\right)^{0.14} = \left(\frac{0.36}{0.63}\right)^{0.14} = 0.95$$

Convective heat transfer coefficient

$$\mathrm{h_o} = \frac{h_o}{\Phi a}\Phi a = (53)(0.95)$$

$$\mathrm{h_o} = 50\frac{\mathrm{Btu}}{\mathrm{h\ ft^2°F}}$$

$$\mathrm{h_i} = \frac{\mathrm{Nu}_p \mathrm{k}}{\mathrm{D}} = \frac{5791(0.014\frac{\mathrm{Btu}}{\mathrm{h\ ft\ °F}})}{1.771\ \mathrm{ft}}$$

$$\mathrm{h_i} = 82\frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}$$

$$\mathrm{h_{io}} = \mathrm{h_i}\left(\frac{D}{D_1}\right) = \left(82\frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}\right)\left(\frac{0.771\ \mathrm{ft}}{0.83\ \mathrm{ft}}\right)$$

$$\mathrm{h_{io}} = 76\frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}$$

Clean overall coefficient

$$\mathrm{U_c} = \frac{\mathrm{h_{io}\ h_o}}{\mathrm{h_{io} + h_o}} = \frac{(280)(50)}{280 + 50} \qquad \mathrm{U_c} = 40\frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}$$

Design overall coefficient

$$\frac{1}{\mathrm{U_D}} = \frac{1}{\mathrm{U_c}} + R_d = \frac{1}{40\frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}} + 0.006 \qquad \mathrm{U_D} = 33\frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}$$

Required Area

$$\mathrm{A} = \frac{\dot{\mathrm{Q}}}{\mathrm{U_D\ LMTD}} = \frac{333{,}177\frac{\mathrm{Btu}}{\mathrm{hr}}}{\left(\mathbf{33}\frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}\right)\ (45\ °\mathrm{F})} \qquad \mathrm{A} = 224\ \mathrm{ft^2}$$

Required Length of hairpin

$$\mathrm{L} = \frac{Area}{\mathrm{External\ surface\ per\ lin\ ft}} = \frac{224\ \mathrm{ft^2}}{6.283\ \mathrm{ft}} \qquad \mathrm{L} = 36\ \mathrm{ft}$$

Required number of hairpin

$$\mathrm{n} = \frac{\mathrm{Required\ length\ of\ hairpin}}{\mathrm{Heat\ transfer\ surface\ of\ hairpin}} = \frac{36\ \mathrm{ft}}{40\ \mathrm{ft}} \qquad \mathrm{n} = 0.9$$

Actual number of hairpin

$$\mathrm{n'} = 1$$

Actual Length of hairpin

$$\mathrm{L} = (\text{Actual number of hairpin})(\text{Heat transfer surface of hairpin}) = 1 \times 40\mathrm{ft}$$

$$\mathrm{L} = 40\ \mathrm{ft}$$

Actual Area of hairpin

$$\mathrm{A} = (\text{External surface per lin ft})(\text{Actual length of hairpin}) = (6.283\ \mathrm{ft})(40\ \mathrm{ft}) = 251\ \ \mathrm{ft}^2$$

Design overall coefficient

$$\mathbf{U'_D} = \frac{\dot{\mathrm{Q}}}{\mathbf{A}\ \ \mathrm{LMTD}} = \frac{333{,}177\,\frac{\mathrm{Btu}}{\mathrm{hr}}}{(\mathbf{251}\ \ \mathrm{ft}^2)\ (45\ °\mathrm{F})}$$

$$\mathbf{U'_D} = \mathbf{30}\,\frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}$$

Dirt factor

$$\mathbf{R'_D} = \frac{\mathrm{U_C} - \mathrm{U_D}}{\mathrm{U_C}\ \mathrm{U_D}} = \frac{\left(42\,\frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}\right) - \left(\mathbf{30}\,\frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}\right)}{\left(42\,\frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}\right)\left(\mathbf{30}\,\frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}\right)} \qquad \mathbf{R'_D} = \mathbf{0.0095}$$

As $\mathbf{R'_D} > \mathbf{R_D}$,(0.0095 >0.003)

Thus the heat exchanger (cooler) selected is thermally feasible

Hydraulic Calculations

Annulus :Hot Fluid (Gases)	**Inner pipe :Cold Fluid (Water)**
Reynold number	
$Re'_a = \frac{D'_e\ \mathrm{G}_a}{\mu} = \frac{(0.11\ \mathrm{ft})\left(28617\ \frac{\mathrm{lb}}{h\ \ \mathrm{ft}^2}\right)}{1.7\,\frac{\mathrm{lb}}{\mathrm{ft\ h}}}$ $Re'_a = 1852$	$Re_{\boldsymbol{p}} = 987428$
Friction Factor	
$f_a\ \ = 0.0035 + \frac{0.264}{(Re'_a)^{0.42}}\ \ = 0.0035 + \frac{0.264}{(1852)^{0.42}}$ $f_a\ \ = 0.015$	$f_p\ \ = 0.0035 + \frac{0.264}{\left(Re'_p\right)^{0.42}}$ $= 0.0035 + \frac{0.264}{(987428)^{0.42}}$ $f_p = 0.0037$

$\Delta \mathrm{F}_a = \frac{4 f_a {\mathrm{G}_a}^2 L}{2 \mathrm{g} \rho^2 D'_e}$ $\Delta \mathrm{F}_a = \frac{4(0.015)\left(28617 \frac{\mathrm{lb}}{h\ \mathrm{ft}^2}\right)^2 (120\ ft)}{2\left(4.18 \times 10^8 \frac{\mathrm{ft}}{\mathrm{h}^2}\right)\left(62.03 \frac{\mathrm{lb}}{\mathrm{ft}^3}\right)(0.11\ \mathrm{ft})}$ $\Delta \mathrm{F}_a = 0.017\ \mathrm{ft}$	$\Delta \mathrm{F}_p = \frac{4 f_p {\mathrm{G}_p}^2 L}{2 \mathrm{g} \rho^2 D}$ $\Delta \mathrm{F}_p = \frac{4(0.0037)\left(987428 \frac{\mathrm{lb}}{h\ \mathrm{ft}^2}\right)^2 (120\ ft)}{2\left(4.18 \times 10^8 \frac{\mathrm{ft}}{\mathrm{h}^2}\right)\left(0.9 \frac{\mathrm{lb}}{\mathrm{ft}^3}\right)(1.771\ \mathrm{ft})}$ $\Delta \mathrm{F}_p = 1444\ \mathrm{ft}$
Velocity head per hairpin: $\mathrm{V} = \frac{\mathrm{G}_a}{3600\ \rho} = \frac{28617 \frac{\mathrm{lb}}{h\ \mathrm{ft}^2}}{3600\ \left(62.03 \frac{lb}{\mathrm{ft}^3}\right)} \qquad \mathrm{V} = 0.128 \frac{\mathrm{ft}}{s}$	
Entrance & exit losses $\Delta \mathbf{F}_l = \frac{\mathrm{V}^2}{2\mathrm{g}'} = \frac{\left(0.128 \frac{\mathbf{ft}}{\mathrm{s}}\right)^2}{2\left(32.2 \frac{\mathbf{ft}}{s^2}\right)} \qquad \Delta \mathbf{F}_l = 0.00025 \frac{ft}{hairpin}$	
Pressure Drop	
$\Delta \mathrm{P}_a = \frac{(\Delta \mathbf{F}_a + \Delta \mathbf{F}_l)\rho}{144}$ $\Delta \mathrm{P}_a = \frac{(0.017\ \mathrm{ft} + 0.00025\mathrm{ft})\left(62.03 \frac{\mathrm{lb}}{\mathrm{ft}^3}\right)}{144}$ $\Delta \mathrm{P}_a = \mathbf{0.007}\ \mathrm{psi}$ Allowable $\Delta \mathrm{P}_a = 10\ psi$	$\Delta \mathrm{P}_p = \frac{\Delta \mathbf{F}_p\ \rho}{144}$ $\Delta \mathrm{P}_p = \frac{(1444\ \mathrm{ft})\left(0.9 \frac{\mathrm{lb}}{\mathrm{ft}^3}\right)}{144}$ $\Delta \mathrm{P}_p = \mathbf{8}\ \mathrm{psi}$

<table>
<tr><th colspan="6">Specification Sheet</th></tr>
<tr><th colspan="6">Identification</th></tr>
<tr><td colspan="3">Item</td><td colspan="3">Cooler</td></tr>
<tr><td colspan="3">Item no</td><td colspan="3">HX-101</td></tr>
<tr><td colspan="3">Type</td><td colspan="3">Double Pipe</td></tr>
<tr><th colspan="6">Function:</th></tr>
<tr><td colspan="3">Heat Duty</td><td colspan="3">333177 Btu/hr</td></tr>
<tr><td colspan="3">Surface Area</td><td colspan="3">$A = 148\ \mathrm{ft}^2$</td></tr>
<tr><td colspan="3">U_c Calculated</td><td colspan="3">$\mathbf{U_c} = 40 \frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}$</td></tr>
<tr><td colspan="3">U_D Calculated</td><td colspan="3">$U_D = 33 \frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}$</td></tr>
<tr><td colspan="3">Fouling Factor</td><td colspan="3">$0.003 \frac{\mathrm{Btu}}{\mathrm{hr\ \ ft^2\ °F}}$</td></tr>
<tr><th colspan="2">Fluid Allocation</th><th colspan="2">Annulus</th><th colspan="2">Inner Pipe</th></tr>
<tr><td colspan="2">Fluid Name</td><td colspan="2">Water</td><td colspan="2">Gasses</td></tr>
<tr><td colspan="2">Fluid Quantity(Total)</td><td colspan="2">9315 lb/h</td><td colspan="2">2468570 lb/h</td></tr>
<tr><td colspan="2">Temperature(in/out)</td><td colspan="2">25°C to 45°C</td><td colspan="2">55°C to 30°C</td></tr>
<tr><td colspan="2">Pressure</td><td colspan="2">1 bar</td><td colspan="2">10 bar</td></tr>
<tr><td colspan="2">Viscosity</td><td colspan="2">1.7lb/ft.hr</td><td colspan="2">0.36lb/ft.hr</td></tr>
<tr><td colspan="2">Thermal Conductivity</td><td colspan="2">0.36Btu/hr.ft.°F</td><td colspan="2">0.014Btu/hr.ft.°F</td></tr>
<tr><td colspan="2">Pressure Drop</td><td colspan="2">0.007psi</td><td colspan="2">8psi</td></tr>
</table>

5.6 Decanter Centrifuge D-(101):

A centrifuge is most commonly used to separate particles from solutions based on their scale, shape, density, medium viscosity, and rotor speed. In a high-speed circular G-force setting, these machines take advantage of the natural separation realities. These extremely fast devices spin like a high-powered clothes dryer to detach materials from one another. During the centrifugation process, the denser materials detach from the less dense. The word "centrifuge" refers to a broad range of process equipment used in the chemical process industries for a variety of purposes. These units can have different appearances and play important roles in processes that are unrelated to one another.

5.6.1 Classification of Centrifuges:

Centrifuges are categorized based on the mechanism used to separate solids.

Sedimentation Centrifuge

The separation in sedimentation centrifuges is based on the density difference between the solid and liquid phases (solid heavier). The phases are separated by filtration in a filtration centrifuge. The liquid filters through the accumulated cake of solids and is removed through the porous walls of the centrifuge basket.

Tubular bowl

High-speed tubular bowl centrifuges with a vertical axis are used to separate immiscible liquids like water and oil, as well as fine solids. The bowl rotates at about 15,000 rpm (250 Hz), producing a centrifugal force of more than 130,000N.

Disc Bowl

The conical discs in a disk bowl centrifuge split the liquid flow into a series of very thin layers, greatly improving separation efficiency. Disc bowl centrifuges are used to distinguish solids and differentiate liquids and fine solids. 3.

Scroll Discharge

In this sort of device, solids deposited on the bowl's wall are separated by a scroll (a helical screw conveyer) spinning at a slightly different speed than the bowl. Using scroll discharge centrifuges, solids can be washed and comparatively dry solids can be discharged.

Solid Bowl Batch Centrifuge

The most basic type; similar to tubular bowl machines, except the bowl has a smaller lengthto-diameter ratio (less than 0.75). With solids concentrations greater than 1% by volume, the tubular bowl is seldom used. The other three formulations will be used with concentrations ranging from 1% to 15%. The scroll discharge style or the batch type may be used above 15% depending on whether continuous or intermittent operation is needed

Filtration Centrifuge

Depending on how the solids are separated, centrifugal filters can be divided into two categories: fixed bed and moving bed. The solids cake stays on the bowl's walls until manually or automatically removed using a knife mechanism in the fixed-bed form. Its activity is basically cyclic. The mass of solids is pushed around the bowl by the motion of a scroll (similar to solid-bowl sedimentation), a ram (pusher type), a vibration mechanism, or the bowl angle in the moving-bed type. The moving bed form may include zones for washing and drying.

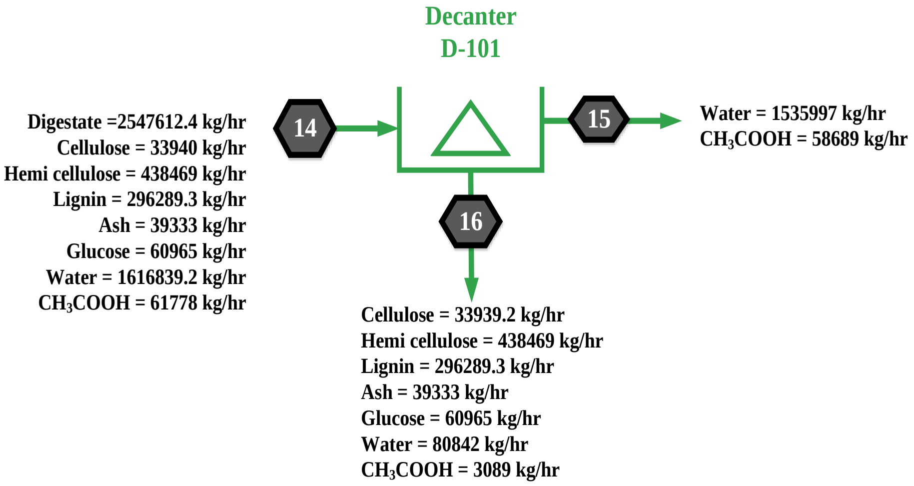


Fig no 5-6 : Decanter Centrifuge (D-101)

5.6.2 Selection of Centrifuge:

There are following factors which must be considered in the selection of centrifuge for a process.

Physical Properties of Materials

The characteristics of the solids and liquids handled in a process will influence centrifuge selection. Process requirements Continuous centrifuges should be considered when the following criteria are important.

Solids and Liquids' Basic Gravities

A decanting centrifuge is not an option if the solids are lighter than the liquid. A decanting centrifuge can be considered if the individual gravities are very similar but the solids are slightly heavier, but only if either the particle size or the centrifugal force increases the solids' settling..

Particle Size

Filtering centrifuges are ideally suited for coarse solids with particle sizes greater than 100 um. Sedimentation centrifuges are best for finer solids with a diameter of less than 100 um.

Concentrate Clarity

The clarity of a decanting centrifuge is the best of all centrifuge forms. Since they use either a filter medium or a screen, filtration centrifuges are normally not used where centrate clarity is the primary process requirement.

Process requirements

Continuous centrifuges should be considered when the following criteria are important.

Pressure and Temperature

Where higher operating pressures are needed, continuous centrifuges are used. Continuous decanters have been used in operations with pressures up to 90 psig and temperatures up to 175 degrees Celsius. Batch centrifuges are limited to applications with lower pressures. There does not appear to be any temperature-related constraint or preference.

Flow rate

The higher the solid flow rate, the more likely continuous centrifugation would be used. Batch centrifuges are suitable for loadings of up to 1 ton/hr as a rule of thumb.

Solid Concentration

With the exception of the screen bowl configuration, continuous filtering centrifuges prefer thick feed slurry (typically 50 percent by weight).

Design Calculation

Design Step

- Volumetric Flow rate
- Length of Decanter Centrifuge
- Residence Time
- Relative Centrifugal Force
- Velocity of Settling

Volumetric Flow rate:

$$\text{Volumetric flow rate} = \frac{\text{Mass flow rate}}{\text{Average density}}$$

$$V = \frac{2547612}{3560}$$

$$V = 715\ \text{m}^3/\text{hr}$$

Length of centrifuge:

L/D=1.5

Since Capacity of centrifuge is

$$V = \frac{3.5LD^2(\rho_s - \rho_L)d^2N^2}{\mu}$$

$$715 = \frac{3.5(1.5D)(D2)(412)(25*10)(10)}{2}$$

D =1.3

L=1.5(1.3)

L=1.95m

Volume of bowl:

$V= \frac{лD^2}{4}L$

$V=5.1m^3$

Residence Time:

Time for slurry = $ʈ = \frac{\text{volume of liquid in bowl}}{\text{volumetric flow rate}}$

Volume of Liquid in bowl = $V_{L} = лL(r_1^2 - r_2^2)$

$r_1 = \frac{D}{2} = 0.65$

$r_2 = \frac{0.65}{2} = 0.325$

Volume of liquid in bowl = $\frac{2.5509}{715} = 0.03$

=0.03*60=1.8min

t=1.8min

Relative Centrifuge force

$RCF= \frac{\omega^2 r2}{g}$

ω= 2лn

ω= 62Rad/sec

RCF= 125

Velocity of settling

$Vs= \frac{dp2\ (\rho_S - \rho_L)\omega^2 r_2}{18\mu}$

Vs=3.5m/sec

Specification Sheet	
Identification	
Item	Centrifuge Decanter
Item no	C-101
Number Required	1
Operation	Continuous
Type	Solid Bowl Centrifuge
Function:	
To separate liquid and solid	
Pressure	1bar
Temperature	30 ºC
Diameter	1.3 m
Length	1.95 m
Volume	5.1 m^3
Time	2 min
RCF	125
Velocity of settling	3.5m/sec

5.7 Scrubber (Sc-101):

The removal of one or many constituents from a gaseous mixture using a suitable solvent is the second important mass transfer operation in Chemical Engineering. Soluble vapors are more or less absorbed in the gas absorption process. A solvent is derived from a combination of inert gas and a solvent. The goal of this type of gas scrubbing is to remove contaminants from the synthesis gas.

Any of the following operations are possible:

- For the separation of components with monetary worth.
- As a step in the manufacturing of a chemical.
- To get rid of an unwanted component (pollution).

5.7.1 Types of Absorption:

- Physical Absorption: Mass transfer occurs solely by diffusion in physical absorption, and physical absorption is regulated by physical equilibria.

- Chemical Absorption: A chemical reaction occurs when a specific component comes into touch with the absorbing liquid then, by lowering the concentration of the component in the liquid phase, the rate of diffusion is increased.

Packed Column	**Plate Column**
Due to decrease liquid holdup and the need to make the unit as compact as possible for safety, a packed column is chosen over a plate column for handling poisonous and combustible liquids	At greater gas flow rates, plate towers have significant pressure dips and liquid holdup.
Foaming and corrosive services are better served by packed towers	Plate columns are often used to foul fouling liquids or solids.

5.7.2 Selection of Packing:

A packed column is chosen as the absorber based on the preceding considerations. Because the solubility of a liquid is infinite, it will absorb as many gases as it comes into contact with, hence a densely packed tower will give more contact. It is simple to use. Principal Requirement of a Tower packing are

- It must be chemically inert to the tower's fluids.
- It must be sturdy without being overly heavy.

- It must have enough channels for both streams to flow freely without causing undue liquid hold-up or pressure decrease.
- It must allow for good liquid-to-gas interaction.
- It must be cost-effective.

Common Packings:

- Berl Saddle.
- Intalox Saddle.
- Rasching rings.
- Lessing rings.
- Cross-partition rings.
- Single spiral ring.
- Double - Spiral ring.
- Triple - Spiral ring.

We've decided on a ceramic Intalox saddle. The most common selections are Intalox saddle and pall rings. Because ceramic Intalox saddles are the most efficient, we chose them. We chose ceramic packing material because oxygen and water are present in our system, which might cause corrosion, and ceramic material will prevent corrosion.

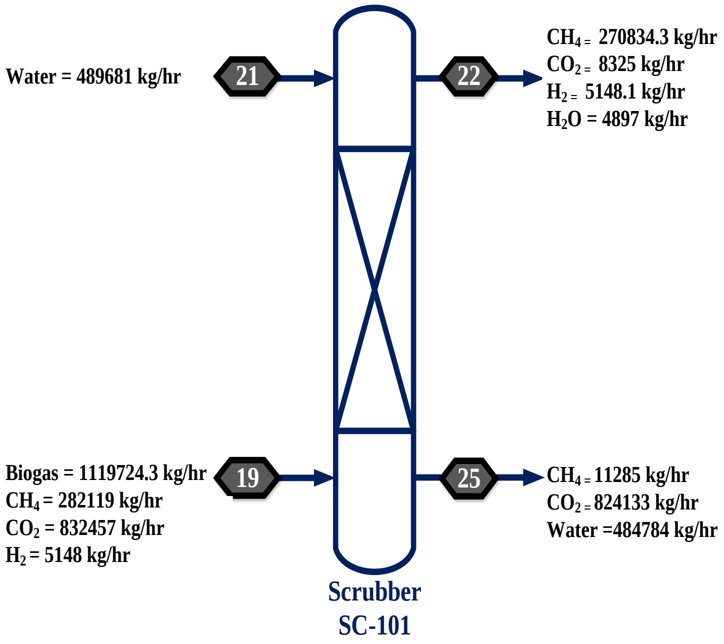


Fig no 5.7 : Scrubber (SC-101)

Selection:

We have selected the Packed column due to following reasons:

1. In the packed column there is a low-pressure drop.
2. Packed columns are more suitable for foaming and corrosive services. Its designed to handle the maximum gas flow rate.
3. More choices in materials of construction for packings especially in corrosive service (e.g. plastic, ceramic, metal alloys).

Design Steps:

The design steps of the scrubber are:

- Calculation of Flow Factor
- Calculation of Diameter of column
- Calculation of height of transfer units
- Calculation of Liquid film Mass transfer Coefficient
- Calculation of gas film Mass transfer Coefficient
- Calculation of gas film transfer unit height
- Calculation of liquid transfer unit height
- Calculation of height of transfer unit height
- Calculation for Operating velocity
- Calculation of height of the tower
- Calculation of wetting rate
- Calculation of Pressure drop

Flow Factor(F_{LV}):

$$\frac{L}{G} = \sqrt{\frac{\rho_g}{\rho_l}} = 0.437$$

$\text{Flow rate of entering gas} = G = 31.1\ {}^{kg}/_{s}$

$\text{Flow rate of entering slovent} = L = 13.6\ {}^{kg}/_{s}$

$\text{For 29 mm of} \frac{H_2O}{m} \text{of packing} \quad \text{(R. K Sinnott)}$

$k_4 = 1.6$ (From fig 11.44)

Diameter of Column:

$$G^* = [\frac{K_4\rho_g(\rho_L-\rho_g)}{13.1F_P({}^{\mu_L}/_{\mu g_L})^{0.1}}]^{0.5} \qquad = 16.86\ {}^{kg}/_{m2s}$$

$\text{Viscosity of liquid(solvent)} = \mu l = 0.00797\ \text{Pa.s}$

$\text{Viscosity of gas mixture} = \mu g = 3.54 \times 10^{-5}\text{Pa.s}$

$\text{Density of liquid(solvent)} = \rho_l = 995.7\ \text{kg/m3}$

$\text{Density of gas mixture} = \rho_g = 7.472\ \text{kg/m3}$

$\text{Packing parameter for 2} - \text{inch ceramic intalox saddles} = \text{Fp} = 210\text{m}^{-1}\ \text{(R.K Sinnott)}$

$$A = \frac{G}{G^*} = \frac{31.1}{16.86} = 1.84\text{m2}$$

$$\text{Diameter of column} = D = \sqrt{\frac{4 \times A}{\pi}}$$

$$= 1.53\text{m}$$

Calculation of height of transfer units:

$$\frac{a_w}{a} = 1 - \exp\left[-1.45(\frac{\sigma_c}{\sigma_L})^{0.75}(\frac{L_W}{a\mu_L})^{0.1}(\frac{Lw^2a}{\rho_{2L}g})^{-0.05}(\frac{L_W}{\rho_L\sigma_La})^{0.2}\right]$$

$$\mathbf{a_w = 30.240\ {}^{m^2}/_{m^3}}$$

$a_w = \text{Effective interficial area of packing per unit volume} = {}^{m^2}/_{m^3}$

$a = \text{Actual area of packing per unit volum} = 108\,{}^{m^2}/_{m^3}\ \text{(Table 11.2)}$

$\sigma_c = \text{Critical surface tension for particular material} = 0.061\ \text{N/m}$

L_W =Liquid mass velocity = 7.39 $\frac{kg}{m^2s}$

$\sigma_L = \text{liquid Surface Tension} = 0.0522\ \text{N/m}$

Calculation of Liquid film Mass transfer Coefficient:

$$K_{L:}\left[\frac{\rho_L}{\mu_Lg}\right]^{\frac{1}{3}} = 0.0051\left[\frac{L_W}{a_w\mu_L}\right]^{\frac{2}{3}}\left[\frac{\mu_L}{\rho_LD_c}\right]^{-\frac{1}{2}}[adp]^{0.4}$$

K_L= 0.89m/s

K_L= liquid film coefficient m/s

d_p= packing size = 51mm (Table 11.2)

$D_L = \text{Diffusivity of liquid (solvent)} = 0.538 \times 10^{-9}\text{m2/s}$

$\rho_L = 995.7\, {}^{kg}/_{m^3}$

$a =$ Actual area of packing per unit volum $= 108\, {}^{m^2}/_{m^3}$ (Table 11.2)

$L_W = 7.39\, \frac{kg}{m^2 S}$

$g = 9.8\ m/s$

Calculation of gas film Mass transfer Coefficient:

$$K_G \frac{RT_g}{D_g a} = K_5 \left[\frac{V_W}{a\mu_g}\right]^{0.7} \left[\frac{\mu_g}{\rho_g D_g}\right]^{1/3} [adp]^{-2}$$

$$\mathbf{K_G = 1.597 \times 10^{-3}\ {}^{kmol}/_{m^2.s.atm}}$$

$K_5 = 5.23$ for packing above 15mm

$V_w = 7.39\ \frac{kg}{m^2 S}$

$a_w = 30.24\, {}^{m^2}/_{m^3}$

$a =$ Actual area of packing per unit volum $= 108\, {}^{m^2}/_{m^3}$ (Table 11.2)

σ_c = Critical surface tension for particular material = 0.061 N/m

D_g = Diffusivity of gases = $0.00001565 m^2/s$

d_p= packing size = 51mm

$\rho_g = 0.649\, {}^{kg}/_{m^3}$

$T_g = 303K$

$g = 9.8\ m/s$

$\mu_g = 1.34 \times 10^{-5} Pa.s$

$R = 0.00820\, {}^{atm\ m^3}/_{kmol\ K}$

Gas Film Transfer Unit Height:

$$H_G = \frac{G_m}{G_m a_w \rho}$$

$\mathbf{H_G = 0.74m}$

H_G = Gas film transfer unit height

G_m = Gas mass velocity = 0.12 kg mol / m^2.s

P_G = Pressure of gases = 3 bar

K_G = Gas film coefficient = 1.95 x 10^{-3} kmol /m^2s.bar

a_w = Effective interfacial area of packing per unit volume = 30.24 m^2/m^3

Calculation of Liquid transfer unit height:

$$H_L = \frac{L_W}{K_L a_w C_t}$$

$\mathbf{H_L}$ **= 0.000556m**

H_L = Liquid film transfer unit height,

L_w = Liquid mass velocity = 7.39kg/m^2 .s

C_t = Total Concentration=ρ_L / Molecular weight of solvent = 55.3 kmol / m^3

K_L = Liquid film coefficient =0.56 m/s

a_w = Effective interfacial area of packing per unit volume = 30.24 m^2/m^3

Calculation of height of transfer unit:

$$H_{OG} = H_G - \frac{mG_m}{L_m} \times H_L$$

$$\mathbf{H_{OG} = 0.9986m}$$

$H_G = 1m$

$H_L = 0.00055m$

$\frac{mG_m}{L_m} = 0.79 \qquad (\text{Range } 0.7 - 0.8)$

Equation for equilibrium curve:

y_1 = Mole fraction of H20, CO2 & CH4 in entering gas stream = 0.41934

y_2 = Mole fraction of H20, CO2 & CH4 in Leaving gas stream = 0.09

$$y_1/y_2 = 4.6$$

$$N_{OG} = 3 (\text{From Fig } 11.40)$$

Calculation of height of Tower:

$$z = N_{OG} \times H_{OG} = 2.97m$$

Allowance for liquid distribution & redistribution = 0.59m + 0.59m

$$\mathbf{z = 4.2m}$$

Calculation of Wetting rate:

$$\text{wetting rate} = \frac{\text{volumetric flow rate}}{a} = \mathbf{3.907 \times 10^{-6}\, m^2/s}$$

$$\text{volumetric liquid flowrate} = 4.22 \times 10^{-4}\, m^3/s$$

$$a = \text{Actual area of packing per unit volume} = 108\, {}^{m^2}\!/_{m^3}$$

Operating Velocity:

$\frac{L}{G} = \sqrt{\frac{\rho_g}{\rho_l}} = 0.437$

$$k_4 = 1.6 \text{ (From fig 11.44)}$$

$$G^* = [\frac{K_4\rho_g(\rho_L - \rho_g)}{131F_P({}^{\mu_L}\!/_{\rho_L})^{0.1}}]^{0.5}$$

$$= 1.45\, {}^{kg}\!/_{m2s}$$

Pressure Drop:

$$\Delta P = \alpha \times 10^{BL}\left(\frac{G^2}{\rho_A}\right)$$

$$\mathbf{\Delta P = 1.56\ Pa}$$

$$\rho_{\ g} = 7.47\, {}^{kg}\!/_{m^3}$$

$$L_{\ .} = 0.752\, {}^{kg}\!/_{m^2s}$$

$$G_{\ .} = 0.501\, {}^{kg}\!/_{m^2s}$$

$\alpha = 0.13$ (From Figure)

$$\beta = 0.15$$

Specification Sheet	
Identification	
Item	Scrubber
Item no	SC-101
Number Required	1
Operation	Continuous
Type	Packed Column
Packing	Ceramics Intralox saddles
Function:	
To absorb CO_2 from Product Stream	
Pressure	10 bar
Temperature	30 ºC
Diameter	1.53 m
Interfacial area of Packing	30.24 m2
Height of transfer unit	0.000656 m
Number of transfer units	3
Column Height	2.97 m
Pressure Drop	1.56 pa

5.8 Stripper (ST-101):

Stripping is a mass transfer technique in which a solute is transferred from a liquid to a gas phase. “Stripping is a unit operation in which one or more components of a liquid stream are removed by contacting them with an insoluble in the liquid stream gas stream." Fundamentally, stripping is a physical separation process in which a vapor stream removes one or more components from a liquid stream. The liquid and vapor streams in industrial applications might have either co-current or countercurrent flows. In most cases, stripping is done in a packed or tray column.

Selection of Packing:

Based on the foregoing principles, a packed column is chosen as the absorber. Because a liquid's solubility is unlimited, it will absorb as many gases as it comes into touch with, resulting in greater interaction in a densely packed tower. It's quite easy to use.

The following are the most important requirements for tower packing:

- It must be chemically inert to the tower's fluids.
- It should be strong yet not too hefty. It must have enough passages to allow both streams to flow freely without producing liquid back up or pressure drops.
- It must be cost-effective and allow for good liquid-to-gas contact.

As a result, the majority of packaging is made of low-cost, inert, and lightweight materials like clay, porcelain, or graphite. Some limes are steel or aluminum rings with a thin wall.

Common Packing’s:

- Berl Saddle.
- Intalox Saddle.
- Rasching rings.
- Single spiral ring.
- Double - Spiral ring.
- Triple - Spiral ring

5.8.1 Selection of packing:

A ceramic Intalox saddle has been chosen. Intalox saddle and pall rings are the most popular choices. We picked ceramic Intalox saddles because they are the most efficient. We picked ceramic packing material since our system contains oxygen and water, both of which can cause corrosion, and ceramic material prevents corrosion.

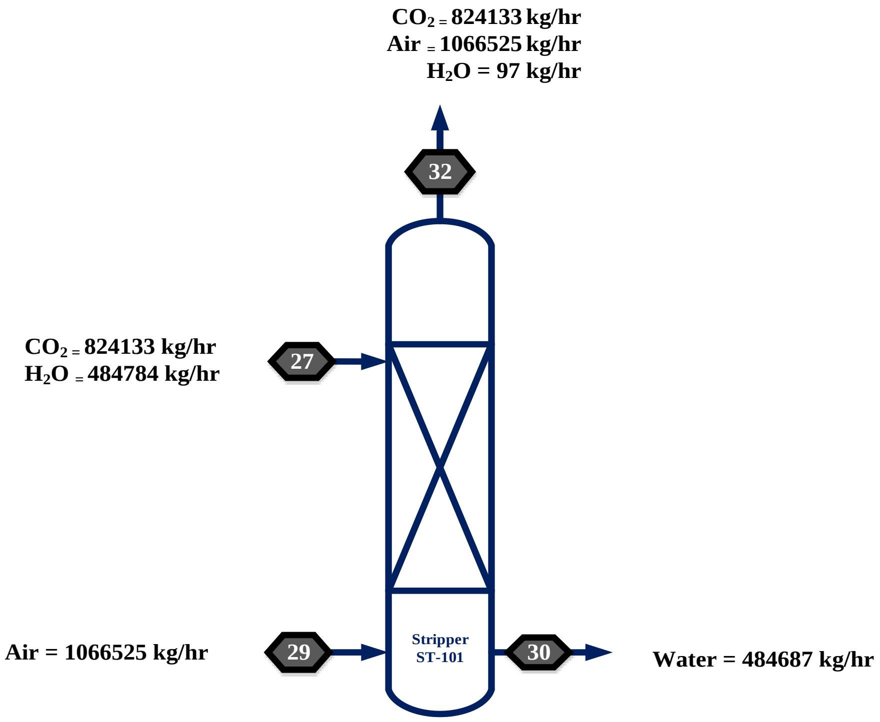


Fig no 5.8: Stripper (ST-101)

Design of Air Stripper:

Selection Criteria:

1. As we use air as an Input stream so, we selected the Air Stripper
2. It is Highly effective at removing VOCs from water, achieving removal rates of up to 99%.
3. Its Requires little maintenance due to the lack of moving parts
4. Its Requires relatively low power inputs compared to steam strippers
5. Ease of operation

Design Steps:

The design steps of the air stripper are:

- Calculation of Flow Factor
- Calculation of Diameter of column
- Calculation of height of transfer units
- Calculation of Liquid film Mass transfer Coefficient
- Calculation of gas film Mass transfer Coefficient
- Calculation of gas film transfer unit height
- Calculation For Equilibrium Curve
- Calculation of Flooding Velocity
- Calculation of the Height of the Tower

- Calculation of Wetting Rate
- Calculation of Pressure Drop

Flow Factor(F_{LV}):

$$\frac{L}{G} = \sqrt{\frac{\rho_g}{\rho_l}} = 0.07$$

$\text{Flow rate of entering gas} = G = 22.89\ {}^{kg}/_{s}$

$\text{Flow rate of entering slovent} = L = 13.46\ {}^{kg}/_{s}$

$\text{For 29mm of}\frac{H_2O}{m}\text{of packing}\quad (\text{R. K Sinnott})$

$k_4 = 1.6\ (\text{From fig 11.44 })$

Diameter of Column:

$$G^* = [\frac{K_4\rho_g(\rho_L - \rho_g)}{131F_P({}^{\mu_L}/_{\rho_L})^{0.1}}]^{0.5} \qquad = 6.723\ {}^{kg}/_{m2s}$$

$\text{Viscosity of liquid(solvent)} = \mu_l = 0.0079\ \text{Pa. s}$

$\text{Viscosity of gas mixture} = \mu g = 1.51 \times 10^{-5}\text{Pa. s}$

$\text{Density of liquid(solvent)} = \rho_l = 995.7\ \text{kg/m3}$

$\text{Density of gas mixture} = \rho_g = 5.31\ \text{kg/m3}$

$\text{Packing parameter for 2} - \text{inch ceramic intalox saddles} = Fp = 210m^{-1}\ (\text{R. K Sinnott})$

$$A = \frac{G}{G^*} = \frac{22.89}{6.723} = 3.4$$

$$\text{Diameter of column} = D = \sqrt{\frac{4 \times A}{\pi}} = 2.20m$$

Calculation of height of transfer units:

$$\frac{a_w}{a} = 1 - \exp\left[-1.45(\frac{\sigma_c}{\sigma_L})^{0.75}(\frac{Lw}{a\mu_L})^{0.1}(\frac{Lw^2a}{\rho_{2L}g})^{-0.05}(\frac{Lw}{\rho_L\sigma_L a})^{0.2}\right]$$

$$\mathbf{a_w = 31.37\ {}^{m^2}/_{m^3}}$$

$a_w = \text{Effective interficial area of packing per unit volume} = {}^{m^2}/_{m^3}$

$\mathrm{a} =$ Actual area of packing per unit volume $= 95\ \mathrm{m^2}/_{\mathrm{m^3}}$ (Table 11.2)

$\sigma_c =$ Critical surface tension for particular material $= 0.061\ \mathrm{N/m}$

L_W =Liquid mass velocity = 6.11 $\frac{\mathrm{kg}}{\mathrm{m^2S}}$

$$\mu_L = 0.0056\mathrm{N/m^2s}$$

$$\sigma_L = 0.0443\ \mathrm{N/m}$$

Calculation of Liquid film Mass transfer Coefficient:

$$K_{L:}\left[\frac{\rho_L}{\mu_L g}\right]^{1/3} = 0.0051\left[\frac{L_W}{a_w\mu_L}\right]^{2/3}\left[\frac{\mu_L}{\rho_L D_c}\right]^{-1/2}[\mathrm{adp}]^{0.4}$$

$$\mathbf{K_L = 4.05 \times 10^{-4} m/s}$$

K_L= liquid film coefficient m/s

d_p= packing size = 51mm (Table 11.2)

$D_L =$ Diffusivity of liquid (solvent) $= 4.5 \times 10^{-7}\mathrm{m2/s}$

ρ_L= 995.74 $\mathrm{kg}/_{\mathrm{m^3}}$

$\mathrm{a} =$ Actual area of packing $= 95\ \mathrm{m^2}/_{\mathrm{m^3}}$ (Table 11.2)

L_W =6.11 $\frac{\mathrm{kg}}{\mathrm{m^2S}}$

$\mu_L = 0.0056\ \mathrm{N}/_{\mathrm{m^2}}$

$g = 9.8\ \mathrm{m/s}$

Calculation of gas film Mass transfer Coefficient:

$$K_G\frac{RT_g}{D_g a} = K_5\left[\frac{V_W}{a\mu_g}\right]^{0.7}\left[\frac{\mu_g}{\rho_g D_g}\right]^{\frac{1}{3}}[\mathrm{adp}]^{-2}$$

$$\mathbf{K_G = 6.3 \times 10^{-3}\ kmol/_{m^2.s.atm}}$$

K_5=5.23 for packing above 15mm

L_W =6.11 $\frac{\mathrm{kg}}{\mathrm{m^2S}}$

V_w= 1.032 $\frac{\mathrm{kg}}{\mathrm{m^2S}}$

$a_w = 31.37\ {}^{m^2}/_{m^3}$

$a =$ Actual area of packing per unit volum $= 253\ {}^{m^2}/_{m^3}$ (Table 11.2)

σ_c = Critical surface tension for particular material = 0.0061 N/m

D_g = Diffusivity of gases = $\mathbf{1.496 \times 10^{-5}}\ m^2/s$

d_p= packing size = 25mm

ρ_g= $1.25\ {}^{kg}/_{m^3}$

$T_g = 393K$

$g = 9.8\ m/s$

$\mu_g = 1.87 \times 10^{-5} Pa.s$

$R = 0.008206\ {}^{atm\ m^3}/_{kmol\ K}$

Gas Film Transfer Unit Height:

$$H_G = \frac{G_m}{G_m a_w \rho}$$

$$\mathbf{H_G = 0.61m}$$

G_m = Gas mass velocity = 0.0279 kgmol/m^2 .s

P_G = Pressure of gases = 1 bar

K_G = Gas film coefficient = 6.31×10^{-4} kmol/m^2 .s.bar

a_w = Effective interfacial area of packing per unit volume = 31.37 m^2 /m^3

H_G = Gas film transfer unit height, m

Calculation of Liquid transfer unit height:

$$H_L = \frac{L_m}{K_L a_w C_t}$$

$$\mathbf{H_L = 0.75m}$$

L_m = Liquid mass velocity = 1.179 kg/m^2 .s

C_t = Total Concentration=ρ_L / Molecular weight of solvent = 3.60kmol/m^3

K_L = Liquid film coefficient =4.05×10^{-4} m/s

a_w = Effective interfacial area of packing per unit volume = 31.37 m^2 /m^3

H_L = Liquid film transfer unit height, m

Calculation of height of transfer unit:

$$\mathrm{H_{OG} = H_G - \frac{mG_m}{L_m} \times H_L}$$

$$\mathbf{H_{OG} = 1.21m}$$

$\mathrm{H_G = 0.71m}$

$\mathrm{H_L = 0.75m}$

$\mathrm{\frac{mG_m}{L_m} = 0.75 \qquad (Range\ 0.7 - 0.8)}$

Equation for equilibrium curve:

$\mathrm{y_1}$ = Mole fraction of H2O, CO2 & CH4 in entering gas stream = 1

$\mathrm{y_2}$ = Mole fraction of H2O, CO2 & CH4 in Leaving gas stream = 1

$$\mathrm{{}^{y_1}/_{y_2} = 1}$$

$$\mathrm{N_{OG} = 2 (From\ Fig\ 11.40)}$$

Calculation of height of Tower:

$$\mathrm{z = N_{OG} \times H_{OG} = 2.43m}$$

Allowance for liquid distribution & redistribution = 0.5m + 0.5m

$$\mathbf{z = 3.3m}$$

Calculation of Wetting rate:

$$\mathrm{wetting\ rate = \frac{volumetric\ flow\ rate}{a}} = \mathbf{6.28 \times 10^{-7}\ m^2/_s}$$

$\text{volumetric liquid flowrate} = 5.9 \times 10^{-4}\ {}^{m^3}/_{s}$

$a = \text{Actual area of packing per unit volum} = 253\ {}^{m^2}/_{m^3}$

Operating Velocity:

$k_4 = 0.95$ (From fig 11.44)

$\frac{L}{G} = \sqrt{\frac{\rho_g}{\rho_l}} = 0.07$

$$G^* = [\frac{K_4\rho_g(\rho_L - \rho_g)}{13.1F_P({}^{\mu_L}/_{\rho_L})^{0.1}}]^{0.5} \qquad = 1.025\ {}^{kg}/_{m2s}$$

Pressure Drop:

$$\Delta P = \alpha \times 10^{BL}\left(\frac{G^2}{\rho_A}\right)$$

$$\mathbf{\Delta P = 1.71\ Pa}$$

$\rho_{\ g} = 5.31\ {}^{kg}/_{m^3}$

$L_{\ m} = 6.11\ {}^{kg}/_{m^2s}$

$G_{\ m} = 6.73\ {}^{kg}/_{m^2s}$

$\alpha = 0.13$ (From Figure)

$\beta = 0.15$

<table>
<tr><th colspan="2">Specification Sheet</th></tr>
<tr><td colspan="2">Identification</td></tr>
<tr><td>Item</td><td>Stripper</td></tr>
<tr><td>Item no</td><td>ST-101</td></tr>
<tr><td>Number Required</td><td>1</td></tr>
<tr><td>Operation</td><td>Continuous</td></tr>
<tr><td>Type</td><td>Packed Column</td></tr>
<tr><td>Packing</td><td>Raschig Rings Ceramics</td></tr>
<tr><td colspan="2">Function:</td></tr>
<tr><td colspan="2">To regenerate solvent (water) by absorbing CO_2</td></tr>
<tr><td>Pressure</td><td>1bar</td></tr>
<tr><td>Temperature</td><td>30 ºC</td></tr>
<tr><td>Diameter</td><td>0.6 m</td></tr>
<tr><td>Height of transfer unit</td><td>1.2 m</td></tr>
<tr><td>Number of transfer units</td><td>0.75</td></tr>
<tr><td>Column Height</td><td>2.43</td></tr>
<tr><td>Pressure Drop</td><td>1.71 pa</td></tr>
</table>

CHAPTER # 6

MECHANICAL DESIGN

6-Mechanical Design

Mechanical design basically deals with the geometry of any equipment. In case of a chemical reactor, the main aspects are reactor volume, diameter and height or length of the reactor. Mechanical design should be performed with more care and knowledge, it is important to select the most appropriate material for the construction of equipment to withstand the operating conditions

6.1 LHW Pre-treatment Reactor (R-201):

Material selection:

Stainless Steel 410 is selected

Lowest cost general purpose stainless steel.

Widely use Where Corrosion is not severe.

Minimum Practical wall thickness:

A minimum wall thickness will be necessary to guarantee that any is stiff enough to support its own weight and any identical loads. As a general rule, any vessel's wall thickness should not be less than the numbers shown below, which include a 2mm corrosion allowance.

Diameter of reactor = 1.5 m

Minimum Wall thickness = 7mm

Pressure:

Operating pressure = 10 bar = 1 N/mm^2

Design pressure:

Taken as 10% above operating pressure = 1.1 N/mm^2

Wall thickness:

Material = Stainless Steel 410

Diameter = 1.5 m = 1500 mm

Length = 2.3 m = 2300 mm

Maximum Allowable Stress = f = 122 N/mm^2

Maximum Allowable Joint efficiency = J = 1

This is because we have selected welded butt joint

Maximum allowable pressure = 1.1 N/mm^2

Wall thickness= e = $\frac{P\times D}{2\times f\times J-P} = 7\ mm$

Adding corrosion allowance Ce = 2mm

e = 9 mm

Outer Dia of shell

$D_o = D_i + 2e$= 1518 mm

Baffle spacing:

4 equally spaced baffles are used

Baffle spacing = $\frac{\pi\times D_t}{4}$ = 1.1 m

Width of baffle =$\frac{D_t}{12} = 0.12\ m$

Distance from bottom= $\frac{D_t}{2} = 0.7\ m$

Heads and closure:

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 head
- Tori spherical head

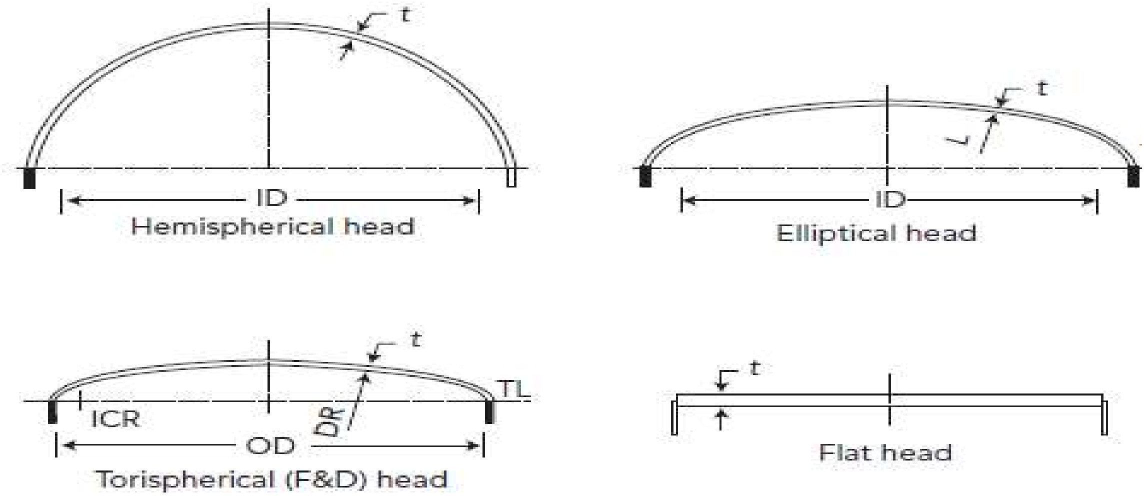


Fig no 6.1:Types of Heads

We have selected ellipsoidal head

$$t = \frac{P \times D}{2 \times f \times J - 0.2P} = 7\, mm$$

Adding 2mm corrosion allowance

t=9 mm

Vessel support:

For reactors bracket support is used

Weight load:

$$W = 240 \times C_v \times D_m \times (H_v + 0.8 \times D_m) \times t$$

Where;

t= thickness of shell H_v = height of vessel C_v = factor to account for vessels internal support

$$D_m = mean\ di = (D_i + t) = 1500\, mm$$

W = 19 N

Wind load:

Wind pressure = Pw = 1030 N/m^2

Total dia = $D_T = (D_t + t) = 1500\, mm$

So wind load is

$$F = Pw \times D$$

= 1.54 N/mm

Stress calculations:

Longitudinal stress:

$$\sigma_h = \frac{P \times D}{2t} = 53\ \mathrm{N/mm2}$$

Circumferential stress:

$$\sigma_L = \frac{P \times D}{4t} = 26\ \mathrm{N/mm2}$$

Dead weight stress:

$$\sigma_w = \frac{W}{\pi \times (D+t) \times t} = 0.28 \frac{N}{mm2}$$

Radial stress:

$$\mathrm{\sigma_r} = \frac{\mathrm{P}}{2} = 0.5\ \mathrm{N/mm2}$$

Bending moment:

$M_x = F \times H$ = 1500 Nm

Bending stress:

$$\sigma_b = \frac{M_x}{l_v} \times \left(\frac{D}{2} + t\right)$$

Where,

$$l_v = \frac{P \times (D_o^4 - D_i^4)}{\pi \times (D+t) \times t} = 1.6 \times 10^6$$

So, σ_b = 1.1 N/m^2

CHAPTER # 7

POWER CALCULATIONS

7-Power Calculations:

7.1 Pumps:

A mechanical device known as a pump is used to compress, elevate, or move fluids. The process fluid receives momentum and mechanical energy from the pump. Liquid can be moved from one location to another using pumps The motors that control can be the subject of numerous best practices. Curves for pumps and devices are frequently used to simulate pump function. Pump curves display a specific pump's horsepower, head, and flow rate at a constant rpm. System curves specify the power and head of a pump system.

Pumps are used to move liquids, such as moving blood and other biological fluids, delivering measured amounts of chemicals, putting out fires, providing irrigation, moving foods and beverages, pumping pharmaceutical and bathroom products, operating sewage systems, transporting solids, providing water and operating petrochemical and chemical plants, among other applications. They are used for site drainage, water-jet cutting, cleaning, and descaling, as well as power transfer, braking systems, servomechanisms, and control. Thus, when pumping liquids that differ greatly in viscosity and composition, pumps provide a wide variety of pressure rises and flow rates.

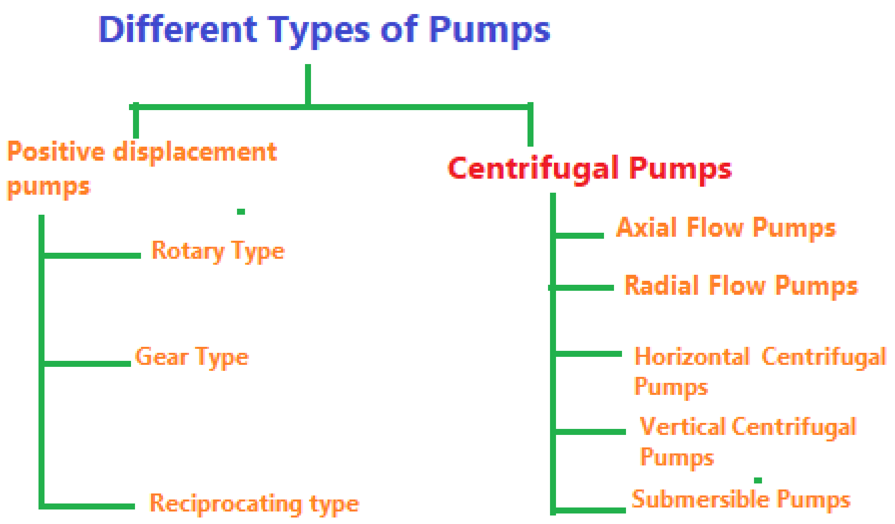


Fig no 7.1: Classification of Pumps

Selection:

The ultimate decision on a pump for a given operation can be influenced by a variety of distinct circumstances. The list of important criteria for choosing a pump is provided below.

1. How much fluid needs to be pumped. The size of the required pump (or pumps) will depend on this factor.

2. The fluid's characteristics. The power needed for a specific set of working conditions depends on the fluid's density and viscosity, and the fluid's corrosive characteristics dictate the appropriate building materials .The amount of clearance required depends on whether or not solid particles are suspended in the fluid; in this case, several types of pumps may not be an option.

3-The increase in fluid pressure brought on by the pumps' labor. The inlet and downstream reservoir pressures, the change in the vertical height of the delivery line, and frictional factors all have an impact on the head change across the pump. This element plays a significant role in figuring out how much power is needed.

4. Flow distribution type. Certain types of pumps, such as simplex reciprocating pumps, may not be suitable if non-pulsating flow is required. Similar to this, intermittent operation may necessitate a self-priming pump, which may make corrosion more challenging.

Calculations:

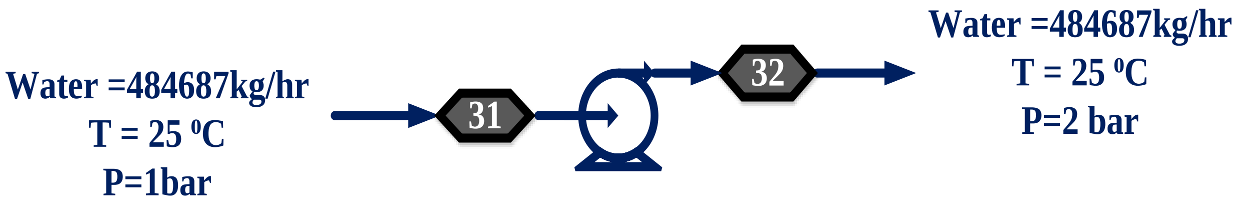


Fig no 7-2:Pump (P-203)

Inlet and Outlet Pressures:

$P_1 = 1 \text{ bar} = 1 \times 10^5 \text{ N/m}^2$

$P_2 = 2 \text{ bar} = 2 \times 10^5 \text{ N/m}^2$

Density of water:

Density of solvent water is 1000 kg/m^3

Head:

$Head = \Delta P / \rho g$

$= 10$ m

Pump work:

$W = \Delta P \times Q$

Volumetric Flow rate = 0.1 m^3/sec

$W = 1 \times 10^5 \times 0.1$

W = 1000 Watt

W = 1.3 hp

Specification Sheet	
Identification	
Item	Pump
Item no	P-203
Number Required	1
Operation	Continuous
Type	Centrifugal Pump
Function:	
To increase pressure of water from 1 bar to 10 bar	
Inlet Pressure	1 bar
Outlet Pressure	2 bar
Flow rate	484687 kg/hr
Density	1000kg/m^3
Work	1.3hp

Specification Sheet	
Identification	
Item	Pump
Item no	P-202
Number Required	4
Operation	Continuous
Type	Centrifugal Pump
Function:	
To increase pressure of water from 1 bar to 10 bar	
Inlet Pressure	1 bar
Outlet Pressure	10 bar
Flow rate	124929 kg/hr
Density	1000kg/m^3
Work	8.8 hp

Specification Sheet	
Identification	
Item	Pump
Item no	P-201
Number Required	5
Operation	Continuous
Type	Centrifugal Pump
Function:	
To increase pressure of water from 1 bar to 10 bar	
Inlet Pressure	1 bar
Outlet Pressure	10 bar
Flow rate	489680 kg/hr
Density	1000kg/m^3
Work	11 hp

7.2 Compressor:

The most popular compressible fluid or gas is air, and compressors are mechanical devices that raise pressure in a variety of other compressible fluids or gases.

In many different industries, compressors are used to push gas through pipelines, supply shop or instrument air, power air tools, paint sprayers and abrasive blast equipment, phase shift refrigerants for air conditioning and refrigeration, and more.

Positive-displacement compressors are more prevalent than centrifugal pumps, despite the fact that both types of pumps can be classed as centrifugal (or dynamic or kinetic) or positive-displacement. They can be as little as a glovebox-sized tire-inflation device or as large as gigantic reciprocating or turbo compressor units used in pipeline maintenance.

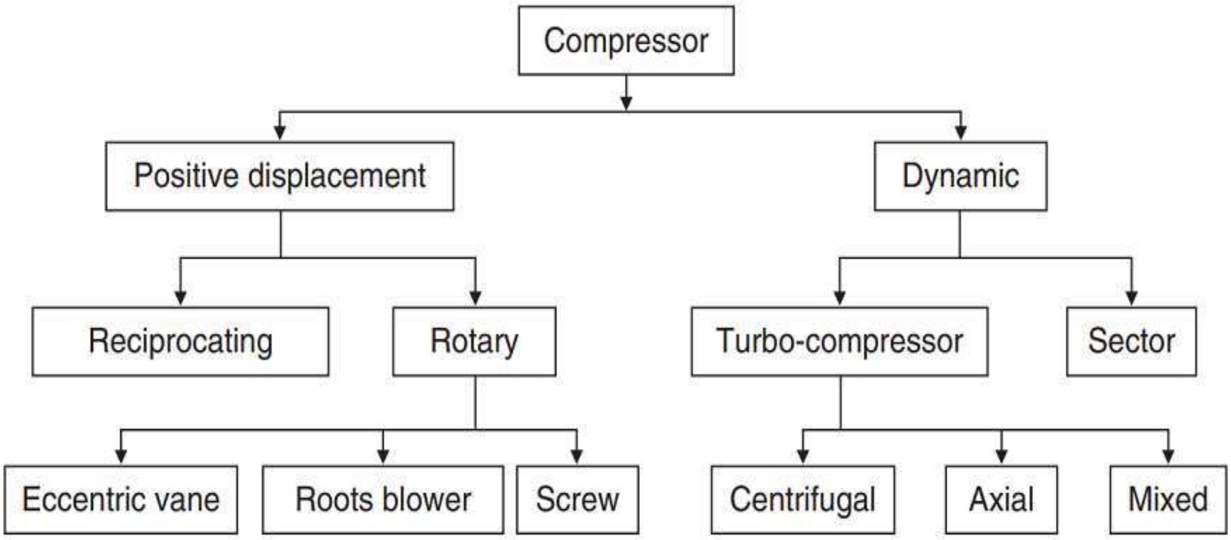


Fig no 7.3: Classification of Compressors

Calculations:

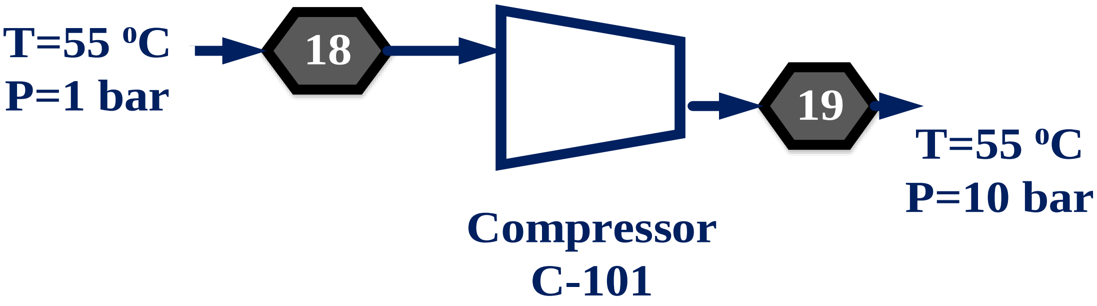


Fig no 7.4: Compressor (C-101)

Power of Compressor:

$P_B = \frac{1.304 \times 10-4}{\eta}$ Ta q_0 $\ln(\frac{Pb}{Pa})$

Where PB = Power required for compressing desired flowrate

Ta = Inlet temperature = 590 R^o

q_0 = Volume of gas = 10311 ft^3/sec

Pa = Inlet Pressure = 1 bar

Pb = Outlet Pressure = 10 bar

Putting these values will give us

P_B = 9 hp

Specification Sheet	
Identification	
Item	Compressor
Item no	C-101
Number Required	1
Operation	Continuous
Type	Centrifugal Compressor
Function:	
To increase pressure of biogas from 1 bar to 10 bar	
Inlet Pressure	1 bar
Outlet Pressure	10 bar
Work	1hp

CHAPTER # 8

COST ESTIMATION

8-Cost Estimation

8.1 Purchased Equipment Cost:

1- Cost of Conveyor:

Length of Conveyor = 10 m

Formula , $Ce = a + b\,S^n$

a = 21,000 b = 340 n = 1

Ce = $ 24400

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = $ 24400 × $\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = $ 39509

2- Cost of Grinder:

Capacity = 270 ton/hr

Formula , $Ce = a + b\,S^n$

a = 400 b = 9900 n = 0.5

Ce = $ 163073

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = $ 163073 × $\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = $ 264055

3-Cost of Dryer:

Purchase Cost in 2015 = $ 49000

The average increase in cost is about 2.5%.

Using this cost we will predict cost in 2022.

Cost in 2022 = \$ 49000 × $(1.025)^7$

Cost in 2022 = \$ 58245

4-Cost of Mixer:

Purchase Cost in 2015 = \$ 50000

The average increase in cost is about 2.5%.

Using this cost we will predict cost in 2022.

Cost in 2022 = \$ 50000 × $(1.025)^7$

Cost in 2022 = \$ 59434

5-Cost of Heat Exchanger:

Area = 266 m^2

Formula , $Ce = a + b\ S^n$

a = 1100 b = 850 n = 0.4

Ce = \$ 9031

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = \$ 9031 × $\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = \$ 14624

6- Cost of Reactor (R-101):

Volume of reactor = $8m^3$

Formula , $Ce = a + b\ S^n$

a = 14000 b = 15400 n = 0.7

Ce = \$ 80021

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = \$ 80021 × $\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = \$ 129573

7- Cost of Reactor (R-102):

Volume of reactor = 6 m^3

Formula , Ce = a + b S^n

a = 1400 b = 15400 n = 0.7

Ce = \$ 67979

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = \$ 67979 × $\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = \$ 110074

8- Cost of Waste Heat Boiler (WHB-101):

Area = $91m^2$

Formula , Ce = a + b S^n

a = 10000 b = 88 n = 1

Ce = \$ 18008

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = \$18008 × $\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = \$ 29159

9- Cost of Waste Heat Boiler (WHB-102):

Area = 76 m^2

Formula , Ce = a + b S^n

a = 10000 b = 88 n = 1

Ce = $ 16688

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = $ 16688 × $\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = $ 27021

10- Cost of Compressor:

Power = 0.74 kW

Formula , Ce = a + b S^n

a = 8400 b = 3100 n = 0.6

Ce = $ 10987

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = $ 10987 × $\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = $ 17791

11- Cost of Blower:

Flow rate = 1878 m^3/hr

Formula , Ce = a + b S^n

a = 4200 b = 27 n = 0.8

Ce = $ 15428

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = $ 15428 × $\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = $ 24982

12- Cost of Decanter:

Diameter = 1.3m

Formula , Ce = a + b S^n

a = 63000 b = 260000 n = 0.8

Ce = $ 383721

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = $383721 $\times \frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = $ 621336

13- Cost of Heat Exchanger:

Area = $20m^2$

Formula , Ce = a + b S^n

a = 500 b = 1100 n = 1

Ce = $ 22500

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = $22500 $\times \frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = $ 36432

14- Cost of Scrubber:

Mass flow rate = 1609 ton/hr

Formula , Ce = a + b S^n

a = 10000 b = 600 n = 0.6

Ce = $ 3187974

Cost of Packing:

Volume of Packing = 6m^3

b = 930 n =1

Ce = $5580

Total Cost = $ 3193554

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = $3193554 × $\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = $ 5171125

15- Cost of Stripper:

Mass flow rate = 1308 ton/hr

Formula , Ce = a + b S^n

a = 10000 b = 600 n = 0.6

Ce = $ 2817361

Cost of Packing:

Volume of Packing = 9.5 m^3

b = 930 n =1

Ce = $8578

Total Cost = $ 2825938

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = $2825938 × $\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = $ 4575869

16- Cost of Separator:

Volume = 4 m^3

Formula , $Ce = a + b S^n$

a = 53000 b = 2400 n = 0.6

Ce = $ 58513

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = \$58513 $\times \frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = $ 94746

17- Cost of Dehydrator:

Volume = 5 m^3

Formula , $Ce = a + b S^n$

a = 53000 b = 2400 n = 0.6

Ce = $ 59303

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = \$59303 $\times \frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = $ 96026

18- Cost of Pump (P-201):

Flow rate = 300 L/s

Formula , $Ce = a + b S^n$

a = 3300 b = 48 n = 1.2

Ce = $ 48359

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = \$ 48359 $\times \frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = $ 78305

19- Cost of Pump (P-202):

Flow rate = 100 L/s

Formula , Ce = a + b S^n

a = 3300 b = 48 n = 1.2

Ce = $ 15357

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = \$ 15357 × $\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = $ 24866

20- Cost of Pump (P-201):

Flow rate = 300 L/s

Formula , Ce = a + b S^n

a = 3300 b = 48 n = 1.2

Ce = $ 48359

Cost index in 2006 = 499

Cost index in 2022 = 808

Cost in 2006 = \$ 48359 × $\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2006}$

Cost in 2022 = $ 78305

8.2 Total Purchased Equipment Cost:

Equipment	Cost $
Conveyor	79018
Dryer	58245
Grinder	264055
Mixer	59434
Reactor 101	129573
Reactor 102	110074
Decanter Centrifuge	621336
Waste Heat Boiler 101	29159
Waste Heat Boiler 102	27021
Heat Exchanger 100	14624
Heat Exchanger 101	36432
Scrubber	5171125
Stripper	4575869
Separator	94746
Dehydrator	96026
Compressor	17797
Blower	15428
Pump 201	78305
Pump 202	49732
Pump 203	49732
Total	**1.1×10^{7}**

8.3 Direct Cost:

Component	% of Purchased cost	Cost $
Purchased Equipment	100	11527999
Installation	40	4611199
Instrumentation and control	18	2075039
Piping	60	6916799
Electricity	13	1498639
Building	15	1729199
Land	6	691679
Service Facility	55	6340399
Yard Improvement	15	1729199
Insulation Cost	9	1037519
Total	-	3.6×10^7

8.4 Indirect Cost:

Component	% of Direct cost	Cost $
Engg & Supervision	25	9201917
Contractor Fee	5	1840383
Construction Expenses	10	3680767
Contingences	8	2944613
Total	-	**1.7**$\times 10^7$

8.5 Total capital investment

Fixed capital = Direct cost + Indirect Cost

Fixed capital = 5.4\times 10^7$

Working capital investment = 15% of Fixed capital investment = 8.1\times 10^6$

Total capital investment = Fixed capital investment + Working capital investment

Total capital investment = $\$6.2\times 10^7$

8.6 Variable Cost:

Raw Material Cost

Flow rate of Sugarcane Bagasse = 451388kg/hr

For 300 days of operating time = 32449993600 kg/year

Price of Bagasse per kg = $0.024/kg

Total price = $\$7.7 \times 10^7$/year

Flow rate of Press Mud = 90277kg/hr

For 300 days of operating time = 755812465 kg/year

Price of Press mud per kg = $0.5/kg

Total price o= $\$3.7\times 10^8$/year

Solvent Cost:

Price of Solvent (Water) = $0.0005/kg

Flowrate of Solvent = 489680kg/hr

Flowrate for 300 days = 352569600 kg/yr

Price of solvent = $\$3.1 \times 10^7$/kg

Miscellaneous Material:

Maintenance cost = 7% of FCI

Maintenance cost = $3813274

Miscellaneous Material = $381327

(It is 10% of maintenance cost)

Utilities:

Steam Cost

Price of steam = $0.021/kg

Total steam required = 592784 kg/hr

For 300 days of operating time = 4268044800 kg/year

Total price of steam per year = $\$8.9 \times 10^7$/year

Cooling water

Cooling Water price = $0.000018/kg

Cooling Water Required = 138560 kg/hr

Cooling water required = 9976632000 kg/year

Total price of cooling water = $18155/year

Variable cost = raw material cost + miscellaneous cost + utilities cost Variable cost

= $\$5.4 \times 10^8$/year

8.7 Fixed Operating Cost:

Type	%FCI	$Cost
Maintenance	7	3813274
Operating Cost of Labor	10	5447535
Laboratory Cost	20	10895070
Supervision Cost	15	8171302
Plant Overhead	50	27237675
Capital Charges	10	5447535
Insurance	1	544753
Local Taxes	2	1089507
Royalties	1	544753
Fixed Operating Cost	-	6.3×10^7

8.8 Direct Production Cost

Direct Production Cost = Variable Cost + Fixed Operating Cost

Direct Production Cost = $\$6 \times 10^8$

8.9 Overhead Charges:

Overhead Charges=30% of direct production cost

Overhead charges = (0.3)(609125904)= $\$1.8 \times 10^8$

Manufacturing cost = Overhead cost + Direct production cost

Manufacturing cost = $\$7.9 \times 10^8$

8.10 General Expenses:

Function	% of Manufacturing Cost	Cost ($)
Administration	2	15837273
Distribution and marketing	2	15837273
Research and development	5	39593183
Total	-	7×10^7

8.11 Total production cost:

Total production cost = Manufacturing cost + General expense

= 863131404 $/yr

8.12 Production cost

Total production rate = 3×10^9 kg/yr

$$\text{Production cost} = \frac{\text{total production cost}}{\text{total production rate}}$$

= $0.2/kg

8.13 Profitability Analysis:

Selling price:

Price of Methane in Market = 0.6 $/kg

Selling price of product = 0.3 $/kg

Profit:

Profit = Selling price - production cost= 0.1 $/kg

Profit per year = 3×10^8 \$/yr

Total Income:

Selling Price = 0.3 \$/kg

Total Production rate = 3×10^9 kg/yr

Total Income = 9×10^8 \$/yr

Gross Profit:

Gross Profit = Total Income - Total Production Cost = 3.6×10^7\$/yr

Depreciation:

Machinery and equipment = 20% of FCI= \$10895070/yr

Building = 4% of Building cost= 69167\$/yr

Total Depreciation = Machinery and equipment + Building= 1×10^7/year \$/yr

Taxes:

Let the tax rate is 40%

Taxes = 0.4×Gross Profit = \$14747438 /yr

Net profit:

Net Profit before Taxation = Gross profit – Depreciation = 25904359 \$/yr

Net Profit after Taxation = Net Profit before Taxation – Taxes = 11156921 \$/yr

Rate or return:

Rate or return = $\frac{\text{Net profit}}{\text{Total Capital Investment}}\times100 = 18\%$

Payback period:

Payback period = $\frac{1}{Rate\ or\ return} = 5.6$ years

CHAPTER # 9

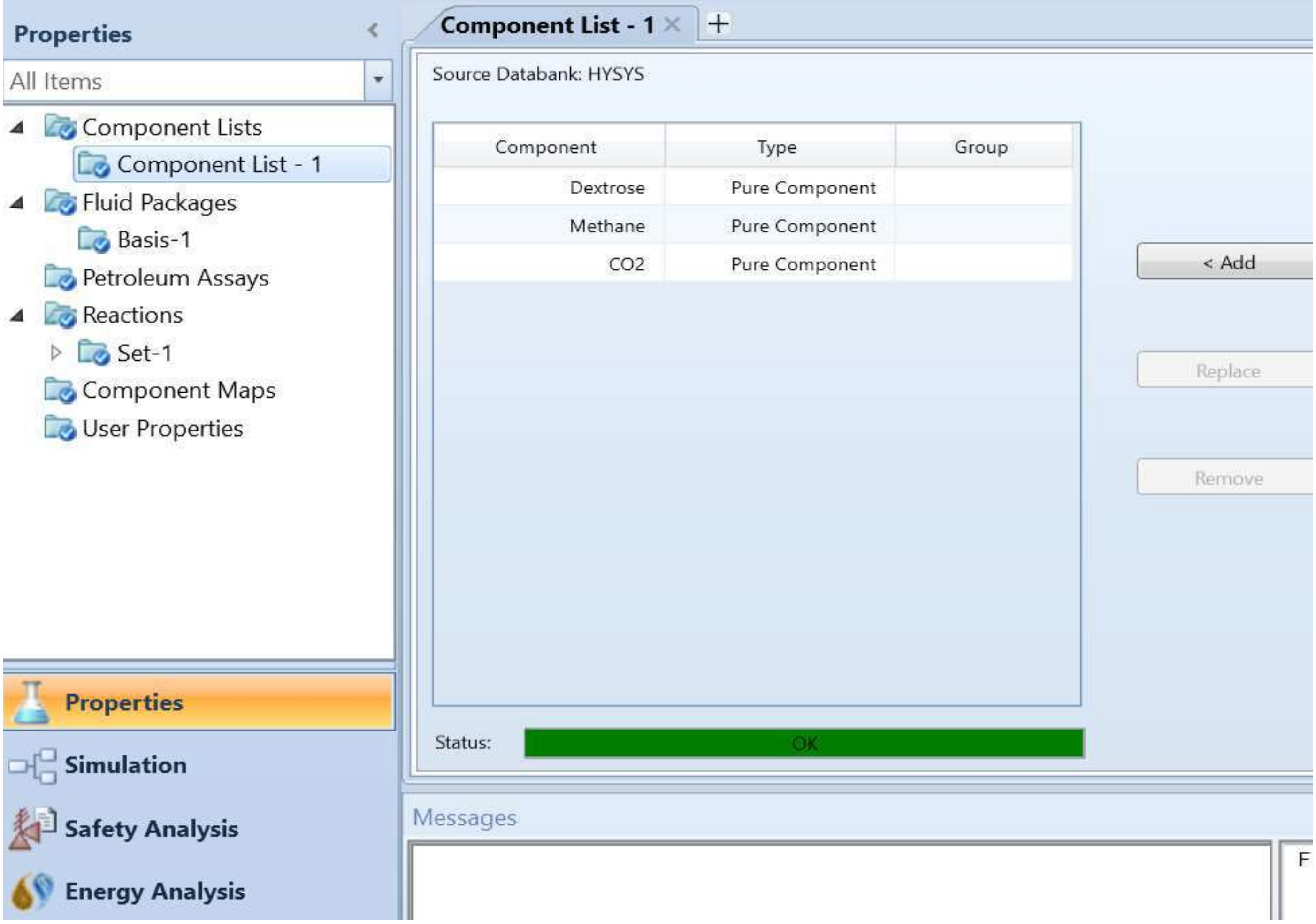
PROCESS SIMULATION

9-Process Simulation

Advanced System for Process Engineering (ASPEN) is an acronym for Advanced System for Process Engineering. It is based on a simulation of a flowsheet. A flowsheet simulation is a piece of software that is used to quantitatively model a chemical processing facility, and involves pre- and post-treatment phases in addition to the central reactor unit. Thus, each icon represents a unit operation, chemical phase, input/output material source, input/output energy stream, or input/output electric/pneumatic signal in the simulation of an entire chemical process, beginning with the raw material and ending with the final finished product.

9.1 Simulation of Reactor

- First step is addition of components which are participating in reaction from components list here glucose (dextrose) is being converted to methane and carbon dioxide so these three are added.



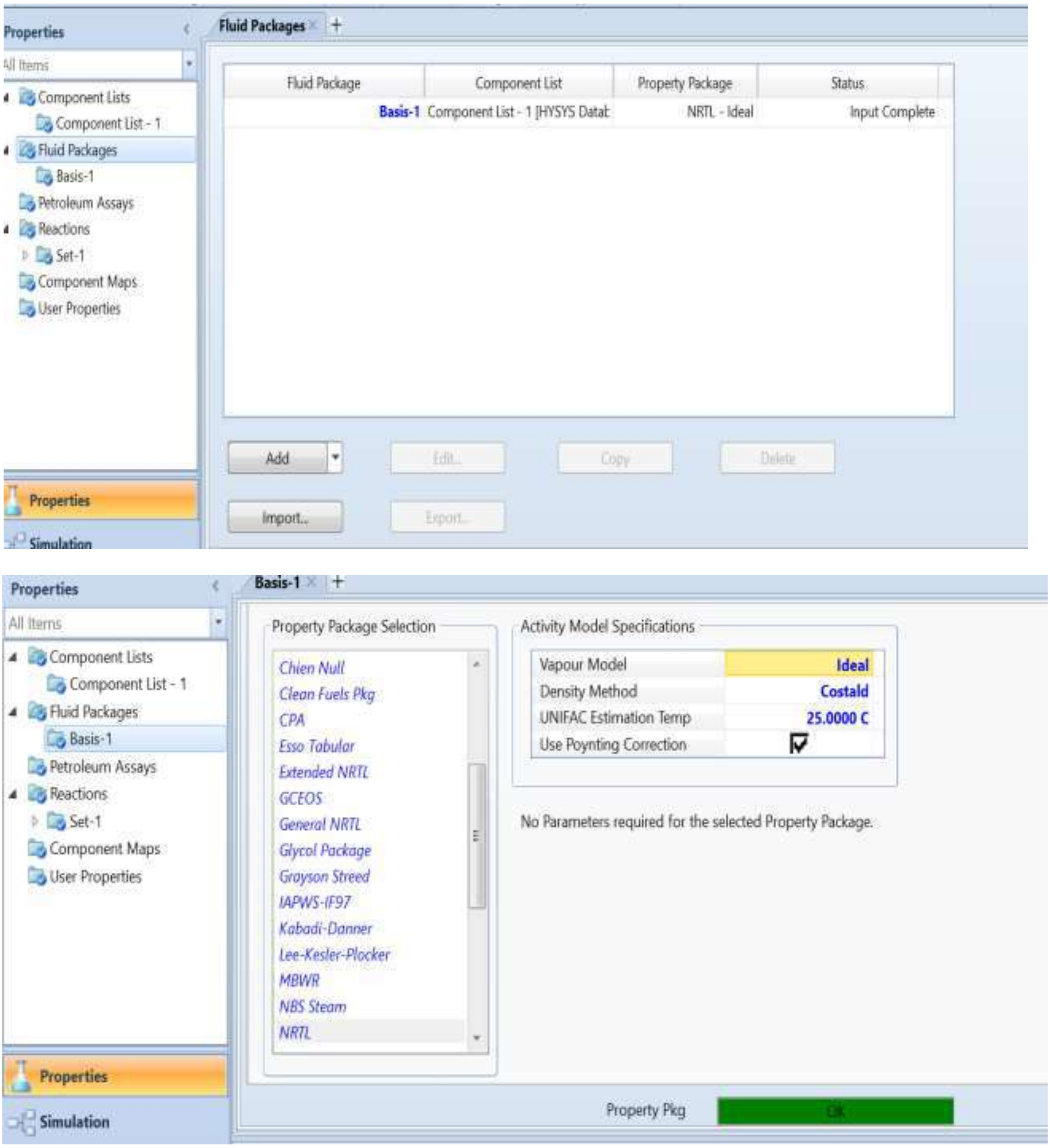
Source Databank: HYSYS

Component	Type	Group
Dextrose	Pure Component	
Methane	Pure Component	
CO2	Pure Component	

Status: OK

Fig no 9.1: Addition of Component

- In next step property package is selected based on components taking steps in reaction Selected property for the given system is NRTL.



Fluid Package	Component List	Property Package	Status
Basis-1	Component List - 1 [HYSYS Datat	NRTL - Ideal	Input Complete

Property Package Selection

Activity Model Specifications

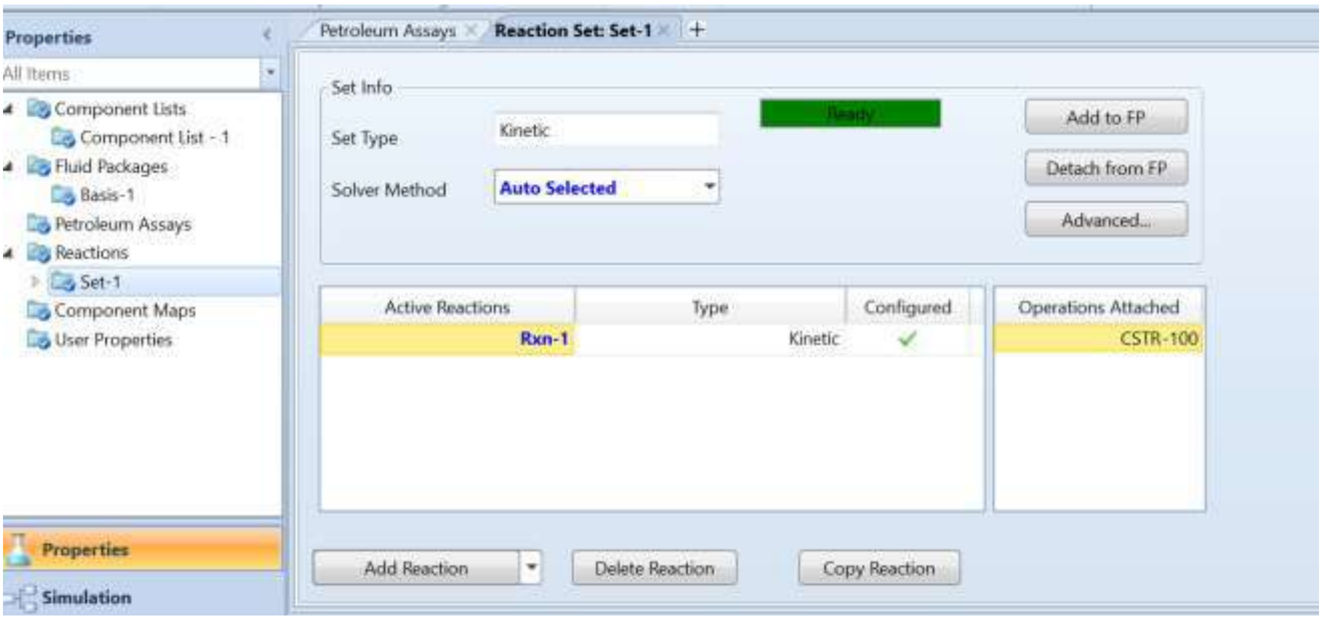
Vapour Model	Ideal
Density Method	Costald
UNIFAC Estimation Temp	25.0000 C
Use Poynting Correction	☑

No Parameters required for the selected Property Package.

Property Pkg OK

Fig no 9.2: Selection of Property Package

- Now reaction set is being added for given system in which there is breakage of glucose here reaction set 1 is added.



Set Info

Set Type: Kinetic

Solver Method: Auto Selected

Active Reactions	Type	Configured
Rxn-1	Kinetic	✓

Operations Attached
CSTR-100

Fig no 9.3 Adding Reaction Set

- In this step reaction components along with their stoichiometric coefficient , molecular weight are added.

Stoichiometry and Rate Info

Component	Mole Wt.	Stoich Coeff	Fwd Order	Rev Order
Dextrose	180.158	-1.000	1.00	0.00
Methane	16.043	1.000	0.00	1.00
CO2	44.010	3.729	0.00	1.00
Add Comp				

Balance Error	0.00000
Reaction Heat (25 C)	-1.4e+05 kcal/kgmole

Basis

Basis	Molar Concn
Base Component	Dextrose
Rxn Phase	LiquidPhase
Min. Temperature	-273.1 C
Max Temperature	3000 C

Basis Units: lbmole/ft3

Rate Units: lbmole/ft3-min

Forward Reaction

A	0.23000
E	0.00000
b	0.00000

Reverse Reaction

A'	<empty>
E'	<empty>
b'	<empty>

Equation Help

r = k*f(Basis) - k'*f'(Basis)

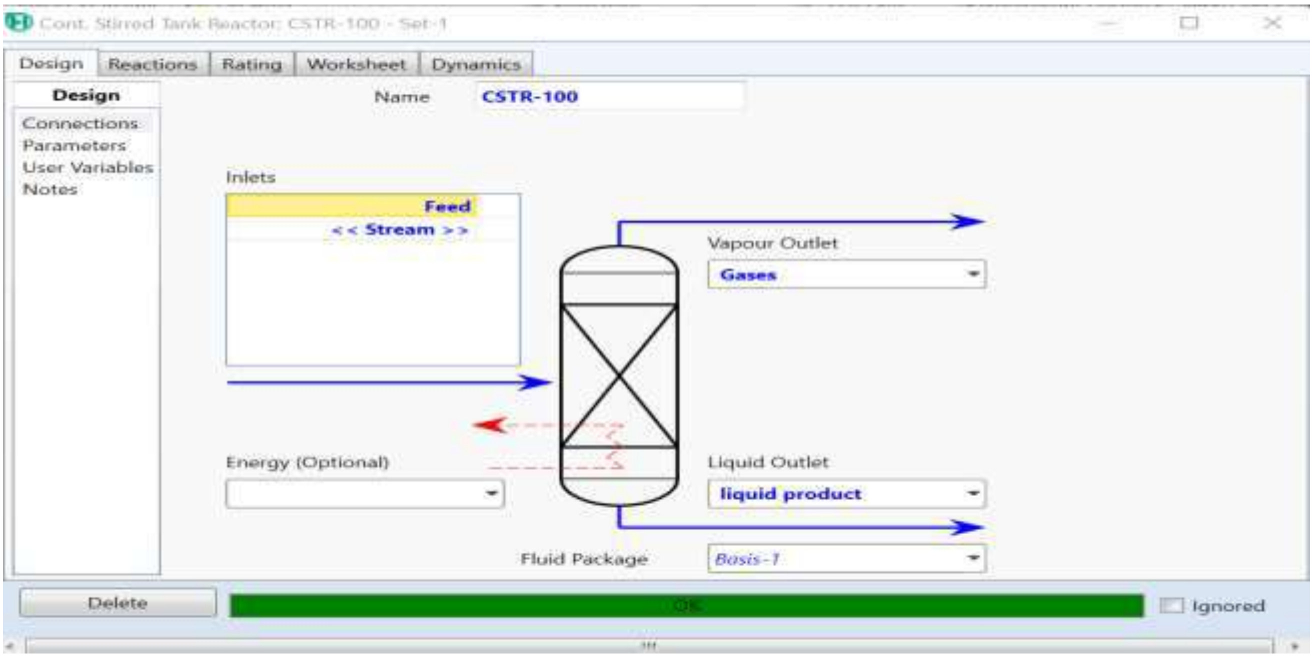
k = A * exp { -E / RT } * T ^b

k' = A' * exp { -E' / RT } * T^b'

T in Kelvin

Fig no 9.4 Adding Reaction Component

- For simulation of reactor all input and output streams are introduced in to reactor



Name: CSTR-100

Inlets: Feed

Vapour Outlet: Gases

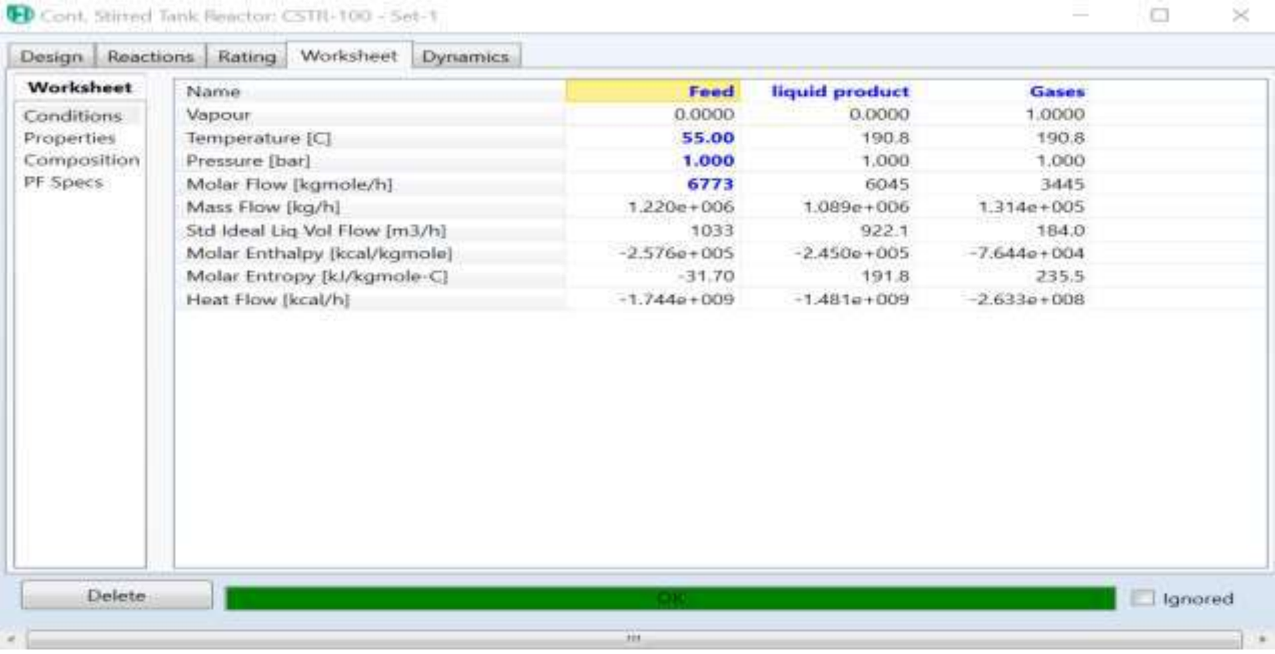
Energy (Optional):

Liquid Outlet: liquid product

Fluid Package: Basis-1

Fig no 9.5 Adding Input and Output

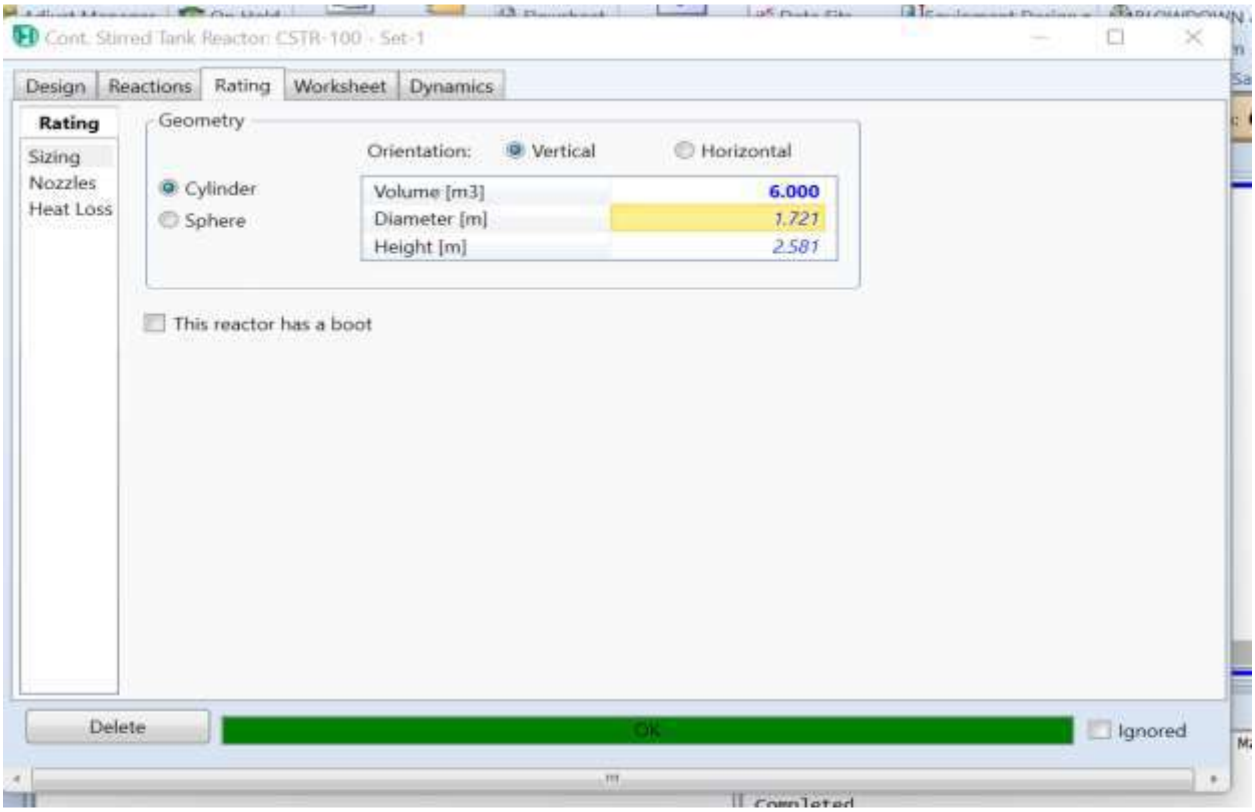
- All streams compositions , temperature , pressure and molar flow rate is added including liquid products stream and gases product stream.



Name	Feed	liquid product	Gases
Vapour	0.0000	0.0000	1.0000
Temperature [C]	55.00	190.8	190.8
Pressure [bar]	1.000	1.000	1.000
Molar Flow [kgmole/h]	6773	6045	3445
Mass Flow [kg/h]	1.220e+006	1.089e+006	1.314e+005
Std Ideal Liq Vol Flow [m3/h]	1033	922.1	184.0
Molar Enthalpy [kcal/kgmole]	-2.576e+005	-2.450e+005	-7.644e+004
Molar Entropy [kJ/kgmole-C]	-31.70	191.8	235.5
Heat Flow [kcal/h]	-1.744e+009	-1.481e+009	-2.633e+008

Fig no 9.6 Adding Input and Output

- In this step reactor volume is specified which show that dimension including height and diameter are same as shown in design of reactor in process equipment design



Cont. Stirred Tank Reactor: CSTR-100 - Set-1

Orientation: ● Vertical ○ Horizontal

● Cylinder

○ Sphere

Volume [m3]	6.000
Diameter [m]	1.721
Height [m]	2.581

☐ This reactor has a boot

☐ Ignored

Fig no 9.7 Adding volume of reactor

- At the last step simulated reactor along with equipment diagram is shown

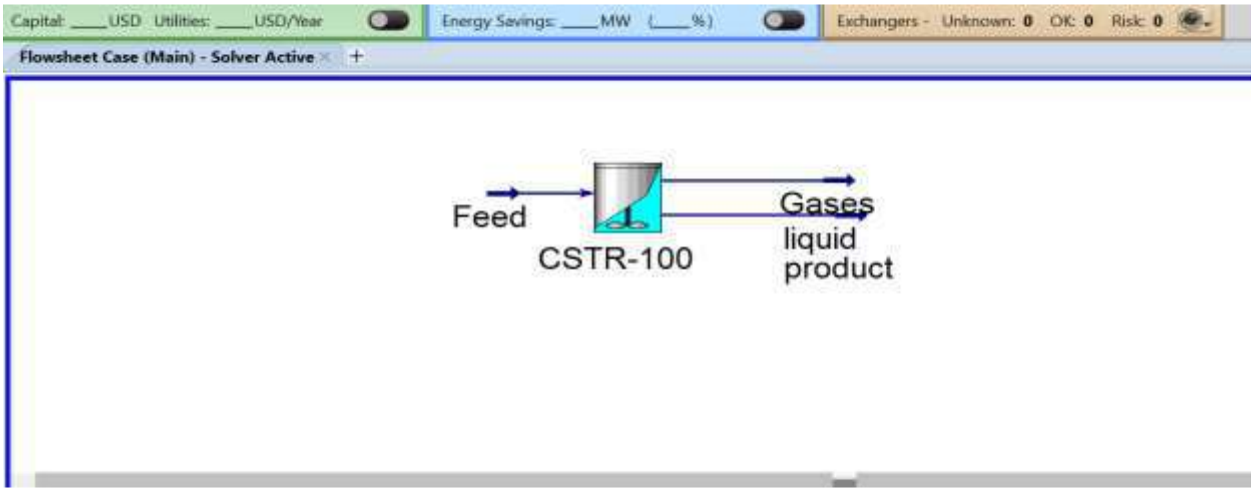
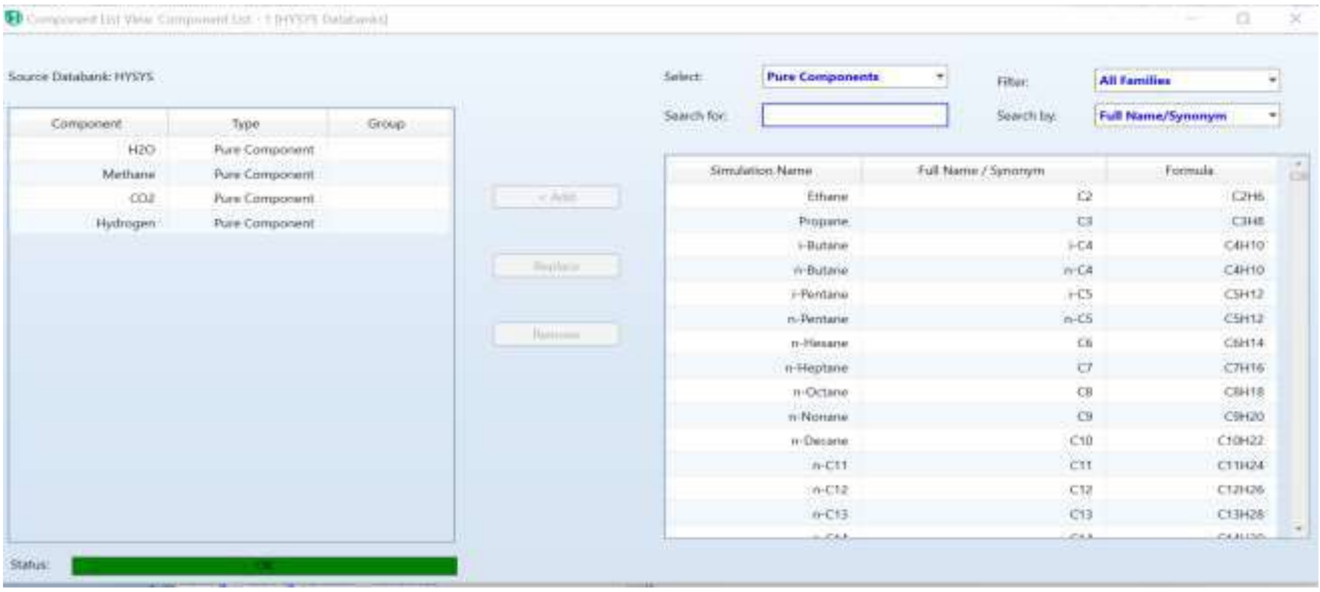


Fig no 9.8: Simulated Reactor

9.2 Simulation of Scrubber:

First step is addition of components adding in scrubber components list here water, methane , carbon dioxide and hydrogen.



Source Databank: HYSYS

Component	Type	Group
H2O	Pure Component	
Methane	Pure Component	
CO2	Pure Component	
Hydrogen	Pure Component	

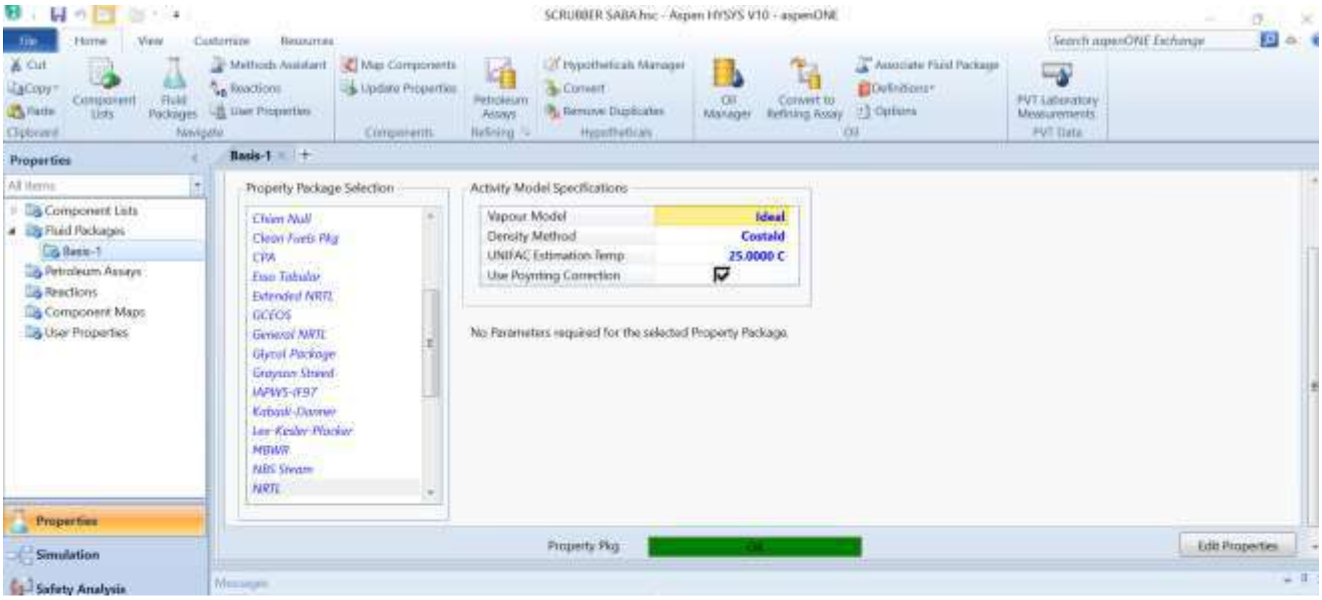
Status: OK

Select: Pure Components
Filter: All Families
Search for:
Search by: Full Name/Synonym

Simulation Name	Full Name / Synonym	Formula
Ethane	C2	C2H6
Propane	C3	C3H8
i-Butane	i-C4	C4H10
n-Butane	n-C4	C4H10
i-Pentane	i-C5	C5H12
n-Pentane	n-C5	C5H12
n-Hexane	C6	C6H14
n-Heptane	C7	C7H16
n-Octane	C8	C8H18
n-Nonane	C9	C9H20
n-Decane	C10	C10H22
n-C11	C11	C11H24
n-C12	C12	C12H26
n-C13	C13	C13H28

Fig no9.9: Addition of Component

- In next step property package is selected based on components taking steps in reaction Selected property for the given system is NRTL.



Property Package Selection

Chien Null
Clean Fuels Pkg
CPA
Esso Tabular
Extended NRTL
GCEOS
General NRTL
Glycol Package
Grayson Streed
IAPWS-IF97
Kabadi-Danner
Lee-Kesler-Plocker
MBWR
NBS Steam
NRTL

Activity Model Specifications

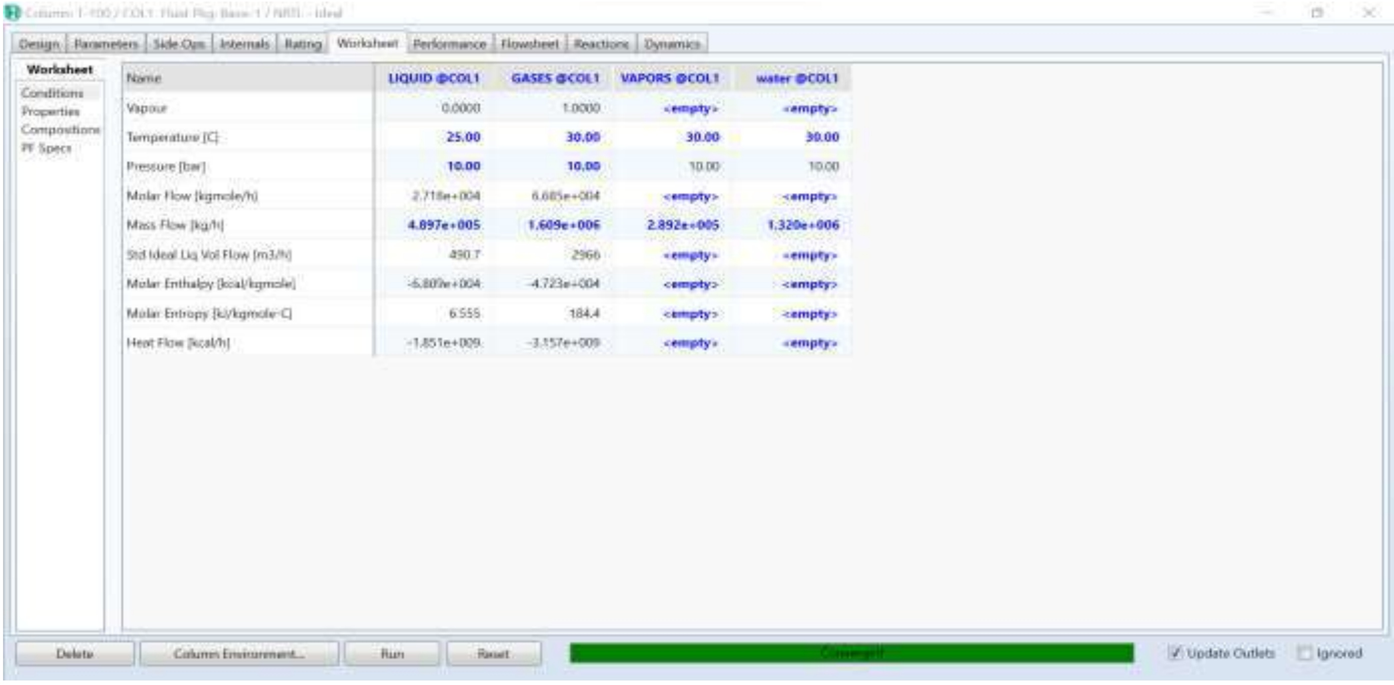
Vapour Model	Ideal
Density Method	Costald
UNIFAC Estimation Temp	25.0000 C
Use Poynting Correction	☑

No Parameters required for the selected Property Package.

Property Pkg OK

Fig no 9.10 : Selection of Property Package

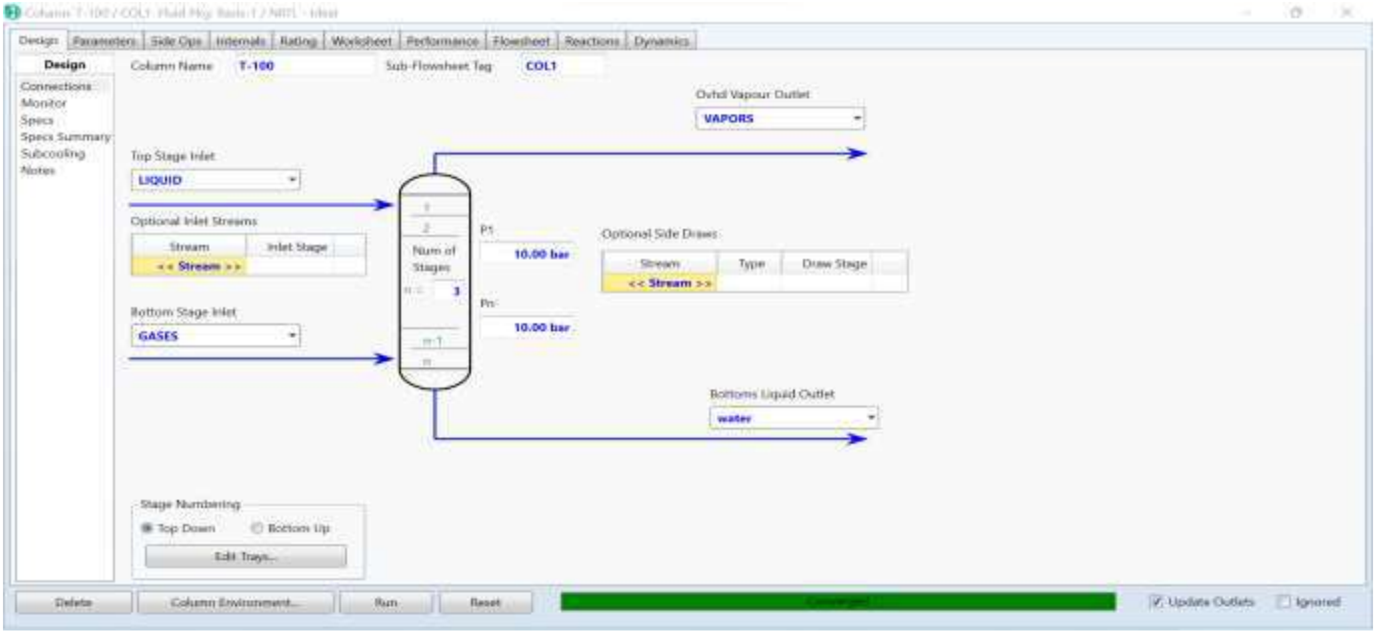
- Adding all conditions of stream including temperature , pressure and mass flow rate.



Name	LIQUID @COL1	GASES @COL1	VAPORS @COL1	water @COL1
Vapour	0.0000	1.0000	<empty>	<empty>
Temperature [C]	25.00	30.00	30.00	30.00
Pressure [bar]	10.00	10.00	10.00	10.00
Molar Flow [kgmole/h]	2.718e+004	6.685e+004	<empty>	<empty>
Mass Flow [kg/h]	4.897e+005	1.609e+006	2.892e+005	1.320e+006
Std Ideal Liq Vol Flow [m3/h]	490.7	2966	<empty>	<empty>
Molar Enthalpy [kcal/kgmole]	-6.809e+004	-4.723e+004	<empty>	<empty>
Molar Entropy [kJ/kgmole-C]	6.555	184.4	<empty>	<empty>
Heat Flow [kcal/h]	-1.851e+009	-3.157e+009	<empty>	<empty>

Fig no 9.11: Adding Input and Output

- Adding For simulation all input and output streams are introduced in to scrubber.



Column Name T-100

Sub-Flowsheet Tag COL1

Ovhd Vapour Outlet VAPORS

Top Stage Inlet LIQUID

Bottom Stage Inlet GASES

Bottoms Liquid Outlet water

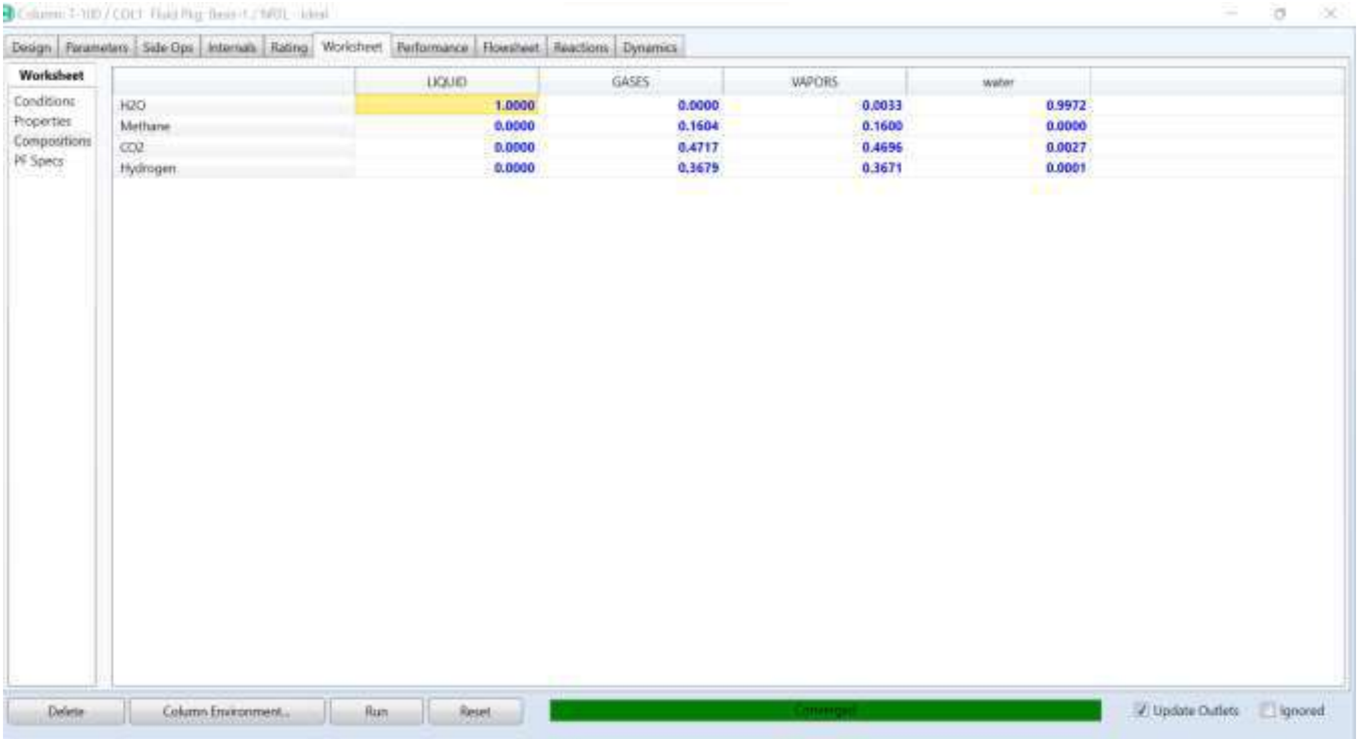
n = 3

P1 10.00 bar

Pn 10.00 bar

Fig no 9.12: Adding Input and Output

- All streams compositions , are added included water , methane , carbon dioxide and hydrogen



	LIQUID	GASES	VAPORS	water
H2O	1.0000	0.0000	0.0033	0.9972
Methane	0.0000	0.1604	0.1600	0.0000
CO2	0.0000	0.4717	0.4696	0.0027
Hydrogen	0.0000	0.3679	0.3671	0.0001

Fig no 9.13: Adding Compositions

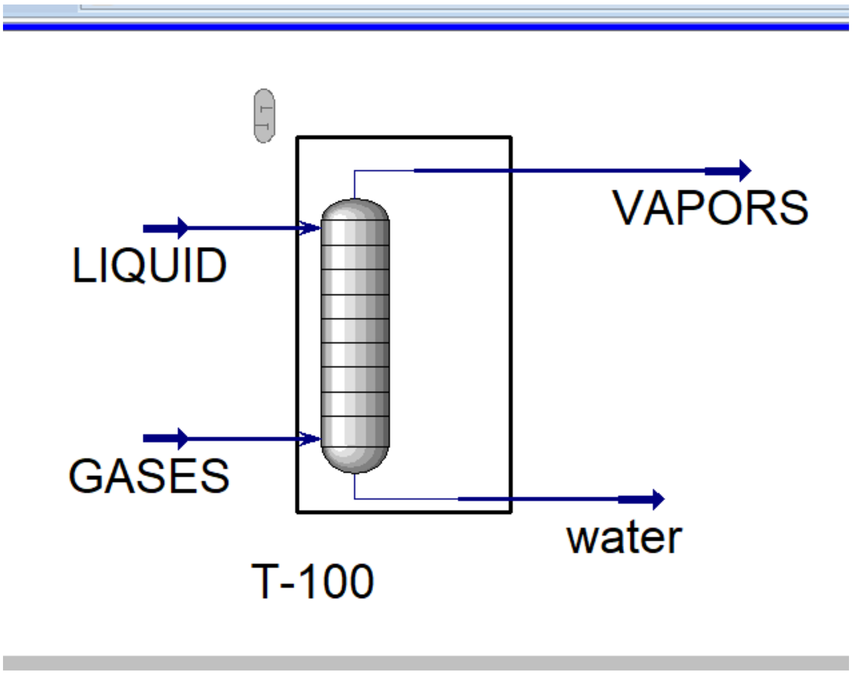
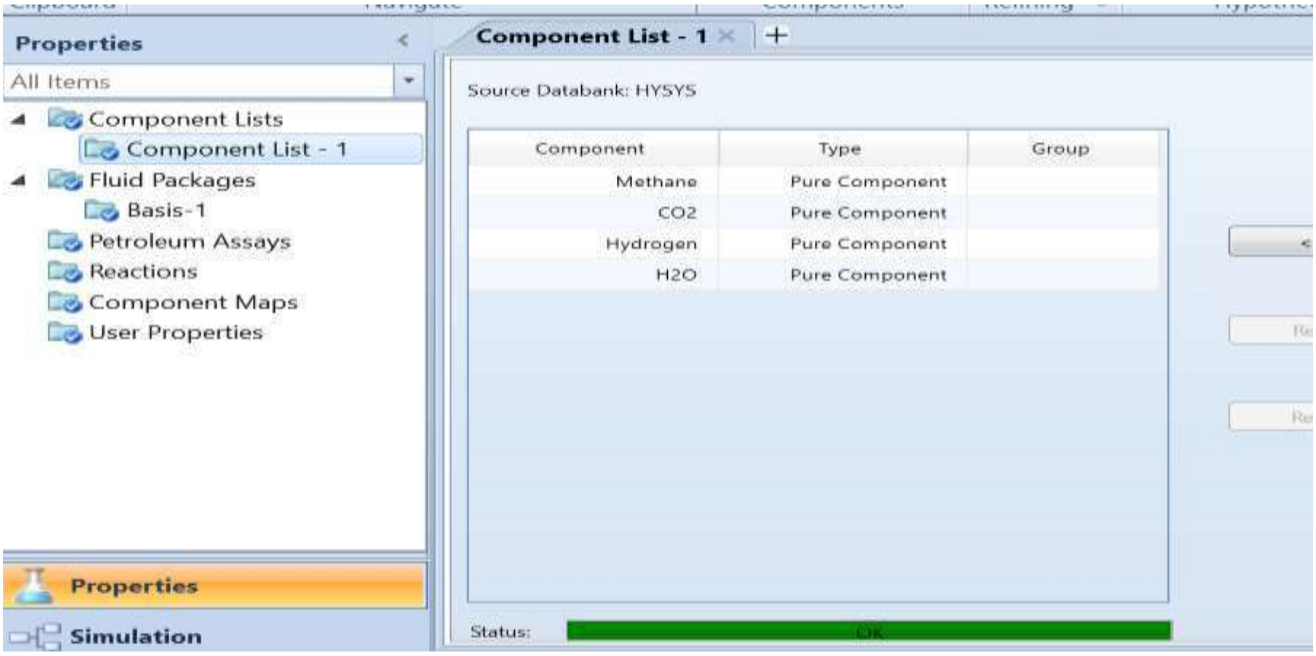


Fig no 9.14: Simulated Scrubber

9-3 Simulation of Heat Exchanger:

- First step is addition of components adding in scrubber components list here water, methane , carbon dioxide and hydrogen.



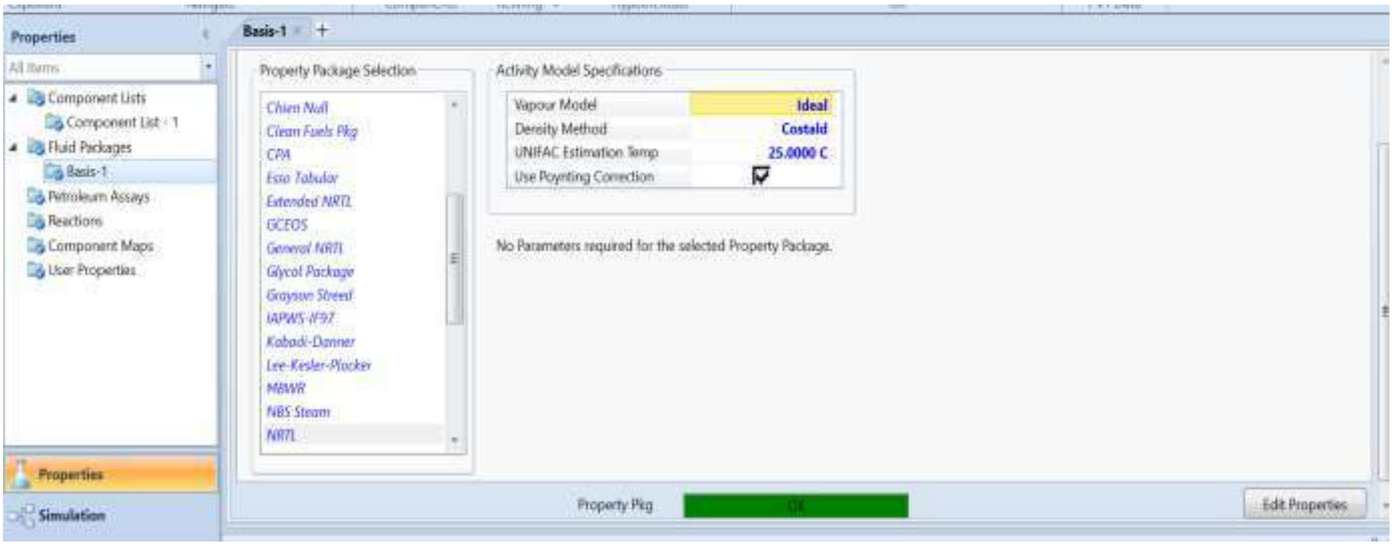
Source Databank: HYSYS

Component	Type	Group
Methane	Pure Component	
CO2	Pure Component	
Hydrogen	Pure Component	
H2O	Pure Component	

Status: OK

Fig no 9.15: Adding Components

- In next step property package is selected based on components taking steps in reaction Selected property for the given system is NRTL.



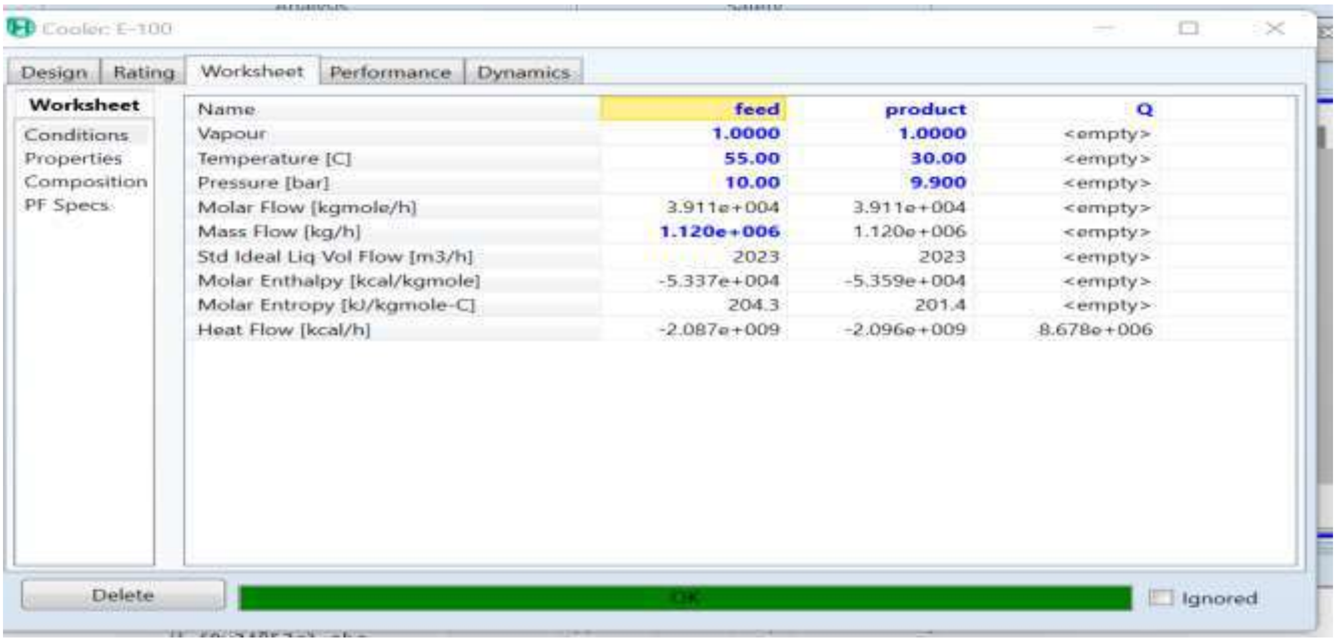
Vapour Model	Ideal
Density Method	Costald
UNIFAC Estimation Temp	25.0000 C
Use Poynting Correction	☑

No Parameters required for the selected Property Package.

Property Pkg OK

Fig no 9.16: Selecting Property Package

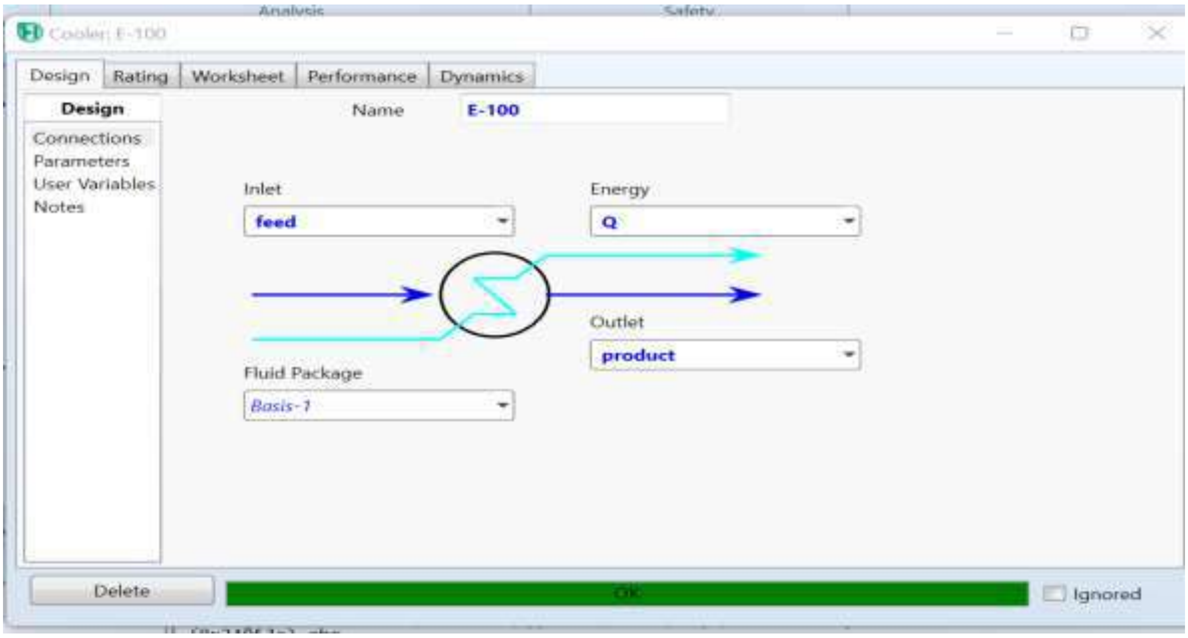
- All streams compositions , temperature , pressure and molar flow rate is added including liquid products stream and gases product stream.



Name	feed	product	Q
Vapour	1.0000	1.0000	<empty>
Temperature [C]	55.00	30.00	<empty>
Pressure [bar]	10.00	9.900	<empty>
Molar Flow [kgmole/h]	3.911e+004	3.911e+004	<empty>
Mass Flow [kg/h]	1.120e+006	1.120e+006	<empty>
Std Ideal Liq Vol Flow [m3/h]	2023	2023	<empty>
Molar Enthalpy [kcal/kgmole]	-5.337e+004	-5.359e+004	<empty>
Molar Entropy [kJ/kgmole-C]	204.3	201.4	<empty>
Heat Flow [kcal/h]	-2.087e+009	-2.096e+009	8.678e+006

Fig no 9.17: Adding Input and Output

- Adding For simulation all input and output streams are introduced in to scrubber.



Name: E-100

Inlet: feed

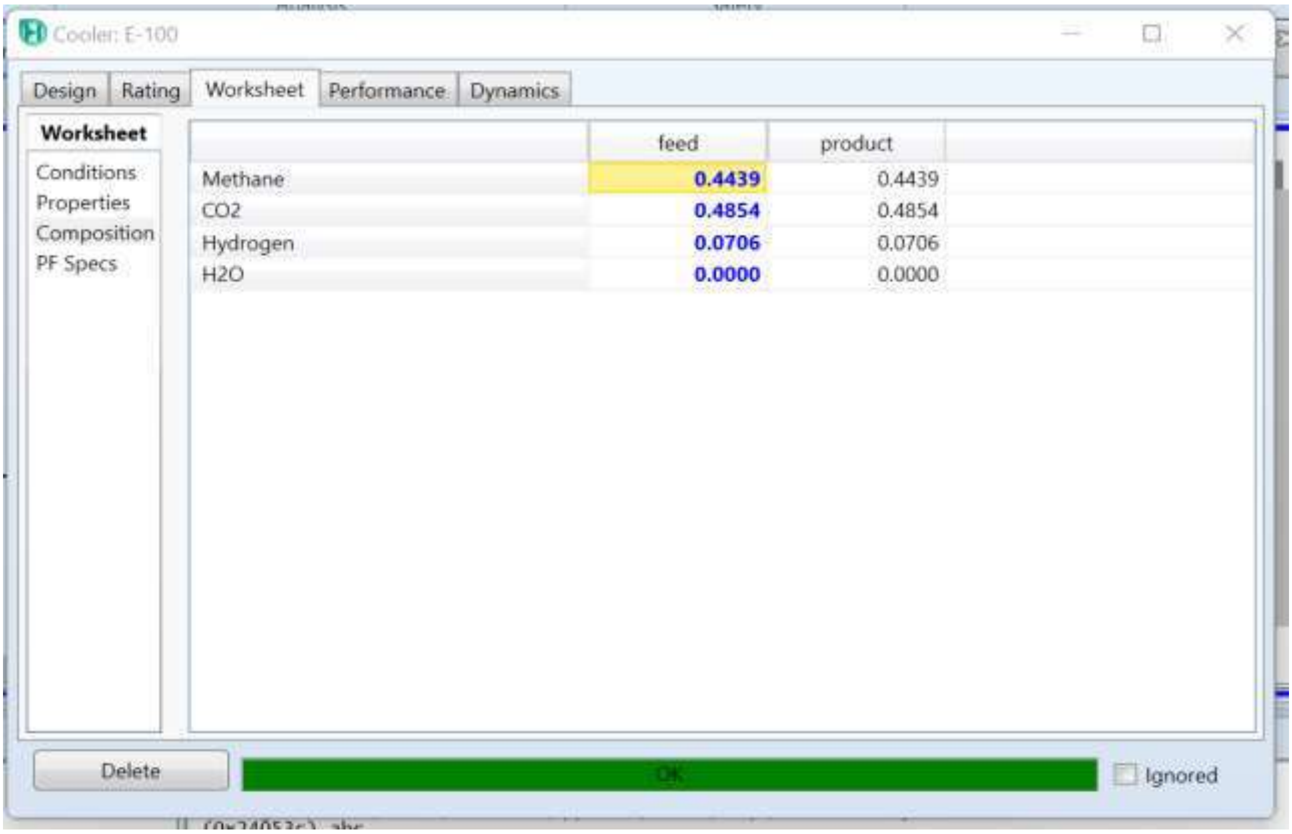
Energy: Q

Outlet: product

Fluid Package: Basis-1

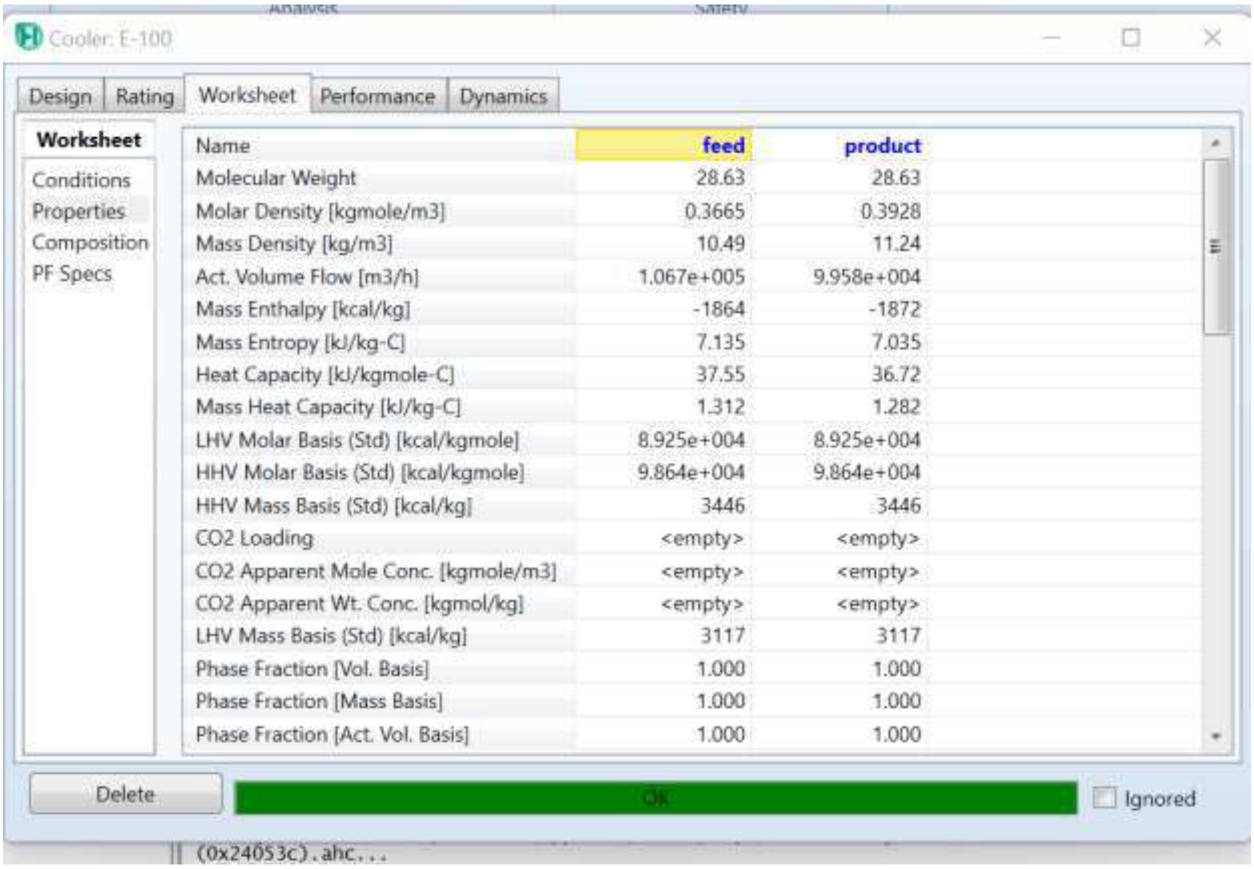
Fig no 9.18: Adding Input and Output

- All streams compositions , are added included water , methane , carbon dioxide and hydrogen.

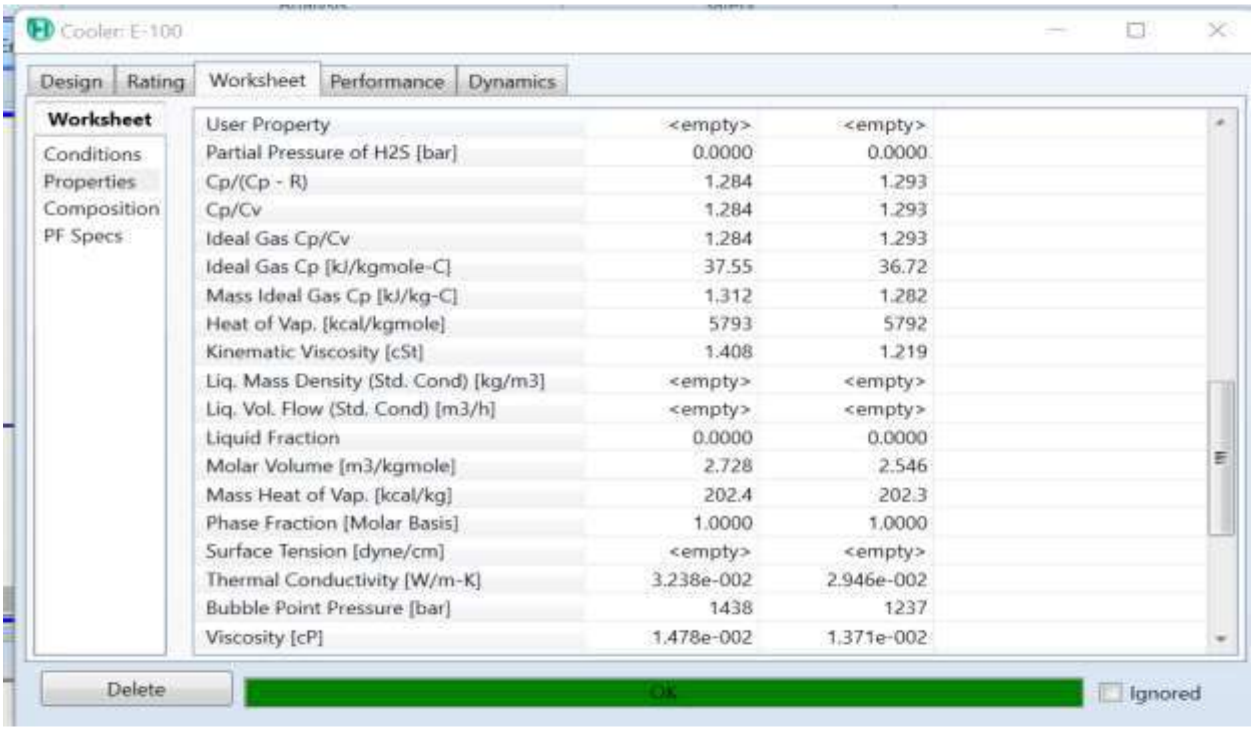


	feed	product
Methane	0.4439	0.4439
CO2	0.4854	0.4854
Hydrogen	0.0706	0.0706
H2O	0.0000	0.0000

Fig no 9.19: Adding Compositions



Name	feed	product
Molecular Weight	28.63	28.63
Molar Density [kgmole/m3]	0.3665	0.3928
Mass Density [kg/m3]	10.49	11.24
Act. Volume Flow [m3/h]	1.067e+005	9.958e+004
Mass Enthalpy [kcal/kg]	-1864	-1872
Mass Entropy [kJ/kg-C]	7.135	7.035
Heat Capacity [kJ/kgmole-C]	37.55	36.72
Mass Heat Capacity [kJ/kg-C]	1.312	1.282
LHV Molar Basis (Std) [kcal/kgmole]	8.925e+004	8.925e+004
HHV Molar Basis (Std) [kcal/kgmole]	9.864e+004	9.864e+004
HHV Mass Basis (Std) [kcal/kg]	3446	3446
CO2 Loading	<empty>	<empty>
CO2 Apparent Mole Conc. [kgmole/m3]	<empty>	<empty>
CO2 Apparent Wt. Conc. [kgmol/kg]	<empty>	<empty>
LHV Mass Basis (Std) [kcal/kg]	3117	3117
Phase Fraction [Vol. Basis]	1.000	1.000
Phase Fraction [Mass Basis]	1.000	1.000
Phase Fraction [Act. Vol. Basis]	1.000	1.000



User Property	<empty>	<empty>
Partial Pressure of H2S [bar]	0.0000	0.0000
Cp/(Cp - R)	1.284	1.293
Cp/Cv	1.284	1.293
Ideal Gas Cp/Cv	1.284	1.293
Ideal Gas Cp [kJ/kgmole-C]	37.55	36.72
Mass Ideal Gas Cp [kJ/kg-C]	1.312	1.282
Heat of Vap. [kcal/kgmole]	5793	5792
Kinematic Viscosity [cSt]	1.408	1.219
Liq. Mass Density (Std. Cond) [kg/m3]	<empty>	<empty>
Liq. Vol. Flow (Std. Cond) [m3/h]	<empty>	<empty>
Liquid Fraction	0.0000	0.0000
Molar Volume [m3/kgmole]	2.728	2.546
Mass Heat of Vap. [kcal/kg]	202.4	202.3
Phase Fraction [Molar Basis]	1.0000	1.0000
Surface Tension [dyne/cm]	<empty>	<empty>
Thermal Conductivity [W/m-K]	3.238e-002	2.946e-002
Bubble Point Pressure [bar]	1438	1237
Viscosity [cP]	1.478e-002	1.371e-002

Fig no 9.20:Property Data

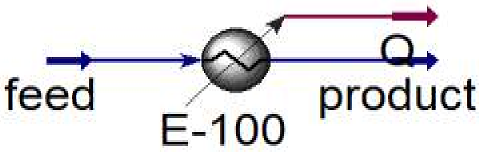


Fig no 9.21: Simulated Heat Exchanger

CHAPTER # 10

INSTRUMENTATION AND PROCESS CONTROL

10- Instrumentation and Process Control

10.1 Introduction:

Instrumentation is the study of automated measurement and control. Many applications of this science may be found in modern research, industry, and daily life. Everything around us is automated, including home thermostats, airplane autopilots, vehicle engine control systems, and pharmaceutical drug production. Choosing the best measurement technique is therefore an essential first step in the design and formulation of any process control system. While using manual control, an operator may periodically read the process variable and adjust the input up or down until the temperature reaches the desired value.

10.1.1 Product Quality Enhancement:

- Increasing the process yield at the production pace
- Increase worker and equipment safety.
- Improvement of working conditions

10.1.2 Objectives of Instrumentation and Control System:

The Instrumentation and Control System aims to accomplish the following things:

- Suppressing and removing outside disturbances
- Ensure the stability of the process.
- Improve how well the process works.

10.1.3 Components of Control System:

Following are the components of the Control System

- Process
- Measuring Element
- Process Variable
- Controller

10.1.4 Process:

Every action or set of actions that lead to the desired outcome is referred to as a process.

10.1.5 Measuring Element:

The measurement element, like the other parts of a control system, is perhaps the most important. The measured variable is chosen to match the expected circumstances in the process, thus if measurements are performed incorrectly, the rest of the system will not work properly either.

10.1.6 Process Variable:

The efficient operation of a process depends on the control of process variables. They are referred to as evolving circumstances in equipment or process materials. Temperature, pressure, flow, and liquid level are the main variables.

There are several types of measuring devices for temperature, pressure, flow, and level.

Table 10.1 :Measuring Devices for Temperature, Pressure, Flow, and Level

Measured Process Variable	Measuring Devices	Comments
Temperature	• Thermocouples, • Thermometer, • Thermistor, • Thermometers	Most typically employed for High-temperature applications for Radiation Pyrometers with Low Temperatures
Pressure	• Manometers • Bourdon tube • Elements Bellow • Elements Strain • Gauges • Capsule gauges • Thermal conductivity Gauge	Floaters or displacers are employed based on the materials' elastic deformation. This gadget converts pressure into an electrical signal. with a view to measuring efficiency.
Flowrate	• Orifice plate • Venture flow nozzle • Pitot tube • Turbine flow meter • Hot wire anemometry • Positive displacement • Mass flowmeter	It is measured how much pressure drops when there is a flow restriction. Quantity Flowmeters for High Precision Mass and Positive Displacement Flowmeters.
Liquid Level	Float actuated devices • Displacer devices • Liquid head • pressure devices • Dielectric measurement	This two-phase system functions well with many types of indicators and signal converters. The method of indirect hydrostatic pressure.

10.1.7 Temperature Measurement and Control:

The output and intake temperatures are controlled using temperature measurements. flows in heat exchangers, reactors, and other devices. Thermocouples are commonly used in the industry to detect temperature since they make it easier to bring the measurement to a centralized place. Bimetallic or filled system thermometers are used less often for local readings at the equipment. The use of high-measurement precision resistance thermometers. All of these meters include thermo-walls that keep them safe when being used locally. This shields against atmospheric elements and other natural hazards.

10.1.8 Pressure Measurement and Control:

Like temperature, pressure is a variable that reveals a substance's state and makeup. In actuality, when combined, these two measures serve as the primary tools for evaluating industrial materials. In the reactor, pressure measurements are crucial. Pumps, compressors, and other process equipment that is linked to pressure changes in the process material have pressure measuring instruments attached to them. As a result, measures of pressure are used to determine whether or not energy has increased. The bulk of pressure measurements in the industry is made using elastic element devices that are either relayed to a centralized location or directly connected for local use. A bourdon tube or a bellow with a diaphragm is the most typical industrial pressure component.

10.1.9 Flow Measurement and Control:

Practically every industrial process includes flow measurement, and there are many different methods for doing so. Similar to pressure measurement, flow measurement frequently makes use of a sensing device coupled to a DP cell. Under unusual circumstances, such as when there is no external disturbance in the fluid stream, magnetic flow meters may be employed instead of other flow meters. To regulate the amount of liquid, flow indicator controllers are employed. All manually set streams also need some type of flow indication or a straightforward sampling device. Variable head devices are used in industry to measure flow. When specific measurement circumstances exist, variables and the many available types are used to a reduced extent.

10.1.10 Controller:

The mechanism in charge of responding to any defect detection technique is the controller. The output of the controller is a predetermined function of the error. Final Control Element: The final control element receives the controller's signal and modifies the process's energy input in accordance with a predetermined relationship.

10.1.11 Type of Controls:

Several types of controls are used in business depending on the needs and preferences of the individual. They may be classified into two main groups, ranging from extremely simple controllers to extremely complex systems:

- Control feed-forward
- Control Feed Backward

Feed Forward Control:

A feedback control works on the same theory as its name suggests. Every modification of an input to a system results in "disturbances" or changes in the system. These alterations are noted, and subsequent remedial action is taken to undo the impact of the change on the input.

Advantages:

- It is not required to locate and quantify the disturbance.
- Irresponsive to modelling errors.
- Parameter changes have no impact.

Disadvantages:

- Control measures are taken if anomalies are discovered.
- Unsatisfactory since the process took a long time and had a lot of dead time.
- The closed-loop response may become unstable as a result.

Feed Backward Control:

On the basis of accurate measurements of disturbances, changes in the value of the modified variables.

Advantages:

- It is beneficial for sluggish systems or systems with a lot of dead time since
- it acts before the system feels the effects of the disruption.
- It does not cause the control system to become unstable.

Disadvantages:

- It requires the quick assessment of any possible disturbances as well as their identification.
- Unmeasured disruptions cannot be handled.
- Responsive to modifications in the process parameters.
- The steady-state offset cannot be removed.
- It demands a complete comprehension of the process model.

10.1.12 Component of Control System:

The primary components of a control system are as follows:

Measuring devices:

The measurement element, like the other parts of a control system, is perhaps the most important. The system as a whole will not operate appropriately if measurements are not made correctly, and the measured variable is chosen to match the process' intended circumstances.

Transducer:

A device that changes one standardized instrumentation signal into another and/or applies some sort of signal processing to that signal.

Transmission Lines:

They are utilized to send measurement data to the controller from the measuring device. Prior to the introduction of electronic analogue controllers and, in particular, the growing usage of digital computers for control, transmission lines were pneumatic (carrying pressurized air or liquids), but they are now utilized to convey electric signals.

Amplifier:

A measuring device's measurement signal is typically quite weak and cannot be sent across great distances. In such cases, amplifiers that enhance the signal level are installed in the transmission cables.

Controller:

The mechanism in charge of responding to any defect detection technique is the controller. The output of the controller is a predetermined function of the error.

Final Control Element:

The final control element receives the controller's signal and modifies the process's energy input in accordance with a predetermined relationship.

10.2 Control Schemes of Reactor:

Control Objectives:

- Temperature inside the Reactor
- Temperature of coolant (water)

Manipulated variables:

The manipulated variable is flow rate of water.

Disturbances:

Following are typical disturbances

- Flow rate of feed

- Temperature of feed
- Flow Rate of water
- Temperature of water

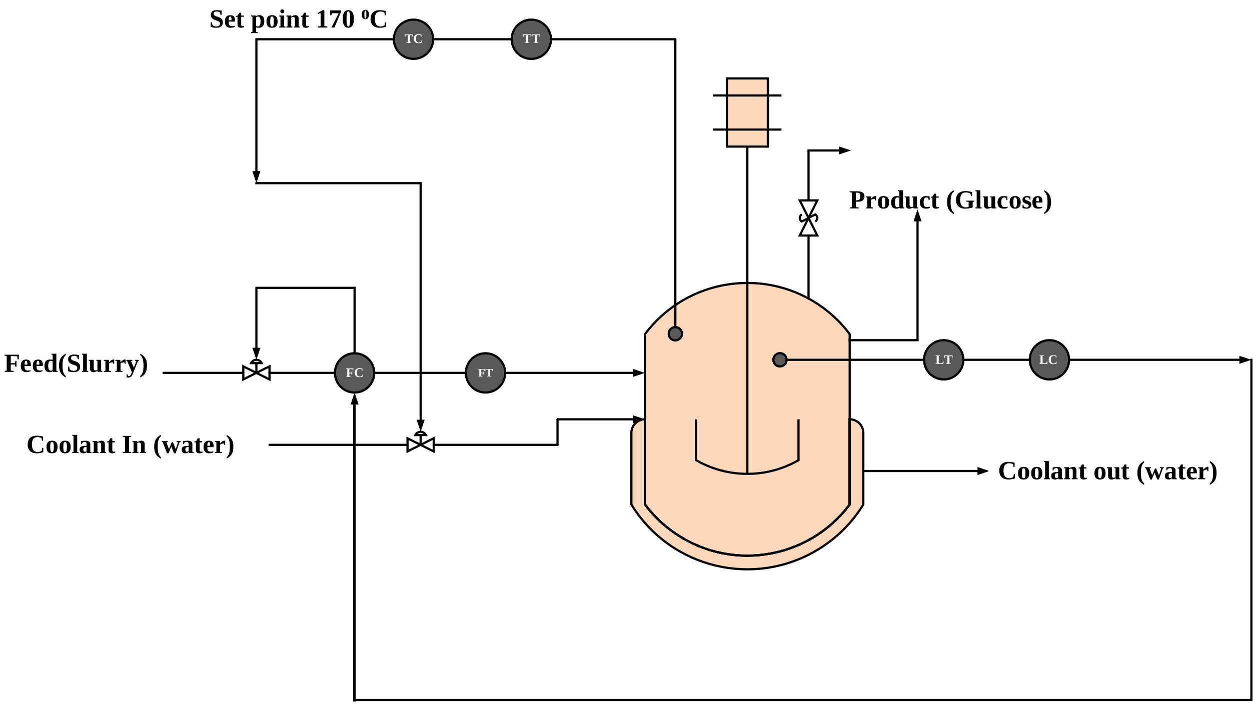


Fig no 10.1: Control loop on CSTR (R-201)

CHAPTER # 11

HAZOP STUDY

11-HAZOP

One of the least well-liked and often used techniques for doing systematic and rigorous hazard assessments is the HAZOP study. It's capable of handling entire plants, production units, or equipment in both new and old plants. Utilize common plant and process data as a database, relying on expertise where engineers and safety experts have the most experience.

Objectives of HAZOP Study:

A HAZOP study's goals can be defined as follows:

- Determination (design areas that may pose significant potential hazards).
- Detect and research design elements that influence the probability of harmful incidents happening.
- Provide the study team with any available design data. Risk

Table 11.1 :Explains the HAZOP Study's guiding words and definitions.

Guide Words	Meanings	Comments
Not ,Not ,None	The purpose is disproved	Nothing more occurs, but no aspect of the design purpose is realized.
More ,Higher ,Greater	Parametric advancement	Applicable to actions like warmth and response as well as to statistics like temperature and flow rate.
Less ,Lower	Parametric advancement	Relates to elements like flow velocity and temperature, as well as operations like heat and response.
As well as	Quantitative increase	All of the concept and operational objectives are met, as well as certain additional activities such as process stream pollution.
Part of	Quantitative increase	A number of the design criteria are accomplished; others are not.
Reverse	The logical absolute opposite of the objective	Most useful for events like flow and chemical reactions. Applied to substances as well, such as toxin instead of solution.
Other Then	Complete substitution	The initial goal is replaced by something new when no aspect of it is fulfilled.

Hazard and Operability Studies:

A key component of any accident prevention system is conducting hazard and maneuverability studies. A Safety and Hazard Study (or HAZOP) is a team's comprehensive and essential analysis of the technical and operational goals of a process to identify possible hazards and risks associated with individual equipment malfunction or disoperation. Evaluate the resulting impact on the plant. whole. Security checks are normal. These can take many forms. Professionals can be consulted in isolation without referencing each other. Instead, they can meet for long sessions to discuss the issues at hand. A HAZOP meeting with a specific structure forces certain organizations to be more effective. They are generalized research techniques that are equally applicable to microchip manufacturing, pharmaceutical synthesis, wastewater plant operation, or other processes. However, they should not be considered the cure-all, the ultimate check. This procedure is just one tool in the safety cabinet and should be considered as a complement to other techniques. In fact, it's best to use different techniques for different stages and apply them as one stage of a multi-stage process. It supplements rather than replaces existing codes of conduct. Nor can it completely replace experience. But both codes of conduct and experience are developed from existing situations. Innovative development requires reviews that examine the unknown. A HAZOP is a systematic and logical approach to identifying problems.

What is Hazard and HAZOP?

The goal of a Safety and Hazards Study (HAZOP) is to identify and assess issues that could endanger people or equipment or obstruct effective operation in a projected or current procedure or operation. a thorough investigation. HAZOP approaches were initially created to study chemical reaction systems, but they have now been used to analyses other kinds of systems, including complicated software and manipulation systems. A multi - disciplinary team (the HAZOP team) uses a key phrase quantitative technology called HAZOP in a sequence of meetings.

When and how to Conduct a Hazard analysis?

To affect the design, Hazard analysis investigations should be carried out as early in the design phase as practicable. Running a HAZOP, however, necessitates a very thorough design. HAZOPs are often conducted as a compromise after thorough planning is finished. He can also conduct HAZOP analyses on already-built facilities to see what improvements need to be done to reduce risks and operational problems.

Why HAZOP carried out?

- Identify (areas of construction with potentially significant risk ability).
- Detect and research design elements that influence the probability of a dangerous accident happening.
- Provide the study team with any available design data.
- Ensure that a thorough examination of potential substantial risk areas is carried out. • Find pertinent design data that the team does not presently have access to.
- Provide a way for the research team's clients to provide input.

Success or Failure of HAZOP:

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

- Completeness and accuracy of drawings and other data on which the study is based.
- Insight into the technical capabilities of the team.
- The group's capacity to apply the method as a creative tool to visualize variations, consequences, and effects.
- The team's capacity to concentrate on identified, most significant risks.
- The process is systematic and helps define the terminology used.

Intention:

Intents define how the plant behaves when there are no deviations in the study nodes. Both descriptive and graphical formats are possible for this. Examples: flow charts, diagrams, P and ID.

Deviation:

These are deviations from intent discovered by targeted use of keywords (e.g. more pressure).

Causes:

There can be variations because of these factors. A deviation can be regarded as a significant divergence once its plausible explanation has been established. These sources include hardware failures, human error, unexpected process conditions (such as compositional changes), and disturbances (such as power outages).

Consequences:

These are the consequences if deviations occur (e.g. release of toxic substances). Trivial results relevant to research purposes have been omitted.

Steps for HAZOP Study

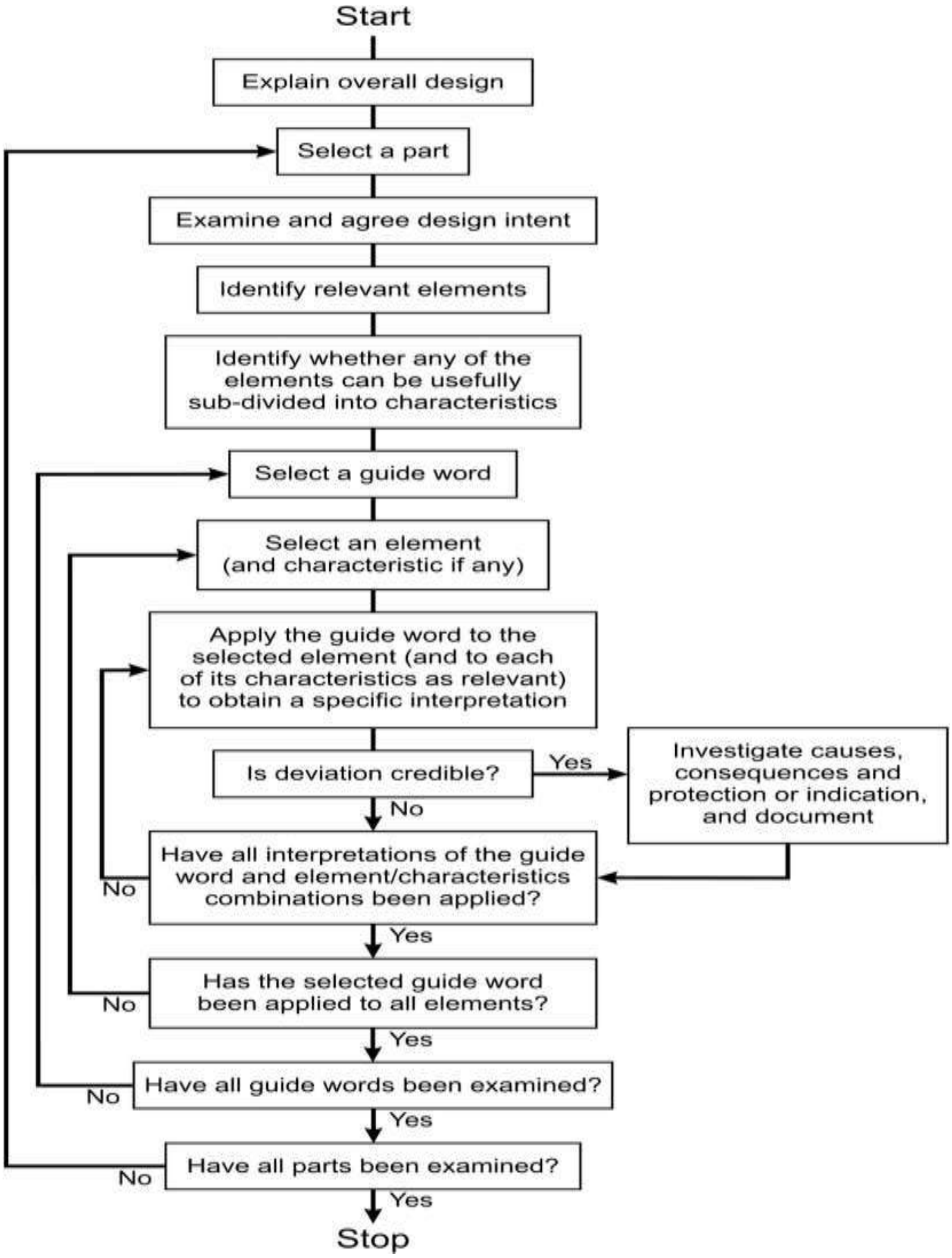


Fig no 11.1 :HAZOP Steps

11.1 HAZOP Study on CSTR (R-201)

A HAZOP study is to be conducted on Reactor, as presented by instrumentation and control diagram in following table.

Table 11.2: HAZOP study on Reactor 201

Parameter/Node	Guide Word	Deviation	Hazard/Operability Problem
Reactor Temperature	High	>5% above setpoint	Thermal runaway, potential for explosion
Reactor Temperature	Low	<5% below setpoint	Reduced reaction rate, potential for unwanted side reactions
Reactor Pressure	High	>10% above setpoint	Potential for vessel rupture or explosion
Reactor Pressure	Low	<10% below setpoint	Reduced reaction rate, potential for air ingress and unwanted reactions
Reactor Agitation	More	>10% above setpoint	Increased shear and potential for product degradation
Reactor Agitation	Less	<10% below setpoint	Inadequate mixing and potential for incomplete reaction
Reactant Flowrate	More	>10% above setpoint	Potential for exceeding vessel capacity, flooding or over-pressurization
Reactant Flowrate	Less	<10% below setpoint	Reduced reaction rate, potential for unwanted side reactions

11..2 HAZOP Study on Heat Exchanger (E-101)

Table 11.3: HAZOP study on Heat Exchanger 101

Guide	Process Parameter	Cause	Consequences	Action
No	Flow rate	Valve stuck closed. Choking of suction strainer of cooling water pump	-Decrease in temperature. -Plant condition will disturb	Repairing of control valve or bypass line. Cleaving of suction strainer
	Temperature	Stuck open of cooling water	Fuel oil production decreases	Repairing of control valve
	Pressure	Pressure regulator valve fault	Decrease in purity of product	Maintenance of Screw of pressure regulator valve
More	Flow rate	More valve opening	Heat leakage exchanger Gas kit	Automatic valve or used bypass line valve
	Temperature	Fault in reactor to produce more heat during exothermic reaction	Heat exchange tube damage	Rectify the reactor fault
	Pressure	Pressure regulator valve faulty	Tubes damage due to high pressure	Maintenance of pressure regulator valve
Less	Flow rate	Cavitation in pump valve partially stuck	Maximum heat transfer and tubes damage	Priming of stand by pump and take in service .rectification of valve
	Temperature	More opening control valve of cooling water	Low heat transfer in heat exchanger	Maintenance valve Of control
	Pressure	Feed pump rupture	Decrease in production	Maintenance of feed pump
As well as	Impurities in feed stream	Blockage of heat exchanger tube due to impurities	Washer trip due to power failure	Maintenance washer of plastic
Part of	More or lesser amount of bagasse in feed	Low or more conversion	Low grade feed compared to high feed materials	Verify the raw materials' products quality.
Others	Substitute parts and materials	Explosion if raw material is temperature sensitive	Collection of plastic is not proper	Better management in raw material collection

CHAPTER # 12

ENVIRONMENTAL IMPACT ASSESSMENT

12-Environmental Impact Assessment

12.1 Environmental Protection Agency

The Environmental Protection Agency (EPA) has methodically revised and tightened several policies and regulations due to growing concerns about the environment's continuous degradation. The EPA, which was created to safeguard the environment, concentrated on removing pollutants from waste streams that were gaseous, liquid, and solid. The most recent federal and state regulations pertaining to environmental protection, worker safety, and health must be understood by chemical engineers. The standards that are issued and updated by the federal regulatory system should be understood by design engineers.

Before taking any significant "action" that could materially affect the environment, the federal agencies are required by the National Environmental Policy Act (NEPA) to prepare such a statement. The process of assessing the potential environmental effects of a project and coming up with solutions to reduce environmental risk is Known as Environmental impact assessment (EIP).

An EIA's main objective is to assess the potential effects of proposed public and private development efforts, both positive and negative. Although the environment (biophysical) is typically in the spotlight, great practice also takes social and economic considerations into account. Examples of EIA policies include dams, industrial facilities, farm activities, transportation infrastructure (such as airport runways and highways), and the exploitation of natural resources. (e.g. sand extraction).

Biomethane

Renewable natural gas (RNG), often referred to as sustainable natural gas (SNG), or biomethane, is a type of biogas with properties similar to those of fossil natural gas and containing at least 90% methane. Gas grid operators can make it simple for customers to switch to renewable gas sources thanks to biomethane. Smaller, decentralized, or big, centrally situated combined heat and power facilities can employ biomethane to create electricity and heat. Utilizing biomethane might prevent about 8 Gt of carbon dioxide equivalent ($CO2$- eq) emissions.

Renewable Energy Standards:

Environmental organizations may set renewable energy standards or objectives that require a specific portion of energy production to originate from renewable sources, such as biomethane. By increasing market demand for renewable energy, these regulations can encourage the production and use of biomethane.

12.2 Emissions from Biomethane Production:

The process of producing biomethane results in emissions. The principal emitting factors are:

- Anaerobic digestion of feedstock: Gases like methane and carbon dioxide are discharged into the atmosphere as organic matter breaks down in the anaerobic digester.
- From energy consumption: Whether it comes from electricity or natural gas, the creation of biomethane requires a significant quantity of energy. Greenhouse gases like carbon dioxide are released as a result of this energy use.
- Transportation: Greenhouse gases are also released during the delivery of the feedstock to the plant and the biomethane to the final consumer**.**

However, compared to the generation of fossil fuels, biomethane has much lower overall emissions. The methane released or emitted during anaerobic digestion can be captured and used for energy, and renewable energy sources can be used to power the production process, both of which can reduce emissions.

12.3 Health Issues:

Possible health problems that could result from biomethane intake in people include:

- Respiratory troubles, such as coughing, wheezing, and shortness of breath, can be brought on by breathing in biomethane gas.
- Headaches and lightheadedness: biomethane gas exposure can cause headaches, lightheadedness, and even nausea.
- When exposed for an extended amount of time, biomethane gas can cause eye discomfort and redness.
- Skin irritation: direct skin contact can result in burns as well as skin irritation.
- Fires and explosions can result from the unexpected release of biomethane since the gas is extremely explosive and can harm neighboring structures as well as cause fires and explosions.
- Reduced cognitive function: prolonged exposure to biomethane gas can impair memory and other cognitive processes.

12.4 Handling:

Biomethane production facilities are built to transform organic. Anaerobic digestion, pretreatment of the raw materials, and upgrading of the biogas to biomethane are some of the processes that make up the production process. To ensure safety and effectiveness, numerous chemicals used in the production process must be managed carefully.

Handling ,Storage and Transportation of Biomethane:

As a highly flammable gas, biomethane must be handled carefully to prevent mishaps. Some recommendations for treating biomethane in manufacturing plants must be followed .

To make sure that the gas is produced and transported safely, it is vital to continuously check the concentration, pressure, and flow rate of biomethane. To reduce the risk of fire or explosion, the manufacturing facility must have sufficient safety precautions in place. Safety valves, pressure relief equipment, flame arrestors, and emergency shutdown systems are a few examples of these precautions. To prevent corrosion and leakage, biomethane must be kept in specially made tanks. The tanks must be situated in a safe location that is well-ventilated and away from potential ignition sources. Biomethane can be moved in a compressed or liquefied state. Use only special trailers or containers for shipment that adhere to safety rules.

Handling and Usage of byproducts:

Digestive waste and CO_2 are significant byproducts of the biomethane generation process, and they need to be handled carefully to guarantee minimal environmental impact. Digestate, which is the byproduct of the anaerobic digestion of organic matter, is a beneficial fertilizer for crops since it includes both macro and micronutrients. Digestate must be carefully handled and processed before being used as fertilizer. To lower the risk of pathogens and eliminate extra nutrients, this may involve pasteurization, drying, and other procedures. Digestate may occasionally also be utilized as a fuel for the creation of additional energy sources, such as biogas.

As a byproduct of the production of biomethane, CO_2 can be collected and used for a number of purposes, such as as a feedstock for industrial processes this procedure, known as CO_2 utilization, is viewed as a viable way to lower greenhouse gas emissions while producing goods with additional value. or as a greenhouse gas for plant development.

The following are a few of the industries that use CO2 as a feedstock:

- Chemical Industry: Chemicals including methanol, formaldehyde, ethylene, propylene, and urea are produced using CO_2 as a raw material. Numerous items, including plastics, adhesives, solvents, and fertilizers, are produced using these compounds.
- Fuel Industry: Fuels like methanol, methane, and syngas can be produced from CO_2 and utilized as an alternative to traditional fossil fuels. These fuels can aid in lowering carbon footprint because they emit fewer greenhouse gases into the atmosphere.
- Food and Beverage Industry: CO2 is utilised as a refrigerant in food preparation as well as to carbonate beverages. Additionally, it is utilised to establish a safe environment for storage and to increase the shelf life of packaged food products.

However, CO_2 is also a strong greenhouse gas, and the atmosphere may become warmer as a result of its release. CO_2 can be caught and stored, either underground or in other long-term storage facilities, to lessen its negative environmental effects. This procedure, sometimes referred to as carbon sequestration or carbon capture and storage (CCS), can dramatically lower the greenhouse gas emissions linked to the generation of biomethane.

12.5 Care for handling the utilities (water, steam, air).

To avoid mishaps and maintain safety, it's crucial to use the right measures when working with utilities. Following are some general guidelines for managing utilities:

- When handling utilities, always adhere to the rules and put on the correct personal protection equipment (PPE).
- Every utility's location, kind, and capacity should be known.
- Utility systems should be regularly inspected and maintained to prevent leaks and damage.
- To avoid accidents, keep utility areas tidy and clear of impediments.
- Staff members should receive training on how to handle, operate, and maintain utility systems.
- Install safety measures like emergency shutdown mechanisms and alerts to stop accidents and reduce damage.

12.6 Safety of workers:

Exposure to hazardous chemicals and gases at biomethane producing sites is one of the biggest concerns. Methane, carbon dioxide, and other gases, During the course of production, workers may be exposed to poisonous vapors, which can cause respiratory issues or, in extreme circumstances, suffocation. Employees must therefore receive training on how to handle dangerous chemicals and wear safety gear including gas masks, gloves, and protective suits. Each employee must receive training on how to safely handle the chemicals and gases to which they may be exposed.

The possibility of fire and explosion at biomethane producing facilities is another potential risk. A spark or an open flame can cause methane, a gas that is very flammable, to catch fire. Workers must receive training in safe equipment handling, and electrical equipment should undergo routine inspections to make sure it is in good operating condition. In order to avoid or reduce the size of future fires, all employees should be aware of where fire protection tools like fire extinguishers and sprinklers are located and how to use them.

References:

[1]-Syed S. Amjid, M. Q. (2011). Biogas, renewable energy resource for Pakistan. Renewable and Sustainable Energy Reviews, 5.

[2]-Solarte-Toro, J. C., Chacón-Pérez, Y., & Cardona-Alzate, C. A. (2018). Evaluation of biogas and syngas as energy vectors for heat and power generation using lignocellulosic biomass as raw material, 33.

[3]- Ghani, H. U., Mahmood, A., Ullah, A., & Gheewala, S. H. (2020). Life Cycle Environmental and Economic Performance Analysis of Bagasse-Based Electricity in Pakistan. Sustainability, 12(24).

[4]-Reza Behnood, B. A. (2016). il spill sorption using raw and acetylated sugarcane bagasse. Journal of Central South University, 9.

[5]-Eswara, A. K., Misra, S. C., & Ramesh, U. S. (2013, November). Introduction to natural gas: A comparative study of its storage, fuel costs and emissions for a harbor tug. In SNAME Maritime Convention. OnePetro.

[6]-Doble, M. (2000). Perry’s chemical engineers’ handbook.

[7]- Morales Udaeta, M. E., Burani, G. F., Arzabe Maure, J. O., & Oliva, C. R. (2007). Economics of secondary energy from GTL regarding natural gas reserves of Bolivia. Energy policy, 35(8).

[8]- Wojciech, M. (2017). Biomethane storage: Evaluation of technologies, end uses, business models, and sustainability. Energy conversion and management.

[9]- Global Biomethane Market (2021-2026) by Process, Feedstock, Application, Geography, Competitive Analysis and the Impact of Covid-19 with Ansoff Analysis, 2021

[10]- Sandro Lemos Machado, Á. C. (2021). Biogas production in a tropical landfill. Long-term monitoring results and analysis of variables of influence, 18.

[11]- Bachmann, N., la Cour Jansen, J., Bochmann, G., & Montpart, N. (2015). Sustainable biogas production in municipal wastewater treatment plants (p. 20). Massongex, Switzerland: IEA Bioenergy.

[12]- Ali Mohammad, A. A. (2019). A Review of the Chemistry of Anaerobic Digestion:Methods of Accelerating and Optimizing Process Efficiency.Processes, 19.

[13]-Devlin, Ger & Group, Charles. (2007). Biomass-to-Energy Systems "A Review of the Potential Role of the Irish Agri- Food Sector".

[14]-Raboni, M., & Urbini, G. (2014). Production and use of biogas in Europe: a survey of current status and perspectives. *Revista ambiente & agua*, *9*, 191-202.

[15]-T. D. Sechoala, O. P. (2019). A Review of Waste-to-Energy Recovery Pathway for Feasible Electricity Generation in Lowland Cities of Lesotho. *Energy recovery from Municipal Solid Waste*.

[16]-Pakistan Economic Survey Finance Division Government of Pakistan 2021-2022.

[17]-Muralidharan, M., Srivastava, A., & Subramanian, M. (2019). A technical review on performance and emissions of compressed natural gas-diesel dual fuel engine.

[18]-Lee, S. W., Lee, H. S., Park, Y. J., & Cho, Y. S. (2011). Combustion and emission characteristics of HCNG in a constant volume chamber. *Journal of mechanical science and technology*, *25*(2), 489-494.

[19]-BANAPURMATH, N. R., & Basavarajappa, H. Y. (2015). Effect of CNG manifold injection on the performance, combustion and emission characteristics of a CNG-Biodiesel dual fuel operation. *International Journal of Automotive Engineering and Technologies*, *4*(4), 223-244.

[20]-Peiris, A. P. T. S. (2016). Feasibility study of production of bio methane from bio wastes in Sri Lanka and develop cost model for the production process.

[21]-Serrano, F. J., Chiappe, L. M., Palmqvist, P., Figueirido, B., Long, J., & Sanz, J. L. (2019). The effect of long-term atmospheric changes on the macroevolution of birds. *Gondwana Research*, *65*, 86-96.

[22]-Eshore, S., Mondal, C., & Das, A. (2017). Production of biogas from treated sugarcane bagasse. *International Journal of Scientific Engineering and Technology*, *6*(7), 224-227.

[23]-Penta, A., Sai, K. A., Medatwa, O., & Rite, Y. (2017). Production of Biogas from Sugarcane Waste. *International Journal of Innovative Research in Science Engineering and Technology*, *6*(5).

[24]-Thiruselvi, D., Kumar, P. S., Kumar, M. A., Lay, C. H., Aathika, S., Mani, Y., ... & Show, P. L. (2021). A critical review on global trends in biogas scenario with its up-gradation techniques for fuel cell and future perspectives. *International Journal of Hydrogen Energy*, *46*(31), 16734-16750.

[25]-Behnood, Reza & Anvaripour, Bagher & Jaafarzadeh, Neematollah & Farasati, Masoumeh. (2016). Oil spill sorption using raw and acetylated sugarcane bagasse. Journal of Central South University. 23. 1618-1625. 10.1007/s11771-016-3216-8.

[26]-Khongchamnan, P., Suriyachai, N., Kreetachat, T., Laosiripojana, N., Weerasai, K., Champreda, V., ... & Imman, S. (2022). Optimization of Liquid Hot Water Pretreatment and Fermentation for Ethanol Production from Sugarcane Bagasse Using Saccharomyces cerevisiae. *Catalysts*, *12*(5), 463.

[27]-Bianchi, B. & Tamborrino, Antonia & Santoro, Francesco. (2013). Assessment of the energy and separation efficiency of the decanter centrifuge with regulation capability of oil water ring in the industrial process line using a continuous method. Journal of Agricultural Engineering. 44. 10.4081/jae.2013.298.\

[28]-Ghaib, K. (2017). Development of a Model for Water Scrubbing-Based Biogas Upgrading and Biomethane Compression. *Chemical Engineering & Technology*, *40*(10), 1817-1825.

[29]-Bashar, M. A. (2018). *Biogas quality improvement using water wash and phosphorus recovery as struvite in Jones Island WWTP* (Doctoral dissertation, The University of Wisconsin-Milwaukee).

[30]-Summerfelt, S. T., Davidson, J., & Waldrop, T. (2003). Evaluation of full-scale carbon dioxide stripping columns in a coldwater recirculating system. *Aquacultural engineering*, *28*(3-4), 155-169.

[31]-Ng, K. C., Chua, H. T., Chung, C. Y., Loke, C. H., Kashiwagi, T., Akisawa, A., & Saha, B. B. (2001). Experimental investigation of the silica gel–water adsorption isotherm characteristics. *Applied Thermal Engineering*, *21*(16), 1631-1642.

Appendices

Appendix A

Tables:

Table A-1 : Maximum Allowable Joint Efficiency

Table A-1 : Maximum Allowable Stress

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Table A-4 :Cost of Packings

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Table A-11: Efficiency of Pump

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Appendix A

Table A-1 : Maximum Allowable Joint Efficiency

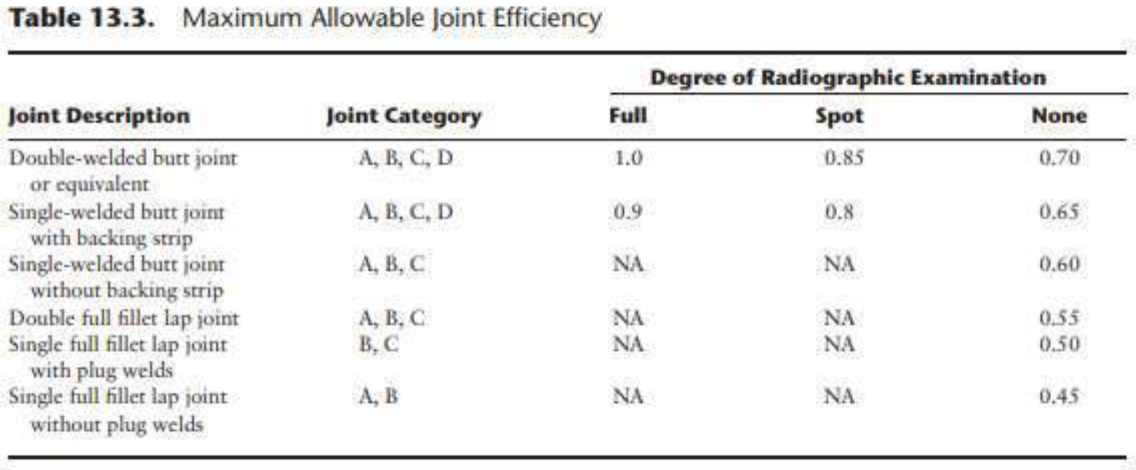


Table 13.3. Maximum Allowable Joint Efficiency

Joint Description	Joint Category	Degree of Radiographic Examination		
		Full	**Spot**	**None**
Double-welded butt joint or equivalent	A, B, C, D	1.0	0.85	0.70
Single-welded butt joint with backing strip	A, B, C, D	0.9	0.8	0.65
Single-welded butt joint without backing strip	A, B, C	NA	NA	0.60
Double full fillet lap joint	A, B, C	NA	NA	0.55
Single full fillet lap joint with plug welds	B, C	NA	NA	0.50
Single full fillet lap joint without plug welds	A, B	NA	NA	0.45

Table A-1 : Maximum Allowable Stress

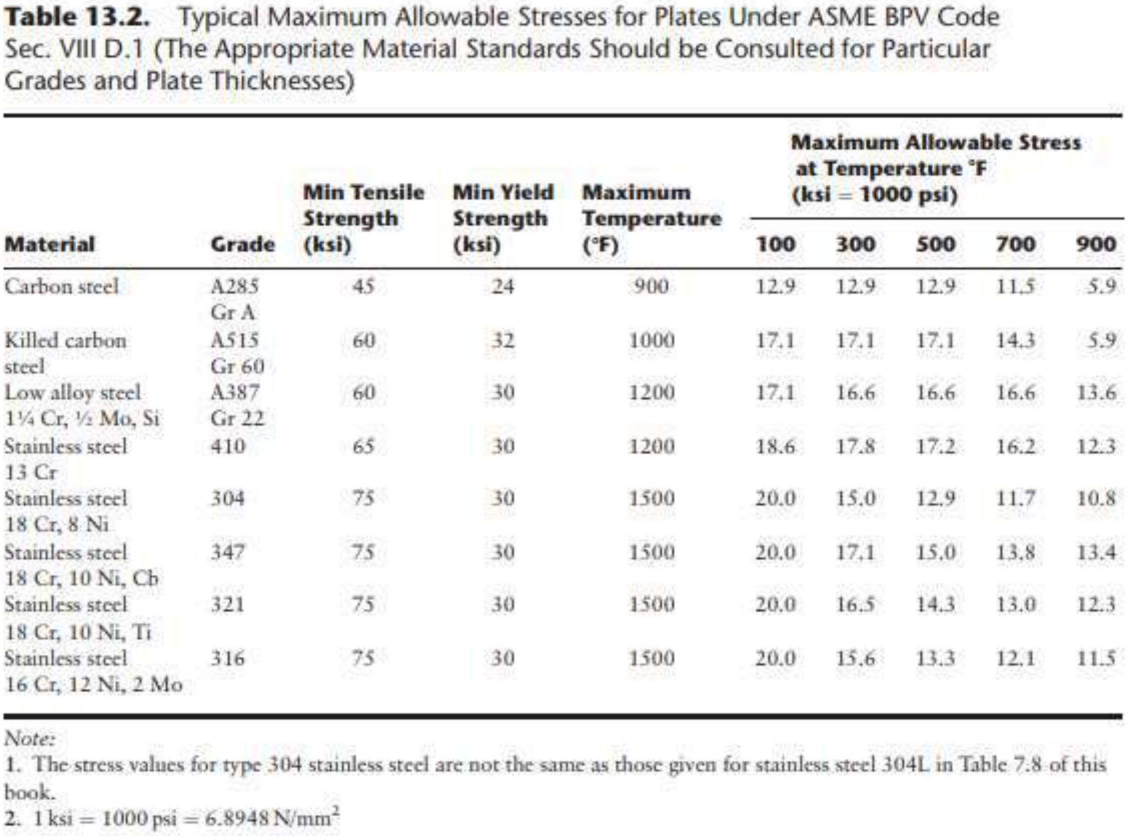


Table 13.2. Typical Maximum Allowable Stresses for Plates Under ASME BPV Code Sec. VIII D.1 (The Appropriate Material Standards Should be Consulted for Particular Grades and Plate Thicknesses)

Material	Grade	Min Tensile Strength (ksi)	Min Yield Strength (ksi)	Maximum Temperature (°F)	Maximum Allowable Stress at Temperature °F (ksi = 1000 psi)				
					100	**300**	**500**	**700**	**900**
Carbon steel	A285 Gr A	45	24	900	12.9	12.9	12.9	11.5	5.9
Killed carbon steel	A515 Gr 60	60	32	1000	17.1	17.1	17.1	14.3	5.9
Low alloy steel 1¼ Cr, ½ Mo, Si	A387 Gr 22	60	30	1200	17.1	16.6	16.6	16.6	13.6
Stainless steel 13 Cr	410	65	30	1200	18.6	17.8	17.2	16.2	12.3
Stainless steel 18 Cr, 8 Ni	304	75	30	1500	20.0	15.0	12.9	11.7	10.8
Stainless steel 18 Cr, 10 Ni, Cb	347	75	30	1500	20.0	17.1	15.0	13.8	13.4
Stainless steel 18 Cr, 10 Ni, Ti	321	75	30	1500	20.0	16.5	14.3	13.0	12.3
Stainless steel 16 Cr, 12 Ni, 2 Mo	316	75	30	1500	20.0	15.6	13.3	12.1	11.5

Note:

1. The stress values for type 304 stainless steel are not the same as those given for stainless steel 304L in Table 7.8 of this book.
2. 1 ksi = 1000 psi = 6.8948 N/mm^2

Table A-3 : Design Data for Packings

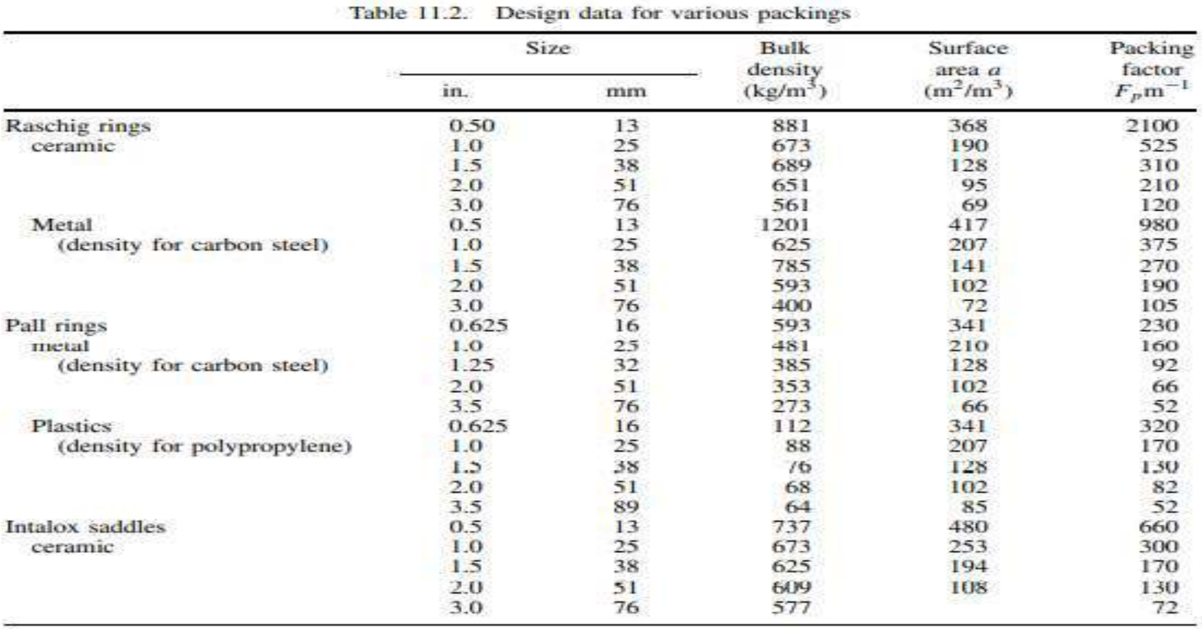
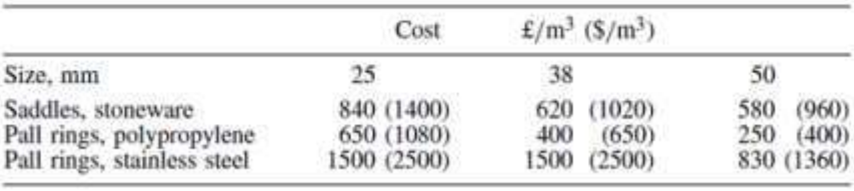


Table 11.2. Design data for various packings

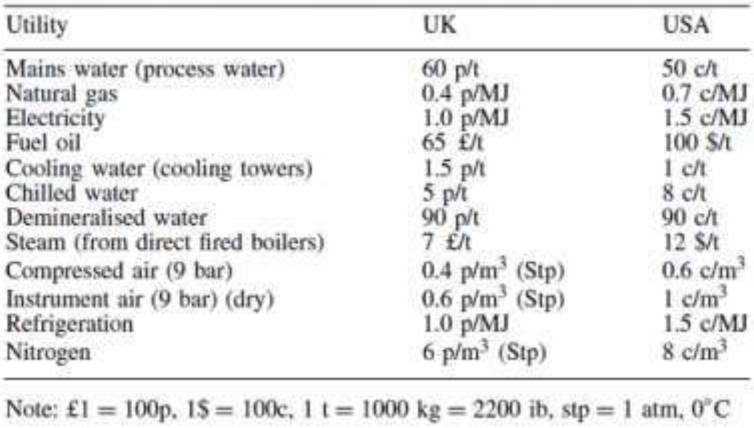
	Size in.	Size mm	Bulk density (kg/m^3)	Surface area a (m^2/m^3)	Packing factor F_pm^{-1}
Raschig rings	0.50	13	881	368	2100
ceramic	1.0	25	673	190	525
	1.5	38	689	128	310
	2.0	51	651	95	210
	3.0	76	561	69	120
Metal	0.5	13	1201	417	980
(density for carbon steel)	1.0	25	625	207	375
	1.5	38	785	141	270
	2.0	51	593	102	190
	3.0	76	400	72	105
Pall rings	0.625	16	593	341	230
metal	1.0	25	481	210	160
(density for carbon steel)	1.25	32	385	128	92
	2.0	51	353	102	66
	3.5	76	273	66	52
Plastics	0.625	16	112	341	320
(density for polypropylene)	1.0	25	88	207	170
	1.5	38	76	128	130
	2.0	51	68	102	82
	3.5	89	64	85	52
Intalox saddles	0.5	13	737	480	660
ceramic	1.0	25	673	253	300
	1.5	38	625	194	170
	2.0	51	609	108	130
	3.0	76	577		72

Table A-4 :Cost of Packings



	Cost	£/m^3 ($/m^3)	
Size, mm	25	38	50
Saddles, stoneware	840 (1400)	620 (1020)	580 (960)
Pall rings, polypropylene	650 (1080)	400 (650)	250 (400)
Pall rings, stainless steel	1500 (2500)	1500 (2500)	830 (1360)

Table A-5:Cost of Utilities



Utility	UK	USA
Mains water (process water)	60 p/t	50 c/t
Natural gas	0.4 p/MJ	0.7 c/MJ
Electricity	1.0 p/MJ	1.5 c/MJ
Fuel oil	65 £/t	100 $/t
Cooling water (cooling towers)	1.5 p/t	1 c/t
Chilled water	5 p/t	8 c/t
Demineralised water	90 p/t	90 c/t
Steam (from direct fired boilers)	7 £/t	12 $/t
Compressed air (9 bar)	0.4 p/m^3 (Stp)	0.6 c/m^3
Instrument air (9 bar) (dry)	0.6 p/m^3 (Stp)	1 c/m^3
Refrigeration	1.0 p/MJ	1.5 c/MJ
Nitrogen	6 p/m^3 (Stp)	8 c/m^3

Note: £1 = 100p, 1$ = 100c, 1 t = 1000 kg = 2200 ib, stp = 1 atm, 0°C

Table A-6 : Tube Side Data

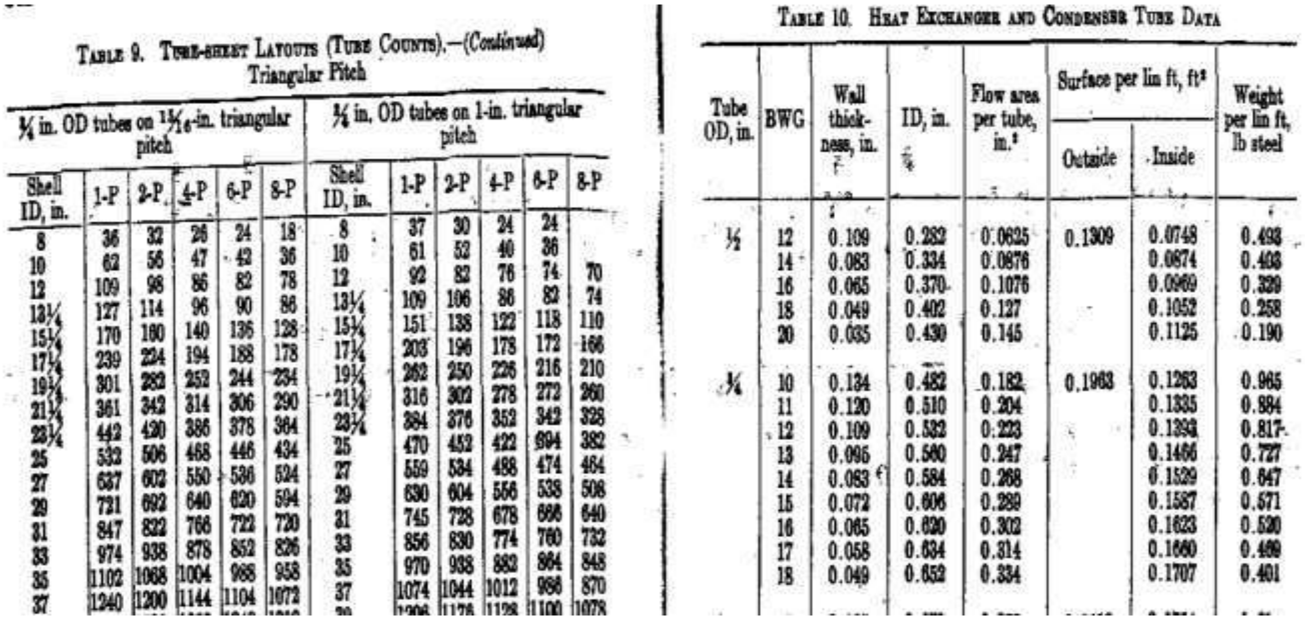


TABLE 9. TUBE-SHEET LAYOUTS (TUBE COUNTS).—(Continued)
Triangular Pitch

¾ in. OD tubes on 1⁵⁄₁₆-in. triangular pitch						¾ in. OD tubes on 1-in. triangular pitch					
Shell ID, in.	1-P	2-P	4-P	6-P	8-P	Shell ID, in.	1-P	2-P	4-P	6-P	8-P
8	36	32	26	24	18	8	37	30	24	24	
10	62	56	47	42	36	10	61	52	40	36	
12	109	98	86	82	78	12	92	82	76	74	70
13¼	127	114	96	90	86	13¼	109	106	86	82	74
15¼	170	160	140	136	128	15¼	151	138	122	118	110
17¼	239	224	194	188	178	17¼	203	196	178	172	166
19¼	301	282	252	244	234	19¼	262	250	226	216	210
21¼	361	342	314	306	290	21¼	316	302	278	272	260
23¼	442	420	386	378	364	23¼	384	376	352	342	328
25	532	506	468	446	434	25	470	452	422	394	382
27	637	602	550	536	524	27	559	534	488	474	464
29	721	692	640	620	594	29	630	604	556	538	508
31	847	822	766	722	720	31	745	728	678	666	640
33	974	938	878	852	826	33	856	830	774	760	732
35	1102	1068	1004	988	958	35	970	938	882	864	848
37	1240	1200	1144	1104	1072	37	1074	1044	1012	986	870

TABLE 10. HEAT EXCHANGER AND CONDENSER TUBE DATA

Tube OD, in.	BWG	Wall thickness, in.	ID, in.	Flow area per tube, in.²	Surface per lin ft, ft²		Weight per lin ft, lb steel
					Outside	Inside	
½	12	0.109	0.282	0.0625	0.1309	0.0748	0.493
	14	0.083	0.334	0.0876		0.0874	0.403
	16	0.065	0.370	0.1076		0.0969	0.329
	18	0.049	0.402	0.127		0.1052	0.258
	20	0.035	0.430	0.145		0.1125	0.190
¾	10	0.134	0.482	0.182	0.1963	0.1263	0.965
	11	0.120	0.510	0.204		0.1335	0.884
	12	0.109	0.532	0.223		0.1393	0.817
	13	0.095	0.560	0.247		0.1466	0.727
	14	0.083	0.584	0.268		0.1529	0.647
	15	0.072	0.606	0.289		0.1587	0.571
	16	0.065	0.620	0.302		0.1623	0.520
	17	0.058	0.634	0.314		0.1660	0.469
	18	0.049	0.652	0.334		0.1707	0.401

Table A-7 : Constants for Heat Exchanger

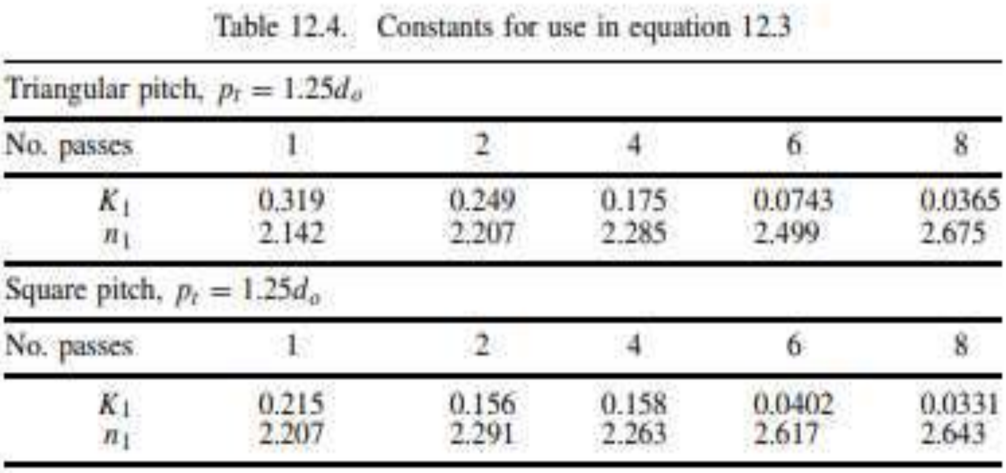


Table 12.4. Constants for use in equation 12.3

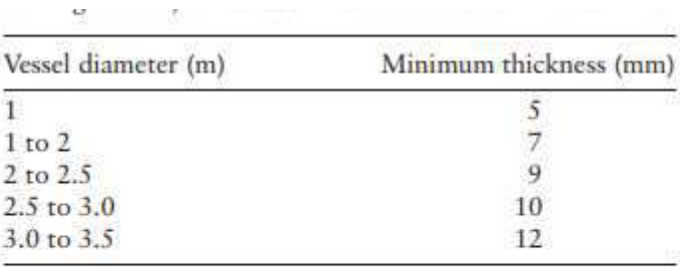
Triangular pitch, $p_t = 1.25d_o$

No. passes	1	2	4	6	8
K_1	0.319	0.249	0.175	0.0743	0.0365
n_1	2.142	2.207	2.285	2.499	2.675

Square pitch, $p_t = 1.25d_o$

No. passes	1	2	4	6	8
K_1	0.215	0.156	0.158	0.0402	0.0331
n_1	2.207	2.291	2.263	2.617	2.643

Table A-8 : Maximum thickness of Vessel



Vessel diameter (m)	Minimum thickness (mm)
1	5
1 to 2	7
2 to 2.5	9
2.5 to 3.0	10
3.0 to 3.5	12

Table A-9: Fouling Factor

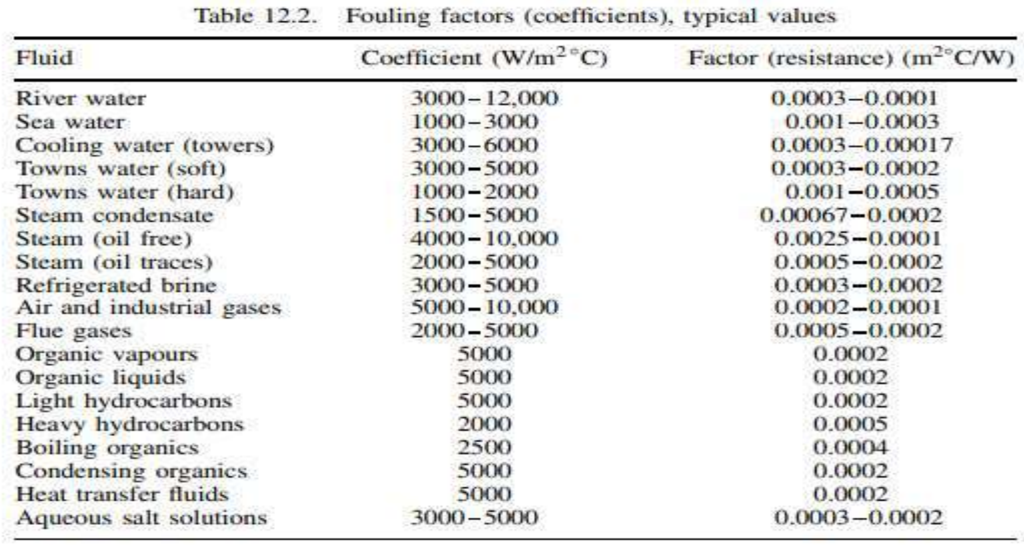


Table 12.2. Fouling factors (coefficients), typical values

Fluid	Coefficient (W/m^2°C)	Factor (resistance) (m^2°C/W)
River water	3000–12,000	0.0003–0.0001
Sea water	1000–3000	0.001–0.0003
Cooling water (towers)	3000–6000	0.0003–0.00017
Towns water (soft)	3000–5000	0.0003–0.0002
Towns water (hard)	1000–2000	0.001–0.0005
Steam condensate	1500–5000	0.00067–0.0002
Steam (oil free)	4000–10,000	0.0025–0.0001
Steam (oil traces)	2000–5000	0.0005–0.0002
Refrigerated brine	3000–5000	0.0003–0.0002
Air and industrial gases	5000–10,000	0.0002–0.0001
Flue gases	2000–5000	0.0005–0.0002
Organic vapours	5000	0.0002
Organic liquids	5000	0.0002
Light hydrocarbons	5000	0.0002
Heavy hydrocarbons	2000	0.0005
Boiling organics	2500	0.0004
Condensing organics	5000	0.0002
Heat transfer fluids	5000	0.0002
Aqueous salt solutions	3000–5000	0.0003–0.0002

Table A-10: Conductivity of metals

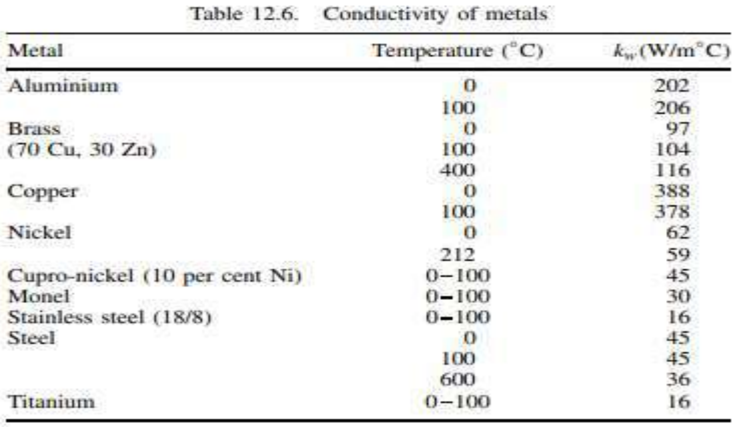
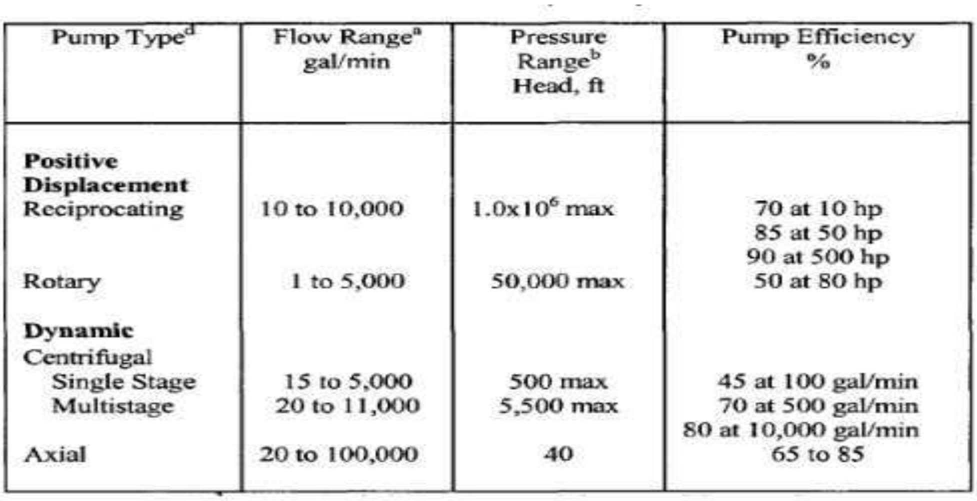


Table 12.6. Conductivity of metals

Metal	Temperature (°C)	k_w (W/m°C)
Aluminium	0	202
	100	206
Brass	0	97
(70 Cu, 30 Zn)	100	104
	400	116
Copper	0	388
	100	378
Nickel	0	62
	212	59
Cupro-nickel (10 per cent Ni)	0–100	45
Monel	0–100	30
Stainless steel (18/8)	0–100	16
Steel	0	45
	100	45
	600	36
Titanium	0–100	16

Table A-11: Efficiency of Pump



Pump Type[d]	Flow Range[a] gal/min	Pressure Range[b] Head, ft	Pump Efficiency %
Positive Displacement			
Reciprocating	10 to 10,000	1.0x10^6 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 A-12 : Purchased Cost of Equipment

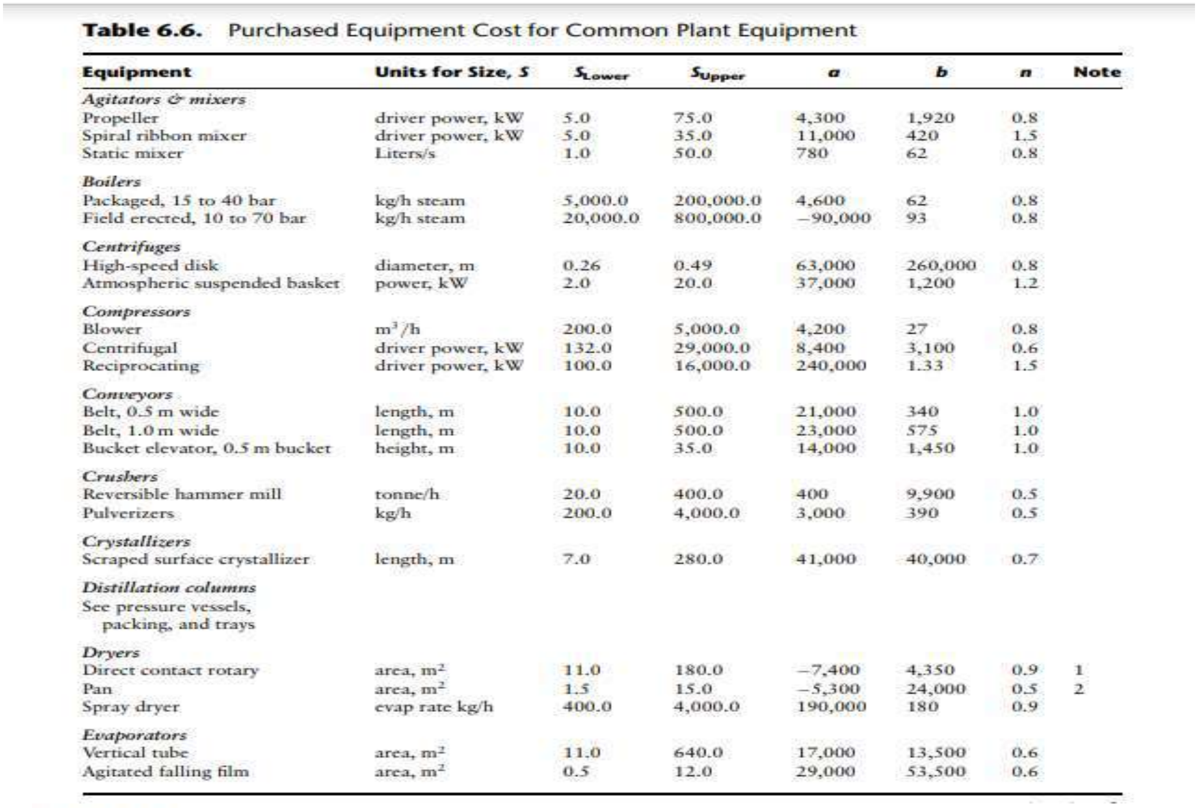


Table 6.6. Purchased Equipment Cost for Common Plant Equipment

Equipment	Units for Size, S	S_{Lower}	S_{Upper}	a	b	n	Note
Agitators & mixers							
Propeller	driver power, kW	5.0	75.0	4,300	1,920	0.8	
Spiral ribbon mixer	driver power, kW	5.0	35.0	11,000	420	1.5	
Static mixer	Liters/s	1.0	50.0	780	62	0.8	
Boilers							
Packaged, 15 to 40 bar	kg/h steam	5,000.0	200,000.0	4,600	62	0.8	
Field erected, 10 to 70 bar	kg/h steam	20,000.0	800,000.0	−90,000	93	0.8	
Centrifuges							
High-speed disk	diameter, m	0.26	0.49	63,000	260,000	0.8	
Atmospheric suspended basket	power, kW	2.0	20.0	37,000	1,200	1.2	
Compressors							
Blower	m^3/h	200.0	5,000.0	4,200	27	0.8	
Centrifugal	driver power, kW	132.0	29,000.0	8,400	3,100	0.6	
Reciprocating	driver power, kW	100.0	16,000.0	240,000	1.33	1.5	
Conveyors							
Belt, 0.5 m wide	length, m	10.0	500.0	21,000	340	1.0	
Belt, 1.0 m wide	length, m	10.0	500.0	23,000	575	1.0	
Bucket elevator, 0.5 m bucket	height, m	10.0	35.0	14,000	1,450	1.0	
Crushers							
Reversible hammer mill	tonne/h	20.0	400.0	400	9,900	0.5	
Pulverizers	kg/h	200.0	4,000.0	3,000	390	0.5	
Crystallizers							
Scraped surface crystallizer	length, m	7.0	280.0	41,000	40,000	0.7	
Distillation columns							
See pressure vessels, packing, and trays							
Dryers							
Direct contact rotary	area, m^2	11.0	180.0	−7,400	4,350	0.9	1
Pan	area, m^2	1.5	15.0	−5,300	24,000	0.5	2
Spray dryer	evap rate kg/h	400.0	4,000.0	190,000	180	0.9	
Evaporators							
Vertical tube	area, m^2	11.0	640.0	17,000	13,500	0.6	
Agitated falling film	area, m^2	0.5	12.0	29,000	53,500	0.6	

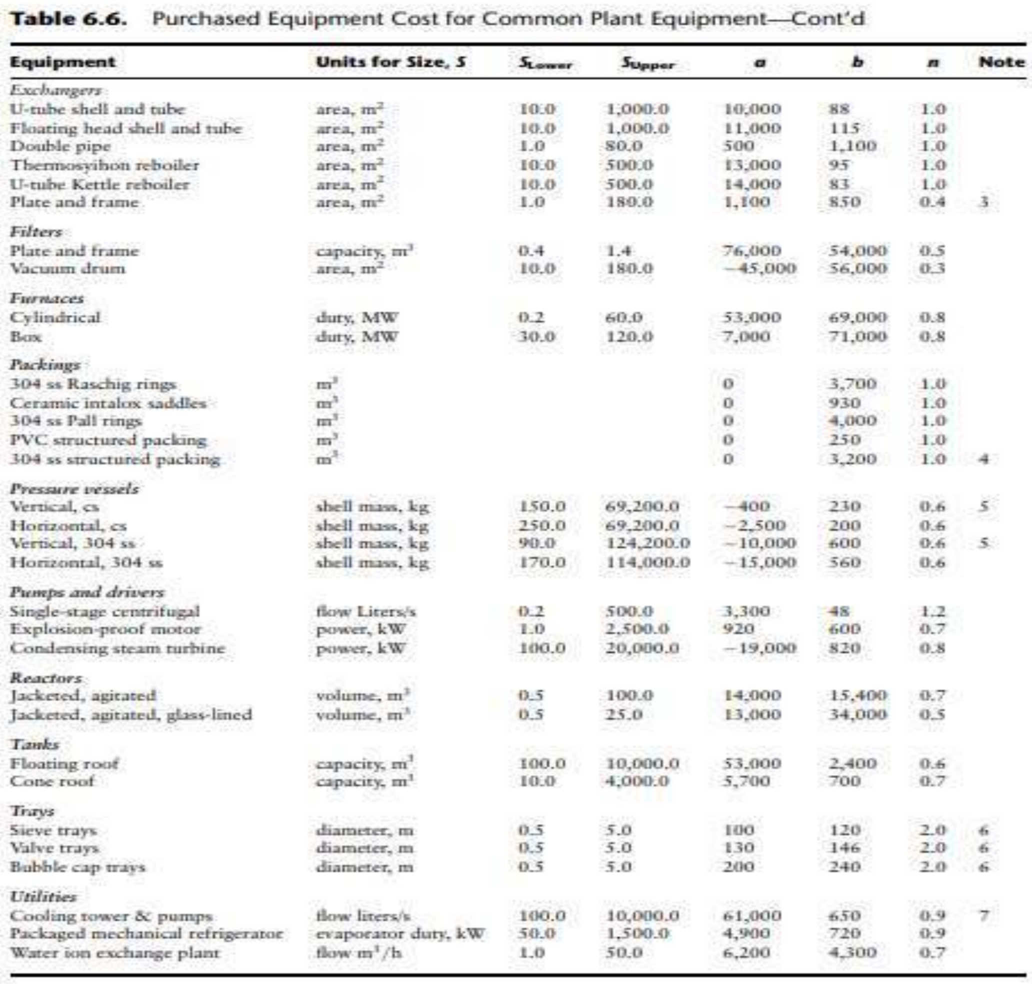


Table 6.6. Purchased Equipment Cost for Common Plant Equipment—Cont'd

Equipment	Units for Size, S	S_{Lower}	S_{Upper}	a	b	n	Note
Exchangers							
U-tube shell and tube	area, m^2	10.0	1,000.0	10,000	88	1.0	
Floating head shell and tube	area, m^2	10.0	1,000.0	11,000	115	1.0	
Double pipe	area, m^2	1.0	80.0	500	1,100	1.0	
Thermosyihon reboiler	area, m^2	10.0	500.0	13,000	95	1.0	
U-tube Kettle reboiler	area, m^2	10.0	500.0	14,000	83	1.0	
Plate and frame	area, m^2	1.0	180.0	1,100	850	0.4	3
Filters							
Plate and frame	capacity, m^3	0.4	1.4	76,000	54,000	0.5	
Vacuum drum	area, m^2	10.0	180.0	−45,000	56,000	0.3	
Furnaces							
Cylindrical	duty, MW	0.2	60.0	53,000	69,000	0.8	
Box	duty, MW	30.0	120.0	7,000	71,000	0.8	
Packings							
304 ss Raschig rings	m^3			0	3,700	1.0	
Ceramic intalox saddles	m^3			0	930	1.0	
304 ss Pall rings	m^3			0	4,000	1.0	
PVC structured packing	m^3			0	250	1.0	
304 ss structured packing	m^3			0	3,200	1.0	4
Pressure vessels							
Vertical, cs	shell mass, kg	150.0	69,200.0	−400	230	0.6	5
Horizontal, cs	shell mass, kg	250.0	69,200.0	−2,500	200	0.6	
Vertical, 304 ss	shell mass, kg	90.0	124,200.0	−10,000	600	0.6	5
Horizontal, 304 ss	shell mass, kg	170.0	114,000.0	−15,000	560	0.6	
Pumps and drivers							
Single-stage centrifugal	flow Liters/s	0.2	500.0	3,300	48	1.2	
Explosion-proof motor	power, kW	1.0	2,500.0	920	600	0.7	
Condensing steam turbine	power, kW	100.0	20,000.0	−19,000	820	0.8	
Reactors							
Jacketed, agitated	volume, m^3	0.5	100.0	14,000	15,400	0.7	
Jacketed, agitated, glass-lined	volume, m^3	0.5	25.0	13,000	34,000	0.5	
Tanks							
Floating roof	capacity, m^3	100.0	10,000.0	53,000	2,400	0.6	
Cone roof	capacity, m^3	10.0	4,000.0	5,700	700	0.7	
Trays							
Sieve trays	diameter, m	0.5	5.0	100	120	2.0	6
Valve trays	diameter, m	0.5	5.0	130	146	2.0	6
Bubble cap trays	diameter, m	0.5	5.0	200	240	2.0	6
Utilities							
Cooling tower & pumps	flow liters/s	100.0	10,000.0	61,000	650	0.9	7
Packaged mechanical refrigerator	evaporator duty, kW	50.0	1,500.0	4,900	720	0.9	
Water ion exchange plant	flow m^3/h	1.0	50.0	6,200	4,300	0.7	

Appendix B

Appendix B

Figure B-1: Shell Side Friction Factor

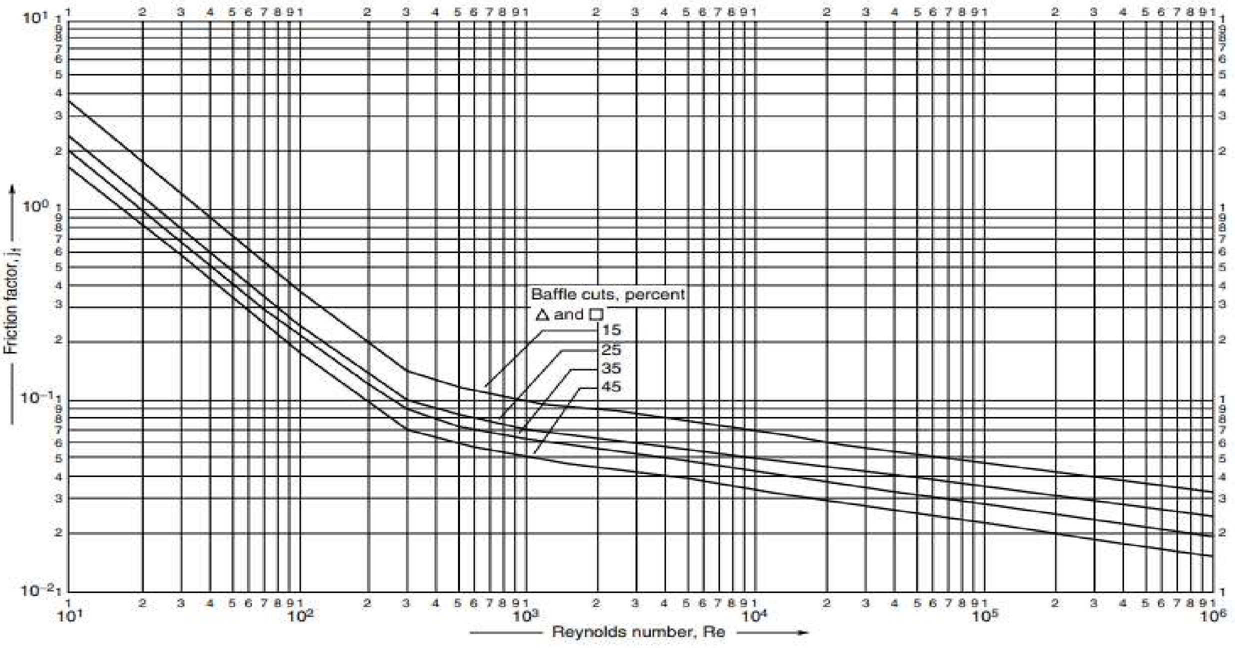


Figure 12.30. Shell-side friction factors, segmental baffles

Figure B-2: Shell Side Heat Transfer Coefficient

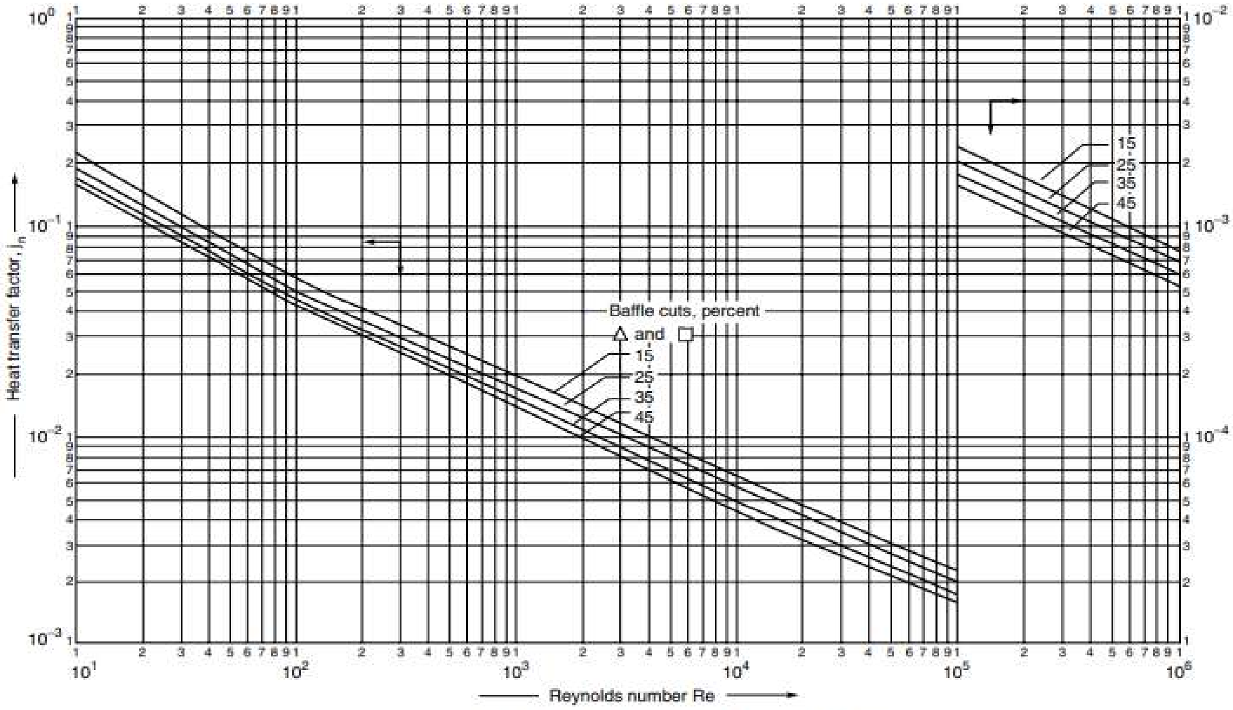


Figure 12.29. Shell-side heat-transfer factors, segmental baffles

Figure B-3 : Tube Side Friction Factor

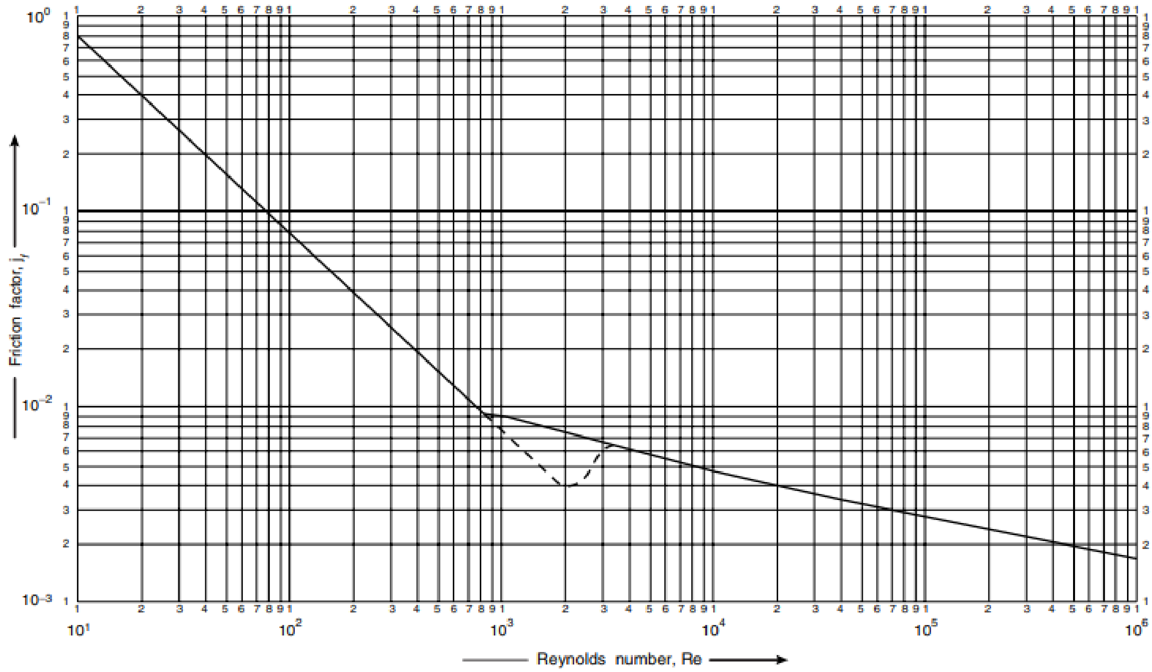


Figure 12.24. Tube-side friction factors

Figure B-4: Tube Side Heat Transfer Coefficient

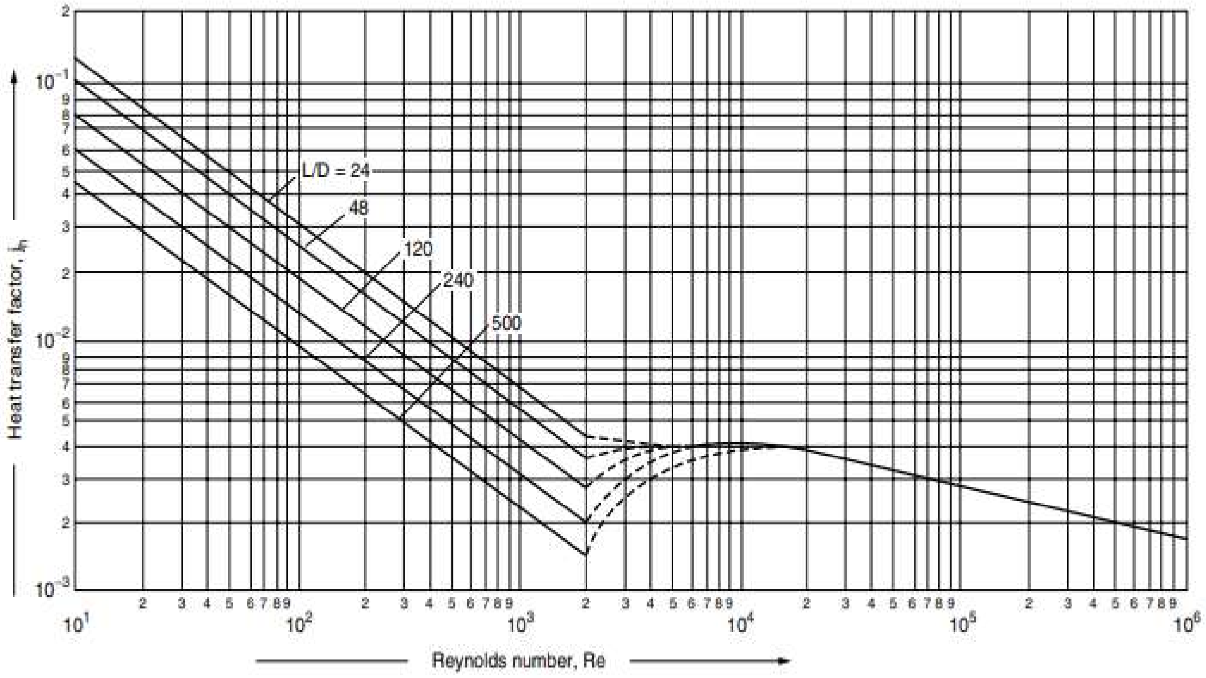


Figure 12.23. Tube-side heat-transfer factor

Figure B-5 : Number of Transfer units

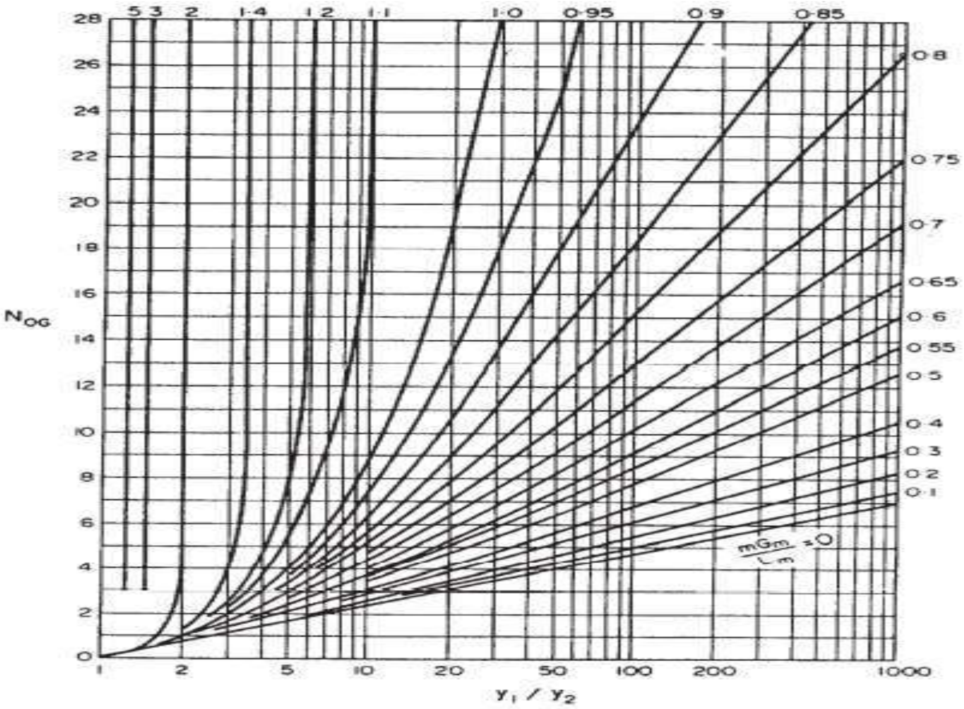


Figure 11.40. Number of transfer units N_{OG} as a function of y_1/y_2 with mG_m/L_m as parameter

Figure B-6 : Generalized Pressure Drop

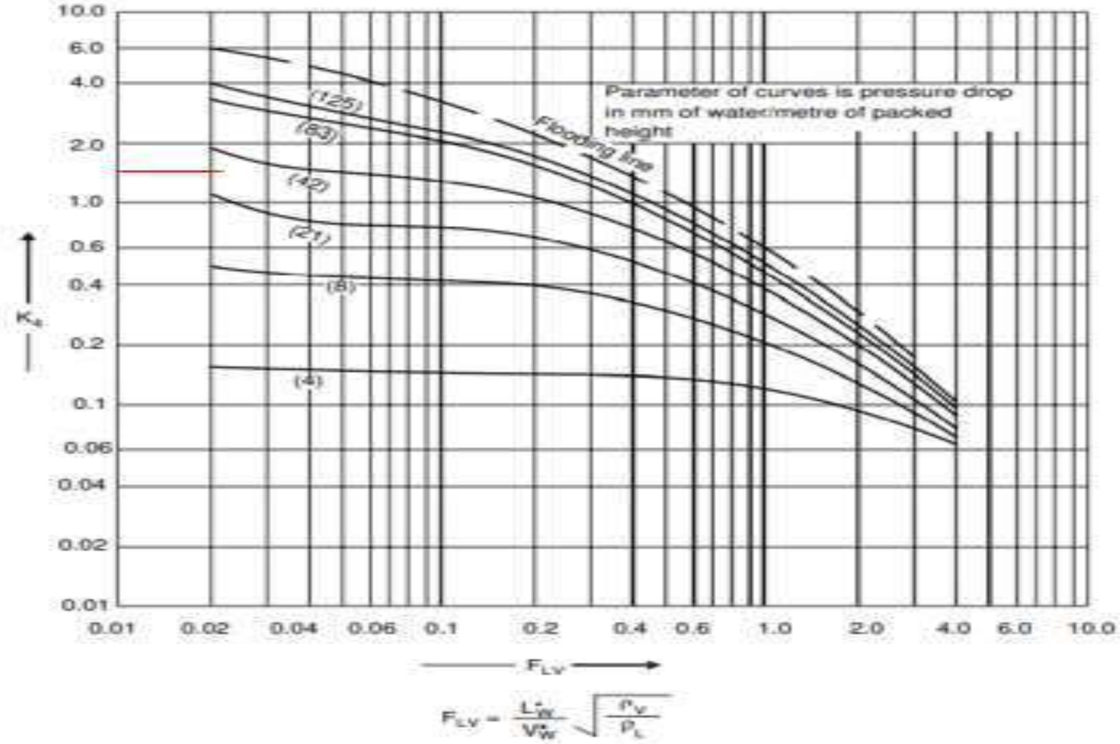


Figure 11.44. Generalised pressure drop correlation, adapted from a figure by the Norton Co. with permission

Figure B-7 : Shell bundle clearance

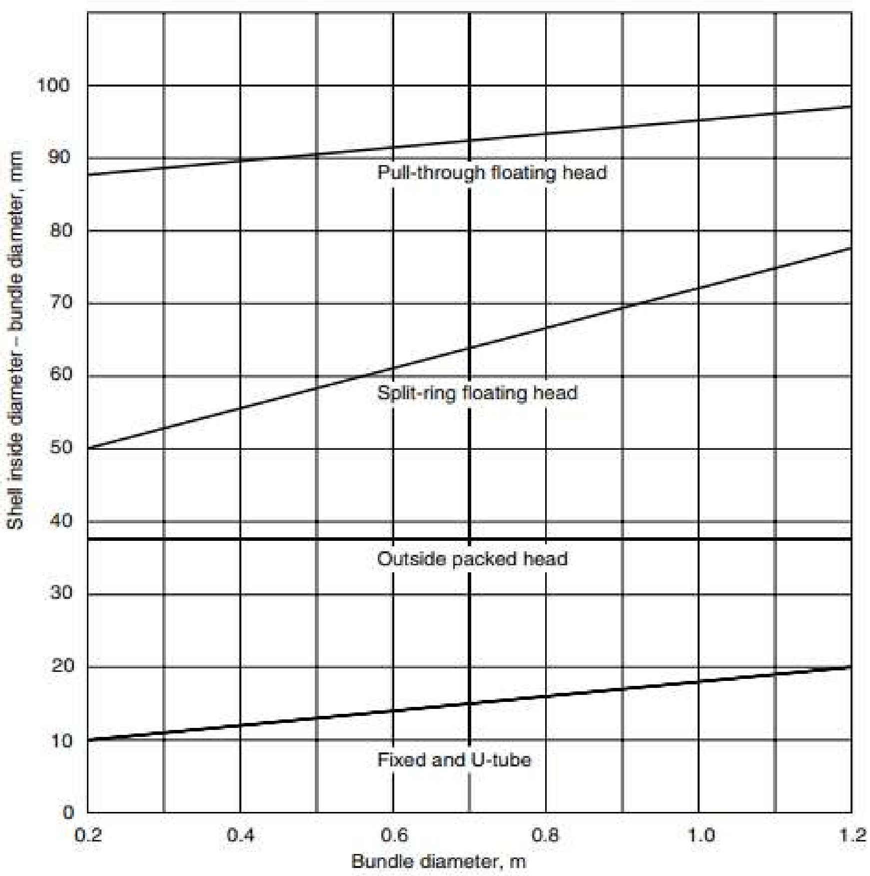


Figure 12.10. Shell-bundle clearance

Figure B-8 : Agitator Selection Guide

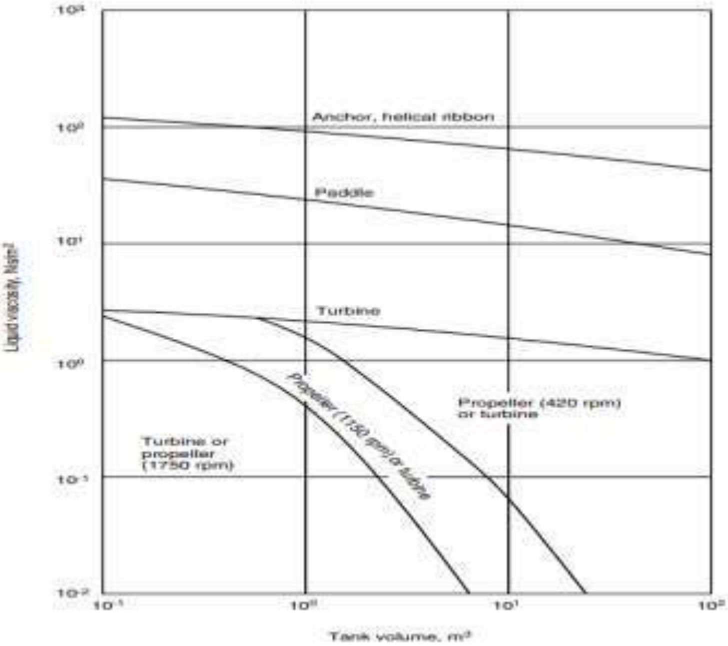


Figure 10.57. Agitator selection guide

Figure B-9 : Power number against Reynold number

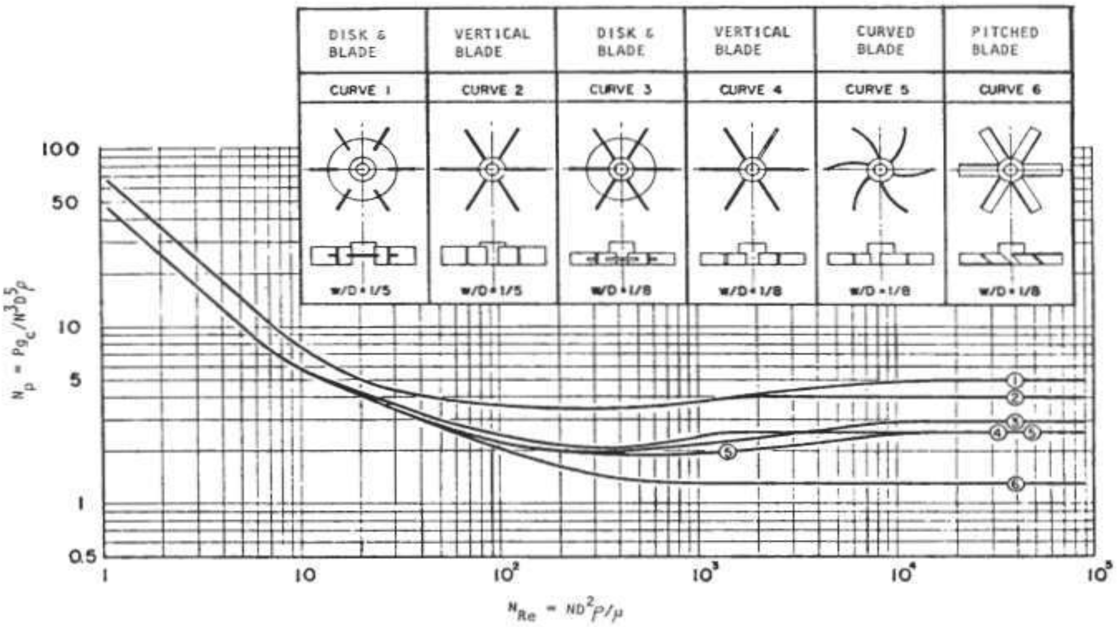


Figure 10.6. Power number against Reynolds number of some turbine impellers [*Bates, Fondy, and Corpstein,* Ind. Eng. Chem. Process. Des. Dev. 2(*4*) *311* (*1963*)].

Figure B-10 : Solubility Data

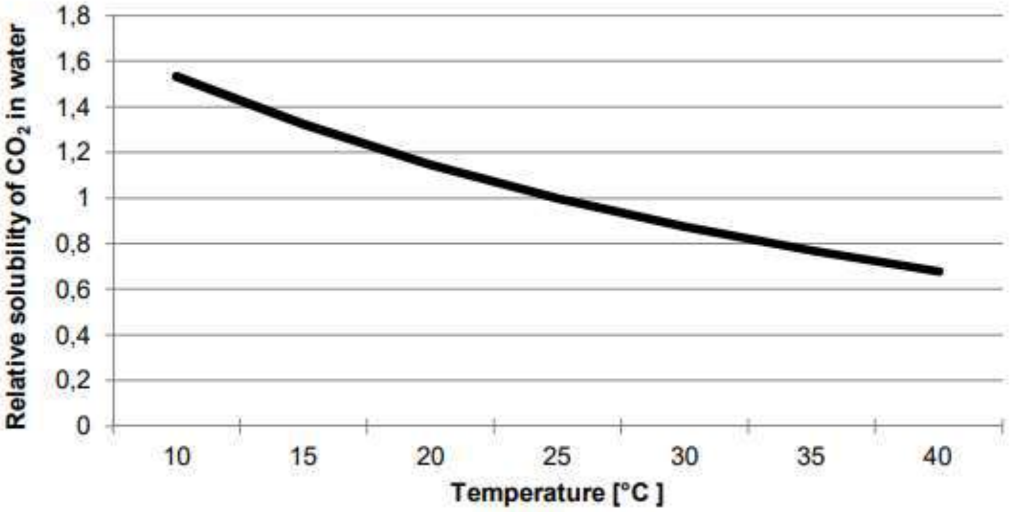


Figure 19 Relative solubility of CO2 in water in the temperature interval between 10°C and 40°C. Solubility normalized to the value at 25°C.

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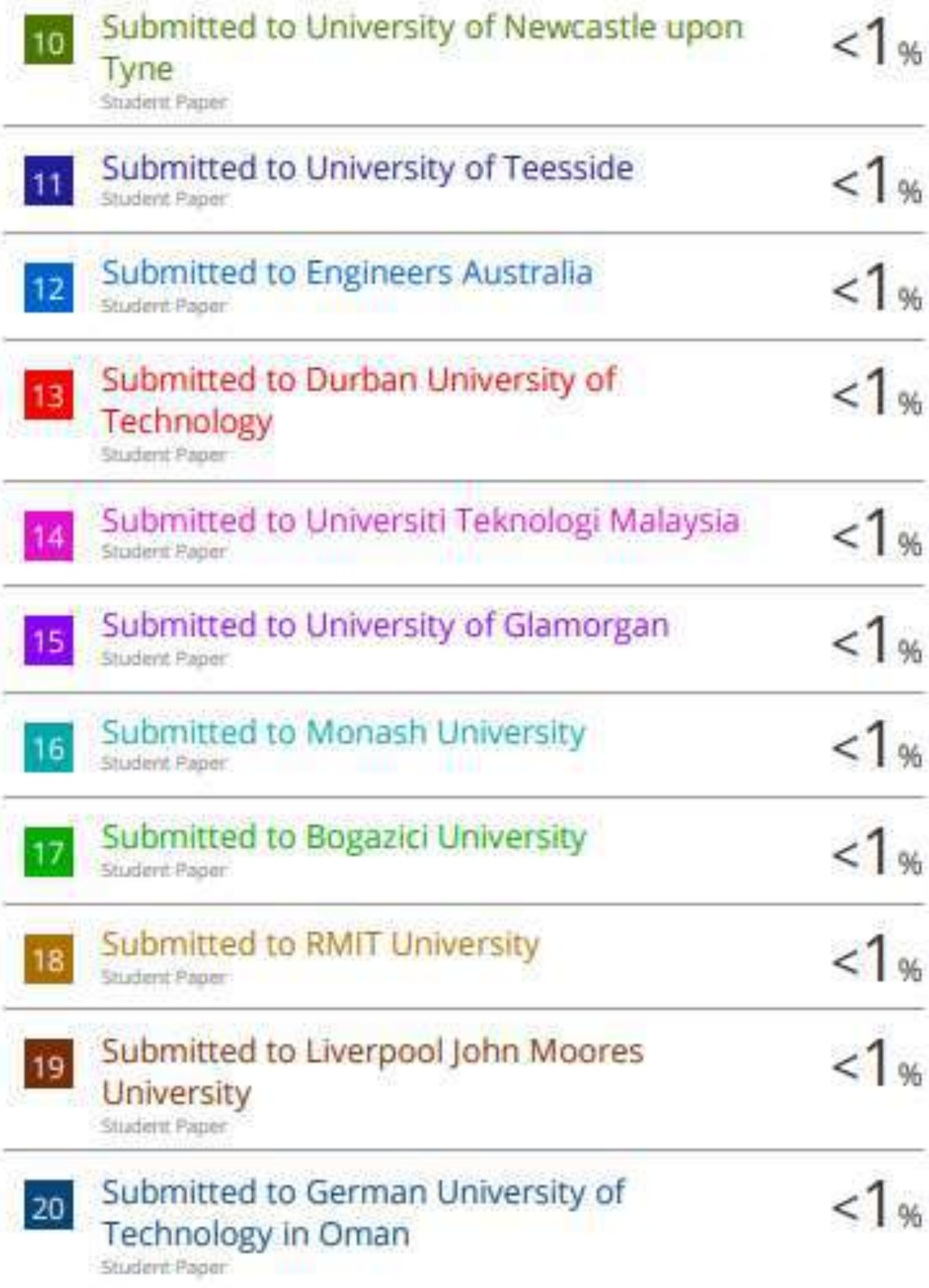

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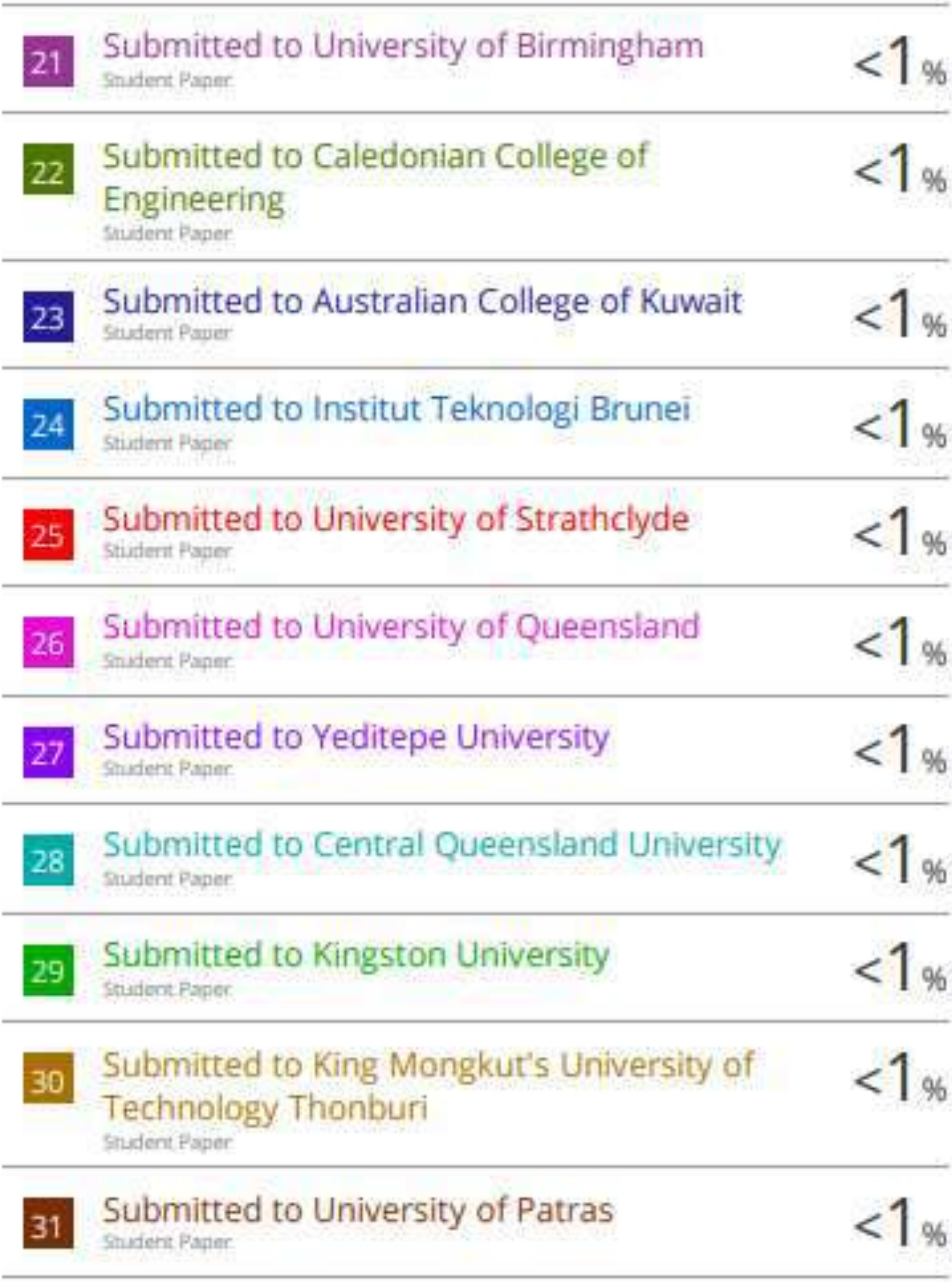

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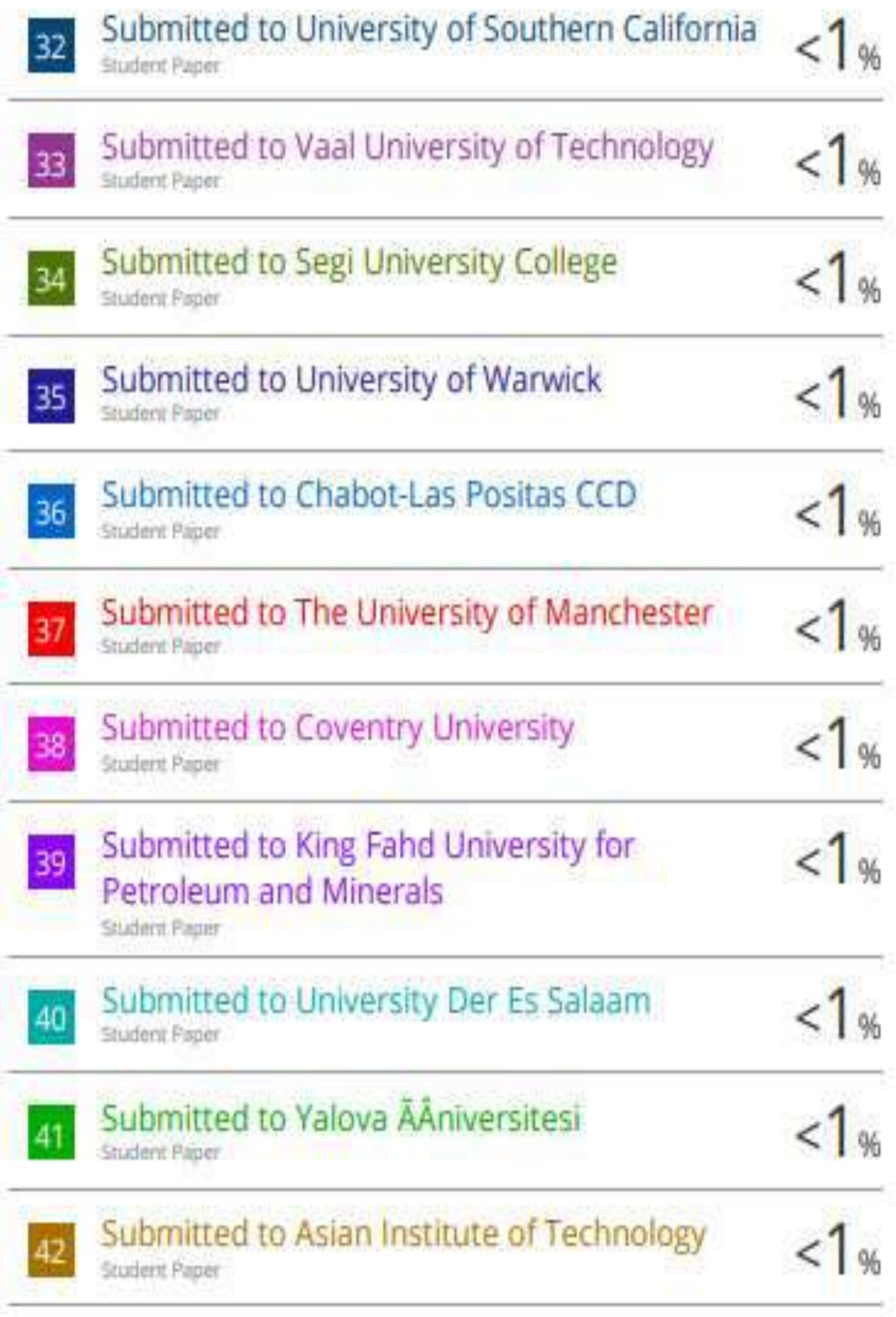

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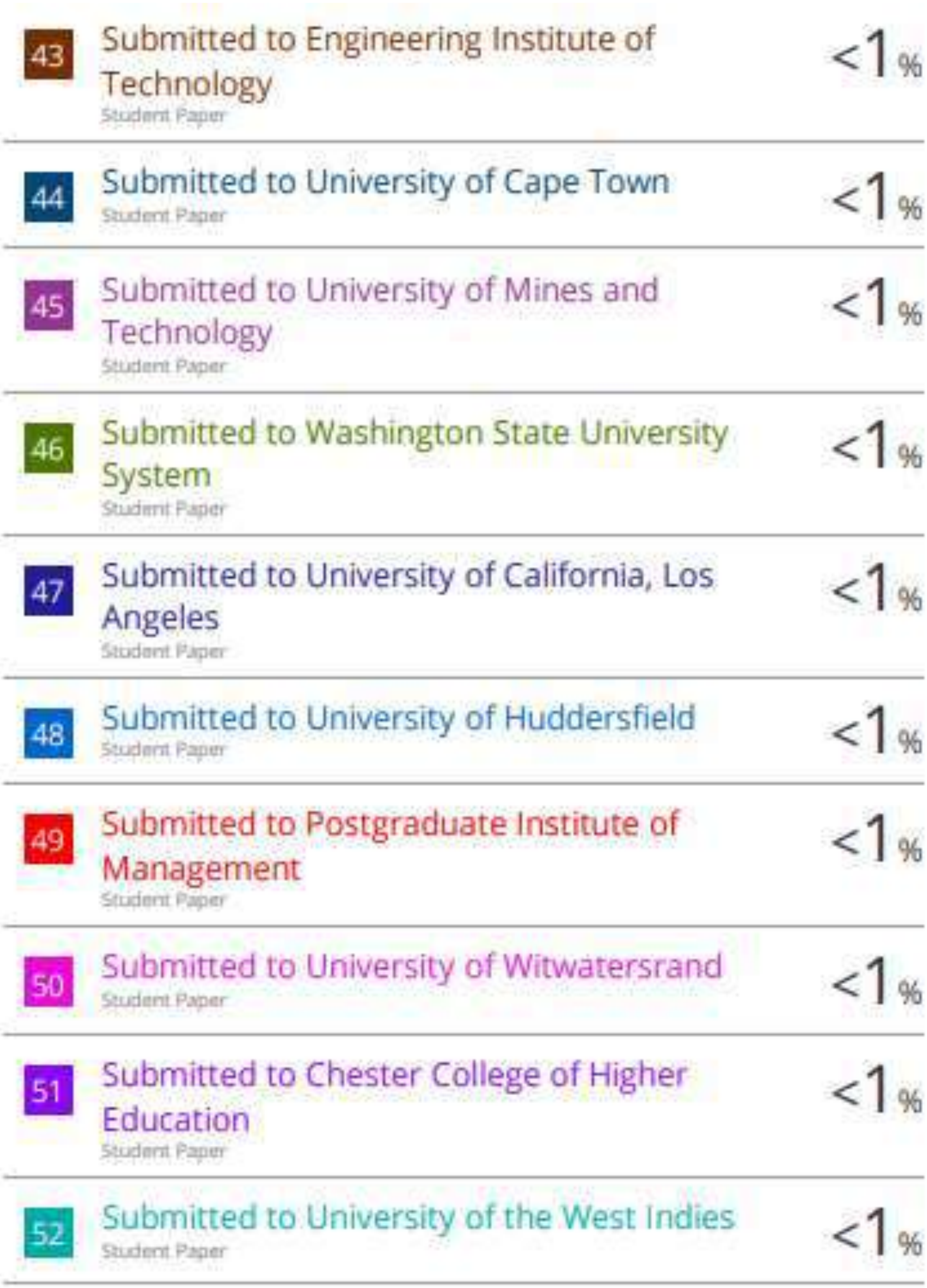

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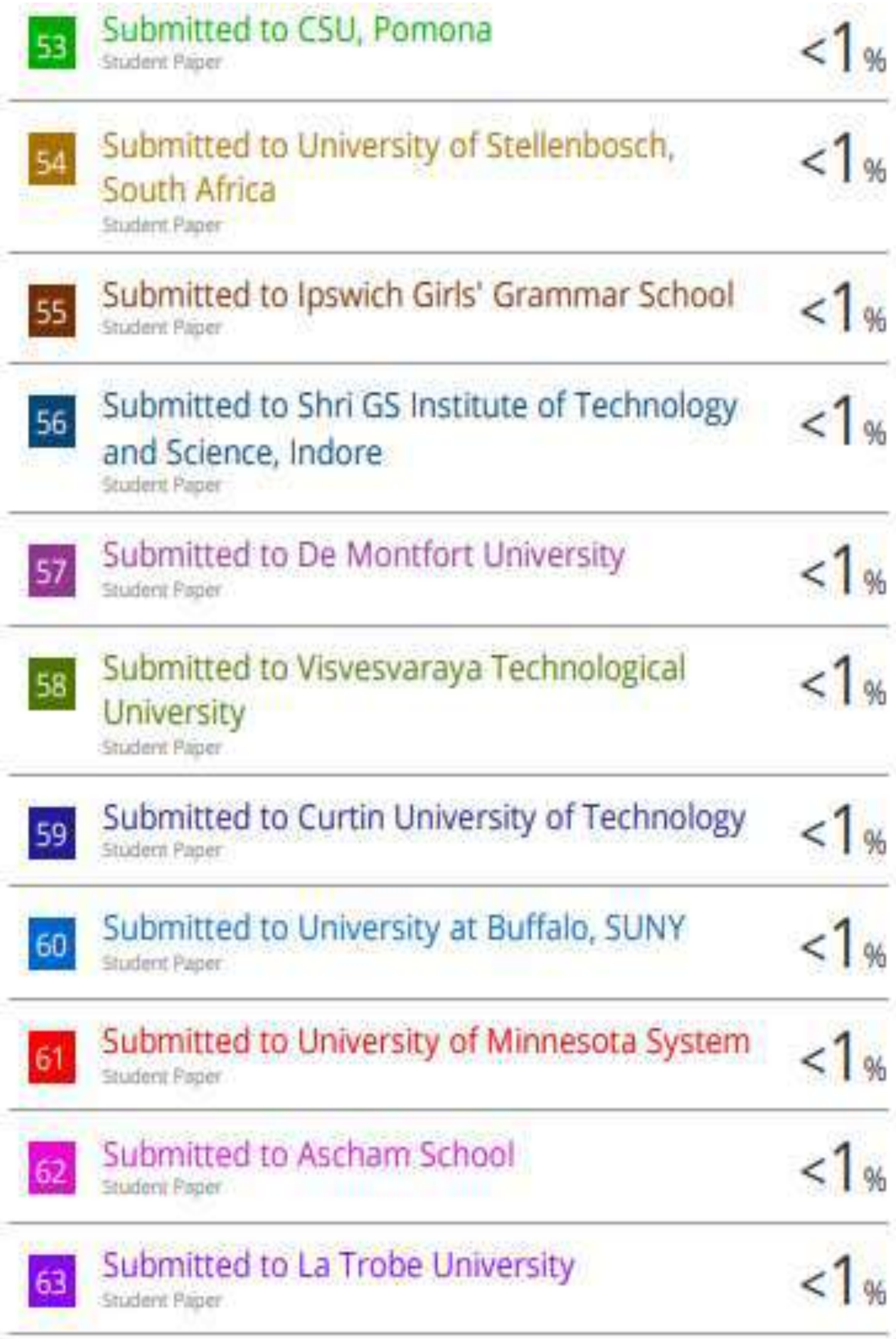

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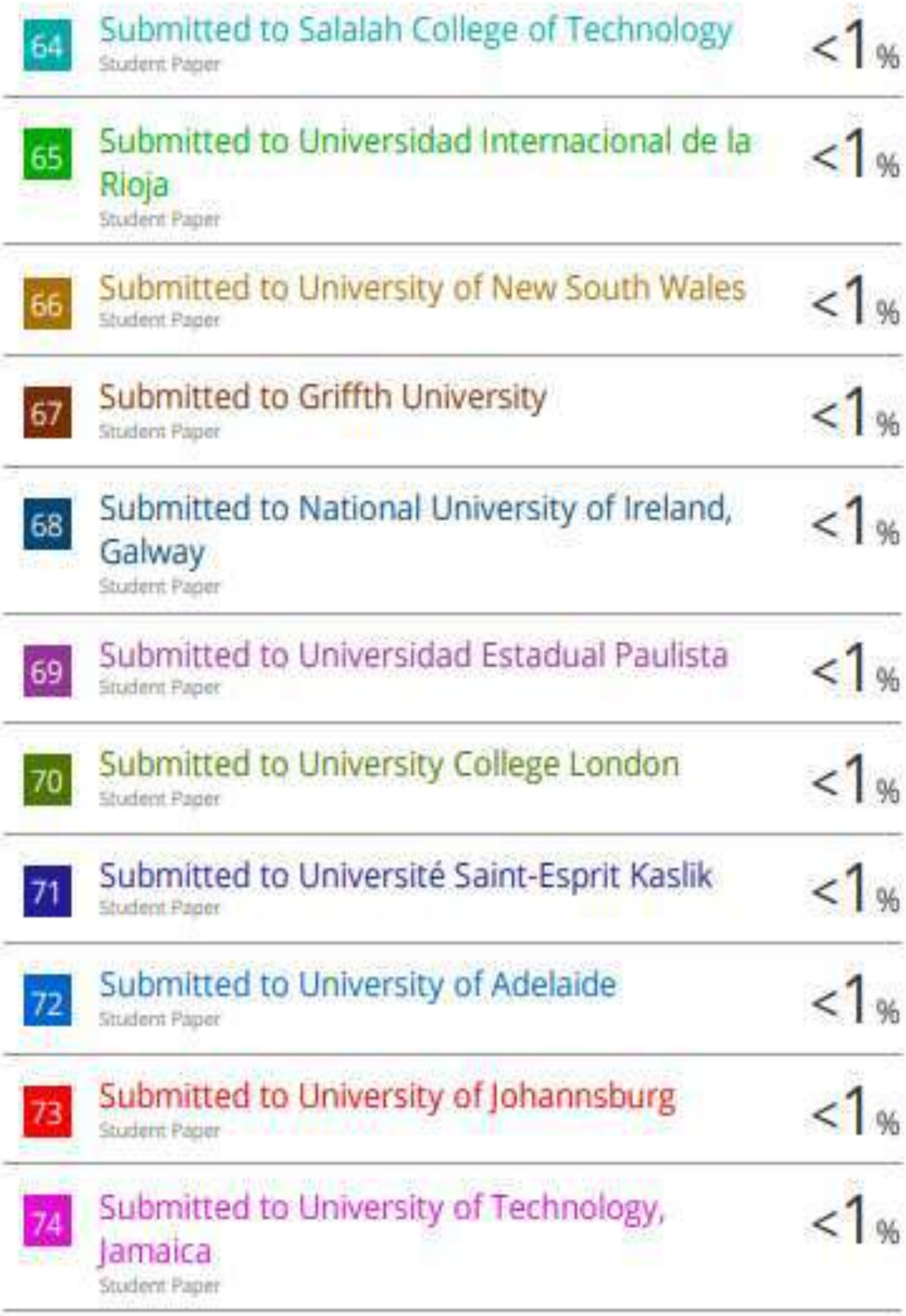

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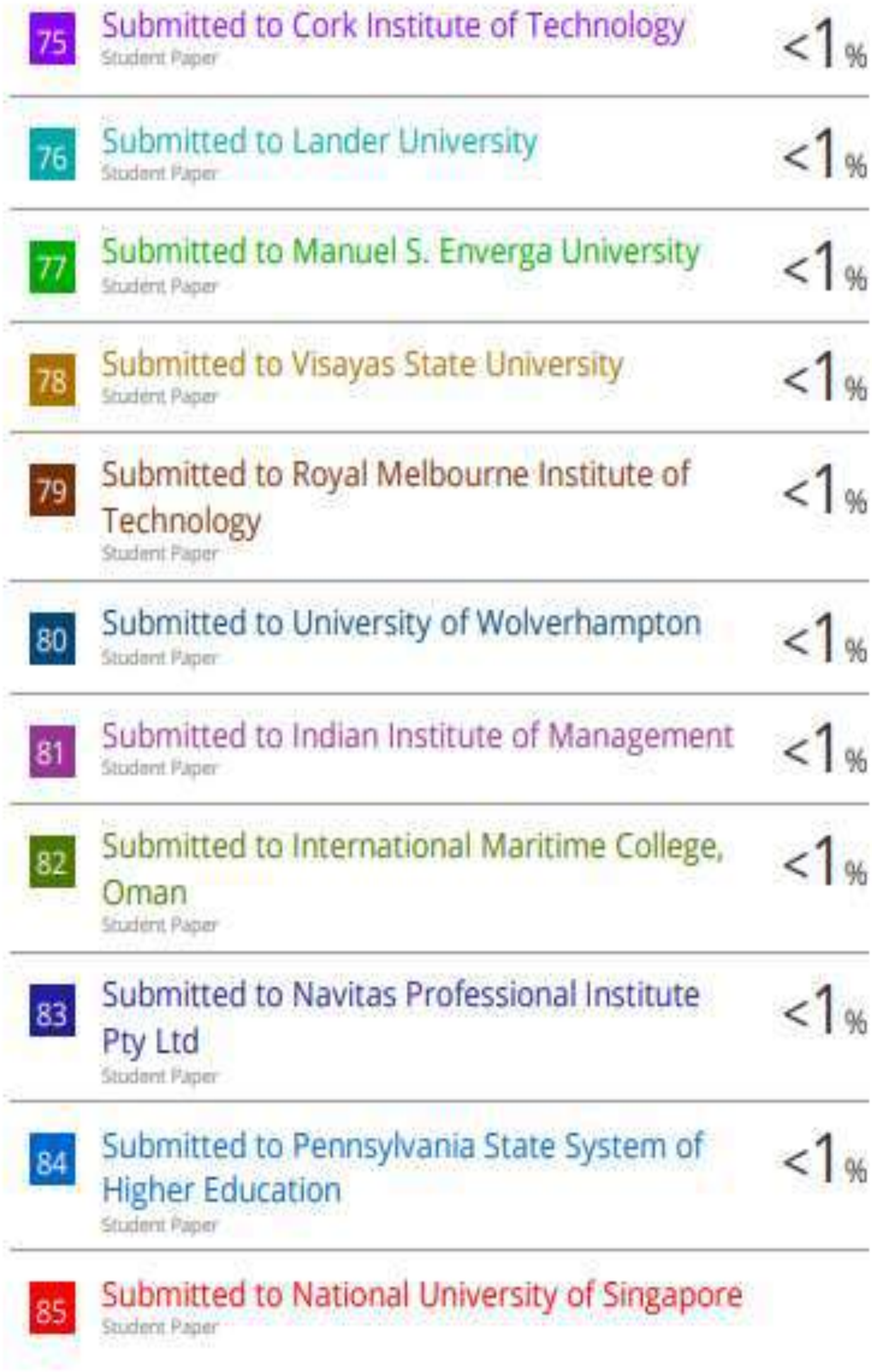

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CONGRATULATIONS

It is required to complete this Design Project in accordance with the PEC standards so it can be included in the Capstone Expo-2023 and have it uploaded to the PEC E-library.

ENGR. MIR MASOOD RASHID
Convener, PPDC, PEC

ENGR. DR. NASIR M. KHAN
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