PRODUCTION OF 13,500 TPD OF BIODIESEL FROM CHICKEN FAT

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In

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Sign: ____________

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Wah Cantt.

DEDICATED

TO OUR RESPECTED, ADMIRED, PROUD, PARENTS AND TEACHERS

&

ALL THOSE WHO GAVE THEIR YESTERDAY FOR OUR IMMACULATE PRESENT

ACKNOWLEDGEMENT

We are thankful to Almighty ALLAH who has blessed us with the courage, wisdom, and strength so that we have been able to complete this final year project report, with the help He has bestowed upon us. We are thankful to our parents who have assisted us financially, mentally and physically so that today we are proud to call ourselves as an educated and important part of the society and will be looking forward to make positive contribution to the society with the knowledge that we've required.

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ABSTRACT

Next-generation biofuels, such as cellulosic bioethanol, biodiesel, synthetic biofuels obtained via thermochemical conversion of biomass are currently at the center of the attention of technologists and policy makers in search of the more sustainable biofuel for future. But the point of concern is that the production of biodiesel from biomass (crops) will jeopardize the food security in the future, so waste material (biomass waste or animal fat) would be the sustainable option for the future biofuels (especially biodiesel). To set realistic targets for future biofuel options, it is important to assess their sustainability according to technical, economical, and environmental measures. Biodiesel is an eco-friendly and efficient fuel, that is regarded nowadays as an alternate “direct-pour” fuel to petroleum-derived diesel. Chicken fat (also known as skin fat) is a waste which is usually disposed-off in Pakistan. In this work, the technical, economical, and environmental assessment of biodiesel from waste fat (chicken fat) was assessed. Biodiesel is produced from chicken fat through a transesterification reaction in which fats reacts with an alcohol to produce methyl ester (biodiesel) and glycerol. In the current work, the complete process was designed with optimization of all process conditions (temperature, pressure etc.) for each process stage to make this project technically feasible/sustainable project. Economic analysis of this process was also made, and all economic indicators show that this is an economically viable project. With positive Present worth value and 3.8-year payback period make this project the most suitable investment. In developing countries like Pakistan, biodiesel would be the alternate and sustainable source of cheap energy (as raw material which waste fat is available at very lower price) and of course it would also reduce GHG emissions.

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CHAPTER 01

INTRODUCTION

1.1 Introduction

One of the most crucial resources for humanity's sustainable progress is energy. The energy crisis is one of the problems facing the world nowadays. Because they can be burned to create a considerable amount of energy, fuels are very important. Fuels are essential to many facets of daily life, particularly the movement of people and things. The primary energy sources related with fossil fuels are petrol, coal, and natural gas. Fossil fuels provide 80% of the energy needed by the world. [1]

Fossil fuels are a type of non-renewable energy. And as they are depleting, therefore the price of fossil fuel-based fuels is increasing. In addition, emissions from burning fossil fuels contribute to air pollution and global warming. As a result, the use of clean, renewable alternative fuels has gained attention both now and in the future.

Due to the negative environmental effects of fossil fuel-powered diesel engines and the depleting supply of petroleum, biodiesel has gained importance as a possible substitute. [1]

1.2 Biodiesel

With the aid of an enzyme, base, or acid catalyst, long-chain fatty acid mono-alkyl esters of biodiesel are created from oil. The main advantages of biodiesel are highlighted, including lower carbon to hydrogen ratio and increased oxygen content compared to traditional fuel. The emissions of particulate matter are low and there is a decrease in the amounts of Sulphur, hydrocarbons, and carbon monoxide. Biodiesel offers sustainable fuel to replace diesel and has been successfully used as blends. Biodiesel performance in cold weather depends on the blend of biodiesel, the feedstock, and the petroleum diesel characteristics. Biodiesel is rapidly biodegradable and completely non-toxic, meaning spillages represent far less of a risk than fossil diesel spillages. [2]

Oils, both edible and not, can be used to make biodiesel. Corn oil, sunflower oil, and other edible oils. Non-edible oils animal fat oil, jatropha oil. Because biodiesel has a higher cetane number (45–65 as opposed to 40–55) than regular fossil diesel, it generally has better combustion quality. However, compared to petroleum-derived diesel (2-3.5 cSt at 40°C), biodiesel has a higher viscosity (3.5-5.5 centistokes at 40°C), which makes it challenging to utilize directly in a traditional diesel engine. Alcohol (mostly methanol) use in the transesterification process has been found to be a successful method for reducing oil viscosity. [3]

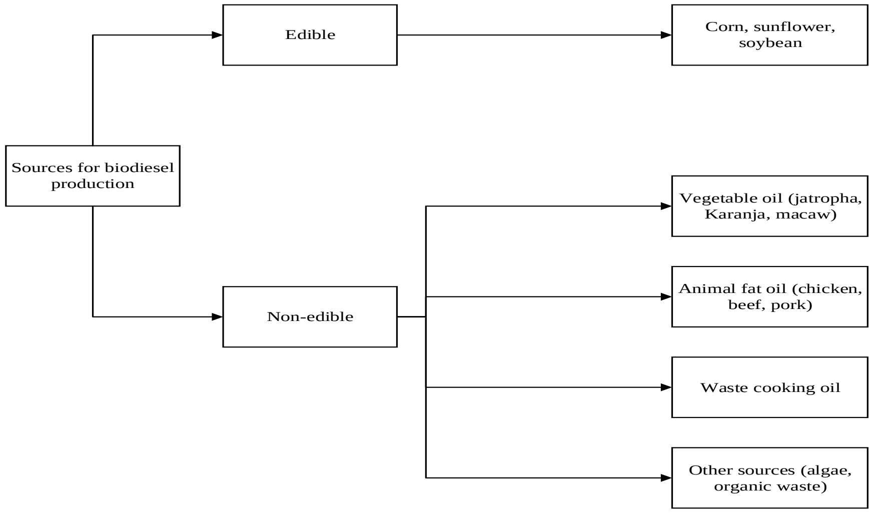


Figure 1.1: Sources of Raw Materials

1.3 Chicken Fat

By rendering chicken feathers or poultry waste, chicken fat is produced. A feather meal can yield between 2% and 12% fat. The three main fatty acids present in chicken fat are linoleic acid (20.5 wt%), palmitic acid (20.9 wt%), and oleic acid (40.9 wt%). Due to the high amount of unsaturated fatty acids in chicken fat, its corresponding methyl esters have a low level of oxidative stability. [4]

The main composition of chicken fat as follows [13]

Table 1.1: Composition of Chicken Fat

Components	Percentage (%)
Free fatty acids	15
Triglycerides	80
Water	3
Impurities	2

1.4 Methanol

The simplest aliphatic alcohol, methanol is an organic compound having the chemical formula CH_3OH (a methyl group connected to a hydroxyl group, commonly written as MeOH).

It is also known as methyl alcohol and wood spirit. It has a pronounced alcoholic fragrance resembling that of ethanol (potable alcohol), and it is a colourless, flammable liquid that is light, volatile, and volatile. Methanol was previously primarily created by the destructive distillation of wood, hence the name "wood alcohol." [5]

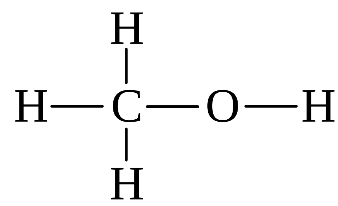


Figure 1.2: Chemical Formula of Methanol

1.5 Thermo-Physical Properties of Biodiesel

Table 1.2: Thermo-Physical Properties of Biodiesel

PROPERTY	VALUE
Density Range (kg/m^3 , at 288 K)	860–894
Cetane Number	48 – 65
Flash Point (^{o}C)	100 – 170
Pour point (^{o}C)	-15
Calorific Value (MJ/kg)	38.71
Kinematic Viscosity Range (mm^2 /s, at 313 K)	3.3-5.2
Boiling Point Range (K)	>475

1.6 Application of Biodiesel

1.6.1 Power Generation

Power generation systems have been built to use bio diesel as a fuel and use it in power generators with varied capacities. This generator uses just pure biodiesel, 100 percent. Such a power generator was utilized for the burning of biodiesel. [6]

We used bio diesel as a fuel to run the power generation plant.

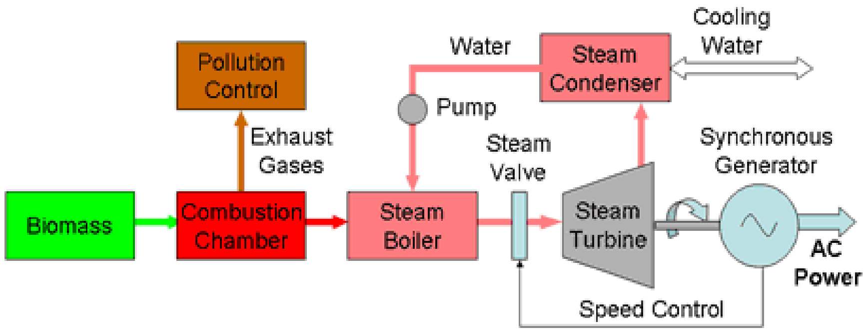


Figure 1.3: Energy Generation by Biomass

1.6.2 Oil Spill Cleanups

Cleaning up oil spills after a liquid petroleum discharge into the environment, particularly on marine ecosystems, is a labor-intensive and expensive task. Depending on the fatty acid, crude oil is soluble in biodiesel. Because bio diesel has a higher tendency than crude oil, we used it as a solvent to clean up oil spills on seashores. [6]

1.6.3 Heating of Oil

When used as a fuel to heat residential and commercial boilers, biodiesel can be based on heating oil in a variety of proportions. It is dependent on different heat application ratios. Biodiesel has a somewhat different heating system and is used in transportation. The government of some nations has enacted laws and regulations to ensure that heating oil contains a minimum of two percent (2%) biodiesel. [6]

1.6.4 Lubrication

We utilized biodiesel and Sulphur provided the lubricity to fuel, which is important when we keep the engine in good working order and to prevent from infection failure. Lubricant is used to minimize friction and allow for smooth movement. [6]

1.7 Motivation for this Project

These are some reasons from which we selected this project

- Environment friendly
- Optimize engine efficiency
- Improved safety

1.7.1 Optimum Engine Efficiency

The cetane number for that fuel mixture is increased by biodiesel, which also enhances the lubricity of the petrol. Improved fuel lubricity improves engine performance and lengthens the lifespan of its moving parts by eliminating early wear. [6]

1.7.2 Environment Friendly

Regardless of the fuel type used, engines constructed after 2010 must adhere to the same pollution standards. By default, engines driven by biodiesel emit similar emissions, however selective catalytic reduction permits conventional diesel engines to keep up with air pollution laws.

Since the gas emitted during combustion is balanced by the gas absorbed during the growth of its substrates, such as soybean, for example, biodiesel has a lower longevity rating for carbon dioxide emissions. Lower overall emissions have resulted in a significant improvement in air quality. [6]

1.7.3 Improved Safety

Freshly synthesised biodiesel has less of an environmental impact than ordinary petroleum gasoline if it is accidentally spilled. Biodiesel is less flammable and has a higher flash point than normal diesel, making it safer to handle, store, and transport. [6]

1.8 Feasibility

Chicken fat, a waste product from slaughterhouses, is the raw material needed for this method. For the manufacturing of biodiesel, low-cost and readily available feedstock's like chicken fat are also employed, along with inexpensive alcohols like methanol. Pakistan, the 11th-largest producer of poultry, will produce 1.08 billion chickens in 2020, and that number will keep rising. The bio-diesel created from chicken fat has a 97% efficiency. Carbon dioxide, carbon monoxide, and NOx and SOx emissions are quite low. Without requiring any engine changes, it may be used in engines with ease. It extends the life of engines because of its lubricity and good chemical and physical qualities. [7]

1.9 Shipping of the Biodiesel

The transportation tank needs to be made to accommodate biodiesel's tendency to reach greater temperatures than petroleum-based fuel, which is an issue. We must confirm that the shipping container has been thoroughly cleaned and that the tank is empty. Because biodiesel can be permitted to freeze in the tank before being heated at the destination, if the fuel can be delivered in cold weather, the tank may need insulation or heating. [8]

1.10 Storage and Handling of Biodiesel

Before transferring biodiesel, make sure the tank is dry and the transportation container has been cleaned (unless it has already transported Petro-diesel or biodiesel). If transporting biodiesel in cold weather, the tank might need insulation or heating. Alternatively, you may freeze the biodiesel in the tank and then thaw it out when you arrive there. Make sure the tank is dry and the transportation container has been cleaned (unless it has already transported Petro-diesel or biodiesel) before transferring biodiesel. [9]

1.11 Market Assessment

Over the past ten years, the biodiesel and renewable diesel industries have steadily expanded, and there are now industrial production facilities from coast to coast. When industry production

for the first time surpassed one billion gallons in 2011, it marked an important turning point. The market increased in size to more than two billion gallons by 2015. According to EPA data, the market has 2.8 billion gallons in 2019. The industry's overall output has consistently exceeded the Federal Renewable Fuel Standard's biodiesel requirement and has been sufficient to meet the majority of the Advanced Biofuel requirement. [10]

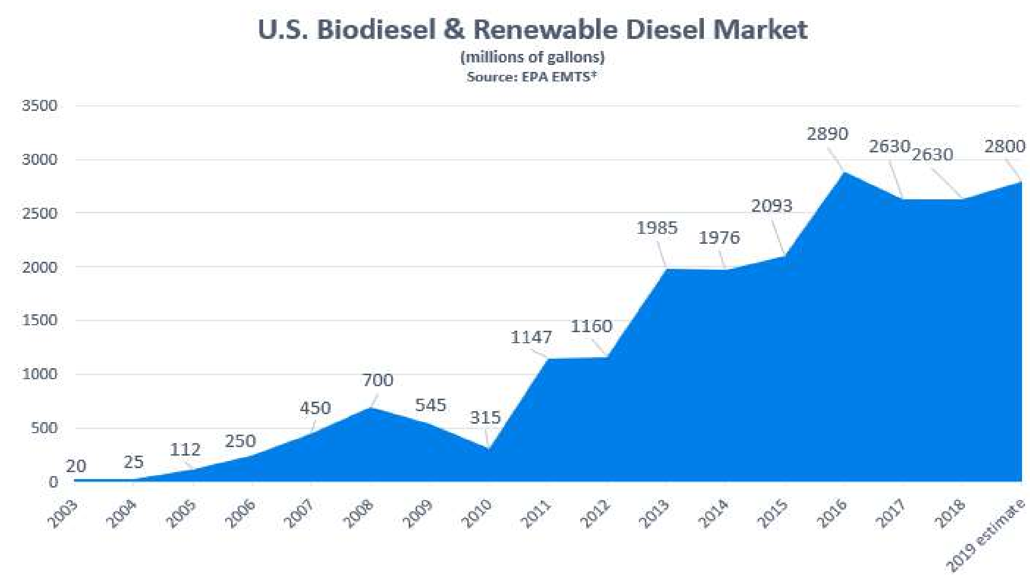


Figure 1.4: Market Assessment of Biodiesel

1.12 Bio-diesel Production and Consumption

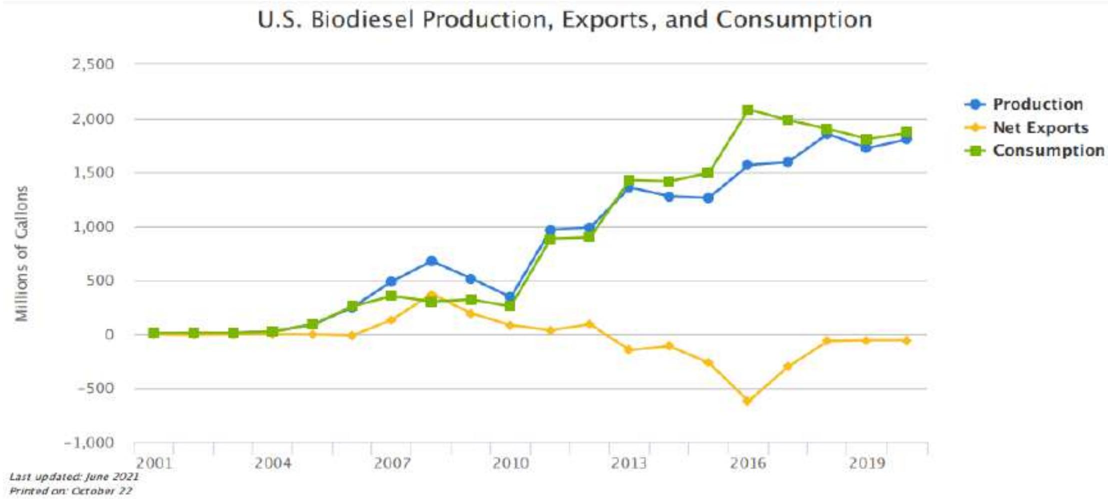


Figure 1.5: Biodiesel Production and Consumption

From 2001 to 2020, this graph displays the production, exports, and consumption trends for biodiesel in the United States. The European Union's biodiesel tax credit had an unforeseen consequence that led to the peak in biodiesel exports in 2008. After the effect was reversed, exports decreased. Beginning in 2011, the Renewable Fuel Standard is mostly to blame for the rising production and consumption. A greater amount of biodiesel was imported than was exported in 2013, as seen by the net export of biodiesel turning negative. Due to tighter regulation and ongoing attempts to minimise greenhouse gas emissions, there has likely been an increase in net exports since 2013. [10]

CHAPTER 02

MANUFACTURING PROCESSES

2.1 Introduction

Biodiesel is commercially produced by using only one technique known as transesterification. For the creation of biodiesel, the transesterification process involves the reaction of alcohol with free fatty acids (TAG) in the presence of a catalyst. They difference in process occurs depending on the type of catalyst employed

The commercially available process for the manufacturing of biodiesel comes in the two categories

- Transesterification using homogenous catalyst
- Transesterification using heterogeneous catalyst

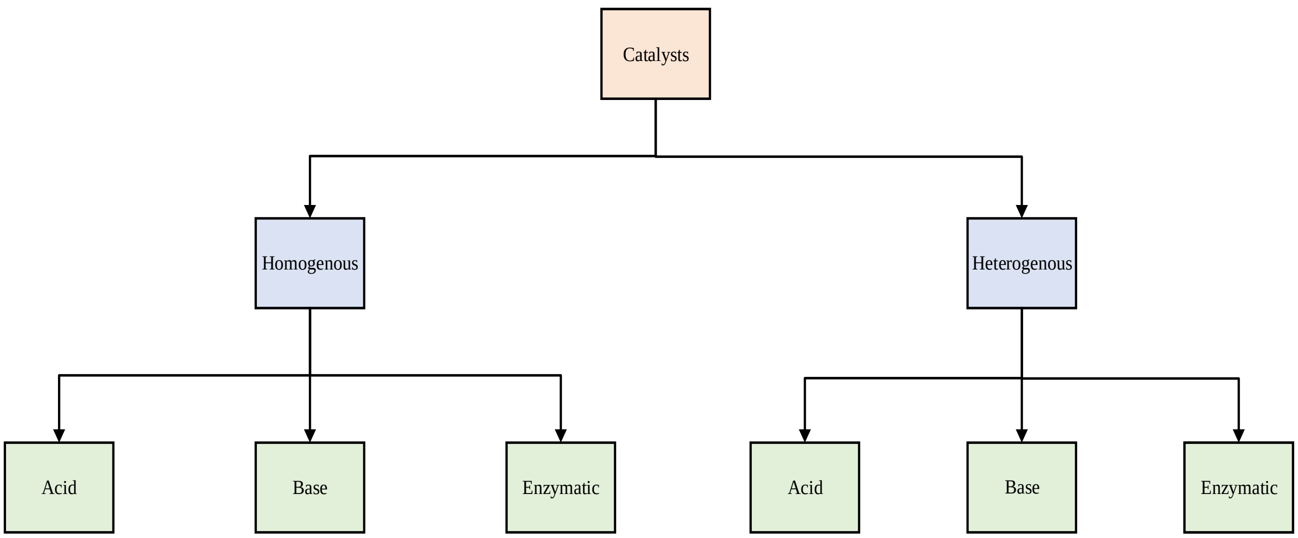


Figure 2.1: Types of Catalysts

2.2. Transesterification using Homogenous Catalyst

The main benefit of homogeneous catalysts is that they operate in the same phase of the reaction mixture, which reduces the mass transfer resistance. Catalysts are basic, acidic, or enzymatic, depending on their nature. Compared to the heterogeneous catalyst, these types of catalysts take less time for higher yields and conversion. [11]

The homogeneous basic catalysts that are easily soluble in methanol, such as NaOH and KOH, are currently utilized the most in the biodiesel industry. Homogeneous basic catalysts have an advantage over homogeneous acid catalysts in that they may produce a high yield of biodiesel quickly and under generally tame operating conditions. Such catalytic systems should not be employed with low grade fat feedstock, which has a high concentration of FFA and moisture, since high purity feedstocks are necessary. The FFA interacts with the basic catalyst to create soaps, reducing the yields of biodiesel and causing catalyst losses.

The transesterification reaction can be carried out in two steps to get around this problem. Alkali transesterification is done after the feedstock has been pretreated with an acid catalyst to lower the level of FFAs and convert them into esters. [11]

2.3 Transesterification using Heterogeneous Catalyst

Heterogeneous or solid catalysts can be easily recovered, refurbished, and used once more. Depending on their makeup, they can be basic, like hydrotalcite and alkaline earth metal oxides (CaO, MgO), acidic, like zirconia and alumina-based catalysts, or enzymatic, like immobilized lipase. [11]

High FFA and water content have a comparable effect on solid basic catalyst performance to homogeneous basic catalysts. Solid acid catalysts are less demanding to operate under harsh conditions than solid basic catalysts, which are also more active. Since catalysts that are solid have lower conversions than homogeneous catalysts, they need more difficult reaction conditions to accomplish the same conversions.

The leaching of the active phase into the reaction mixture should also be taken into account. The contribution is homogeneous as a result of the catalyst leaching. The quality of the biodiesel as well as the catalysts' life expectancy are both impacted by how much leaching occurs. For these reasons, it is necessary to reuse the heterogeneous catalyst and prevent it from leaching. [11]

2.4 Transesterification using Enzyme Catalyst

As catalysts for the production of biodiesel when used in their free state, lipases fall into the heterogeneous category when they are immobilized. Compared to other catalysts, enzymes are more selective, yield purer end products (biodiesel and glycerin), and don't create soap. Enzymes can catalyze the esterification reaction for FFA and the transesterification reaction for triglycerides, which is similar to homogeneous or heterogeneous acid catalysis. Its main downsides are its high cost and possibility for enzyme inactivation by short chain alcohols and products. [11]

2.5. Reaction Occurring

$$\text{T.G} + 3\text{Methanol} \xleftrightarrow{\text{Catalyst}} 3\text{methyl ester} + \text{glycerol}$$

2.6. Block Flow Diagram of Transesterification Process

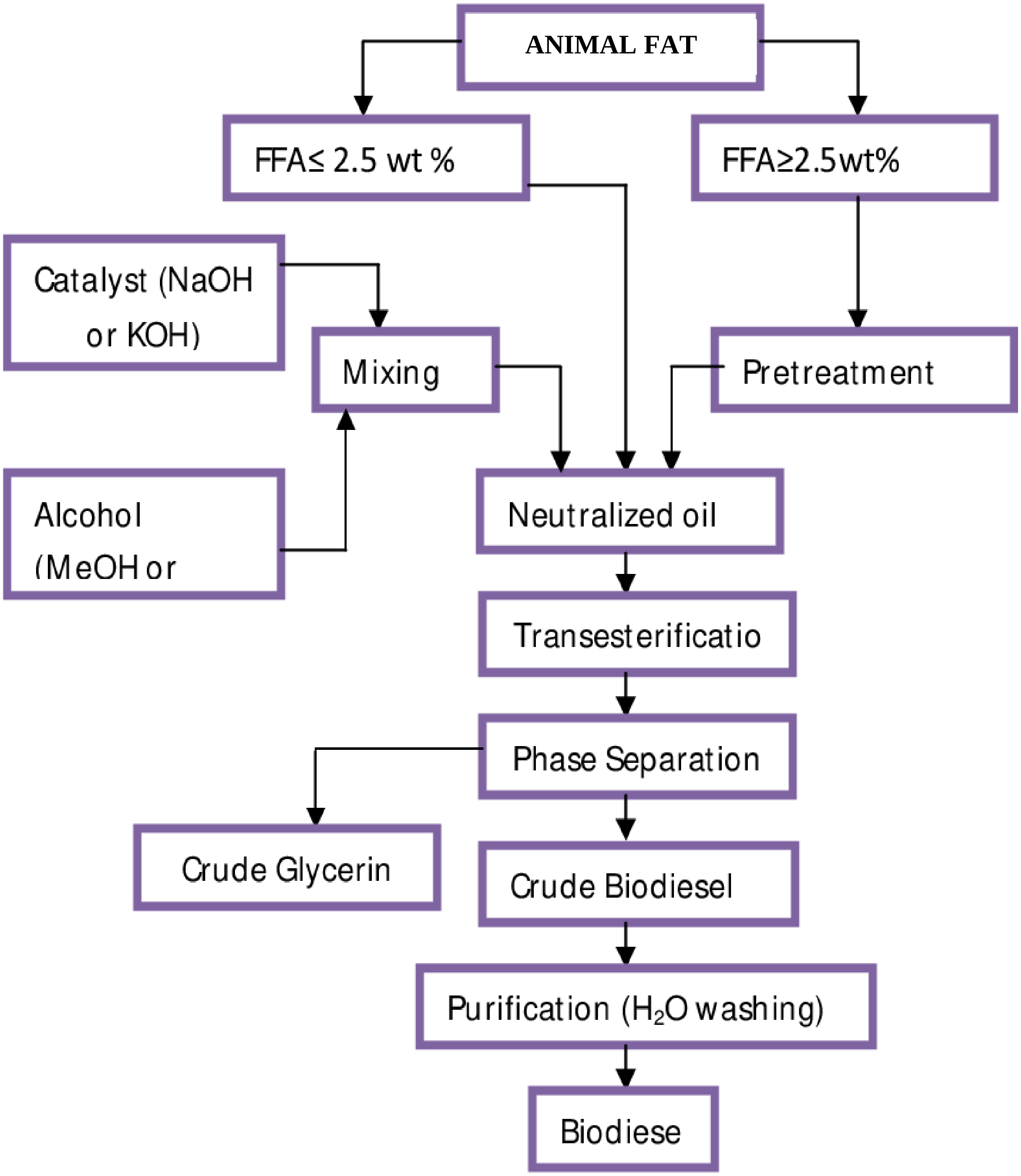


Figure 2.2: Block Flow Diagram of Transesterification of Biodiesel

2.7. Process Comparison

Table 2.1: Process Comparison

PARAMETERS	HOMOGENOUS CATALYST	HETEROGENOUS CATALYST	ENZYME CATALYST
Catalyst	KOH	CaO	Lipase
Residence time	1-2 hr	5 hr	8-70hr
Operating Temperature (°C)	60	180-220	30-50
Yield (%)	94.8	88.5	97
Catalysts de-activation	No	No	Yes
Operating Pressure	1 atm	1 atm	1 atm
Glycerol recovery	Simple	Difficult	Simple

2.8 Process Selection

We have selected “Transesterification with homogenous catalyst” due to following reasons:

- Inexpensive catalyst.
- Operating temperature and pressure conditions are quite reasonable
- Yield of the process is relatively high
- No soap formation due to pre-treatment

2.9. Process Description

The process is divided into 3 main parts:

- Pre-treatment
- Transesterification
- Purification

2.9.1 Pre-treatment

- **Physical Treatment**

In this section, chicken fat is transported to the heater by means of a screw conveyer. On the screw conveyer a certain amount of water is sprayed on the chicken fat. This is done in order to remove any impurities or dirt from it and also it will reduce the size of chicken fat. This process will cause some of the water to go with the fat into the heater. So, the fat is heated at 110^o C in order to remove the water and melts the fat into the oil. Here the heater which is used is a kettle type heat exchanger. After that the oil is filtered out by using a drum filter in order to remove collagen material from the oil.

- **Esterification**

Esterification is used in the chemical process to minimize the free fatty acids in the chicken oil. Esterification is the process in which FFA reacts with alcohol to produce methyl ester and water This is done to reduce the amount of free fatty acids (15 w/w %) to less than 1%. Because higher amount of FFA can cause scaling, soap formation as well as decrease the yield. Here FFA reacts with methanol in the presence of H_2SO_4 as a catalyst to form methyl ester (biodiesel) and water at 60^o C. The catalyst used is 5% of the FFA weight. The methanol to FFA ratio is 20:1. Here the conversion is 92%. The level of FFA is reduced to less than 0.5 wt.% after the esterification. The reaction is as follows [12]

$$\text{FFA + Methanol} \xrightarrow{H_2SO_4} \text{methyl ester + water}$$

- **Removal of Methanol**

After that methanol is removed from the mixture using a distillation column so that it can be reused in the reaction.

- **H_2SO_4 Recovery and Water Removal**

The catalyst H_2SO_4 also acts as a dehydrating agent so it dissolves in water that is formed in the reaction. Also, the water in the mixture is not suitable as it starts hydrolysis of the main product. So, by using a decanter we remove the H_2SO_4 and water mixture.

2.9.2 Transesterification

This is the main section of the process.

In this process triglycerides (TG) reacts with methanol in the presence of the catalyst KOH and in result methyl ester and glycerol is produced. The feed will enter the reactor at 60^o C and at 1 atm. As the reaction is reversible so excess methanol will be used so that the reaction will move forward. The ratio of methanol to oil used is 6:1. The conversion of the process is 99%. The catalyst is dissolved in methanol before adding in the oil, the reason is that it minimizes the chances of soap production. The retention time is 1 hour.

$$\text{Triglyceride + Methanol} \longleftrightarrow \text{diglyceride + Biodiesel}$$

$$\text{Diglyceride + Methanol} \longleftrightarrow \text{monoglyceride + Biodiesel}$$

$$\text{Monoglyceride + Methanol} \longleftrightarrow \text{glycerol + Biodiesel}$$

Overall Reaction

$$\text{Triglyceride + 3 Methanol} \overset{\text{KOH}}{\longleftrightarrow} \text{3 Biodiesel + Glycerol}$$

2.9.3 Purification

After the biodiesel is produced, it is taken for post treatment in order to remove the impurities. This is the last part in the process and it is also known as post treatment,

- **Methanol Removal**

At first methanol is removed in the distillation column. Along with methanol some amount of water also comes. The methanol removed is 99% pure.

- **Recovery of KOH and Glycerol Removal**

Then two decanters are used, the first one removed KOH and the second one will remove glycerol. The recovered methanol and KOH are again used in the reaction.

- **Washing of Biodiesel**

Then the biodiesel is washed using hot water the temperature of which is 50^o C. the amount of water used is 5 w/w % of biodiesel. This step will remove impurities from the biodiesel. After washing the extra water is removed using an evaporator. The steam given to the evaporator is at 110^o C. the biodiesel obtained at the end of the process is 98.5% pure.

2.10 Capacity Selection

Gross calorific value of biodiesel = 38.71 MJ/kg = 38.71×10^6 J/kg [14]

Total power plants on imported fuel = 14

Capacity of power plants on imported fuel = 6000 MW = 6000×10^6 $kg.m^2. s^{-3}$

$$\text{Power} = \text{gross calorific value} \times \text{mass flow rate} \qquad \textbf{2.1}$$

$$\text{Mass flow rate} = \frac{\text{power}}{\text{gross calorific value}}$$

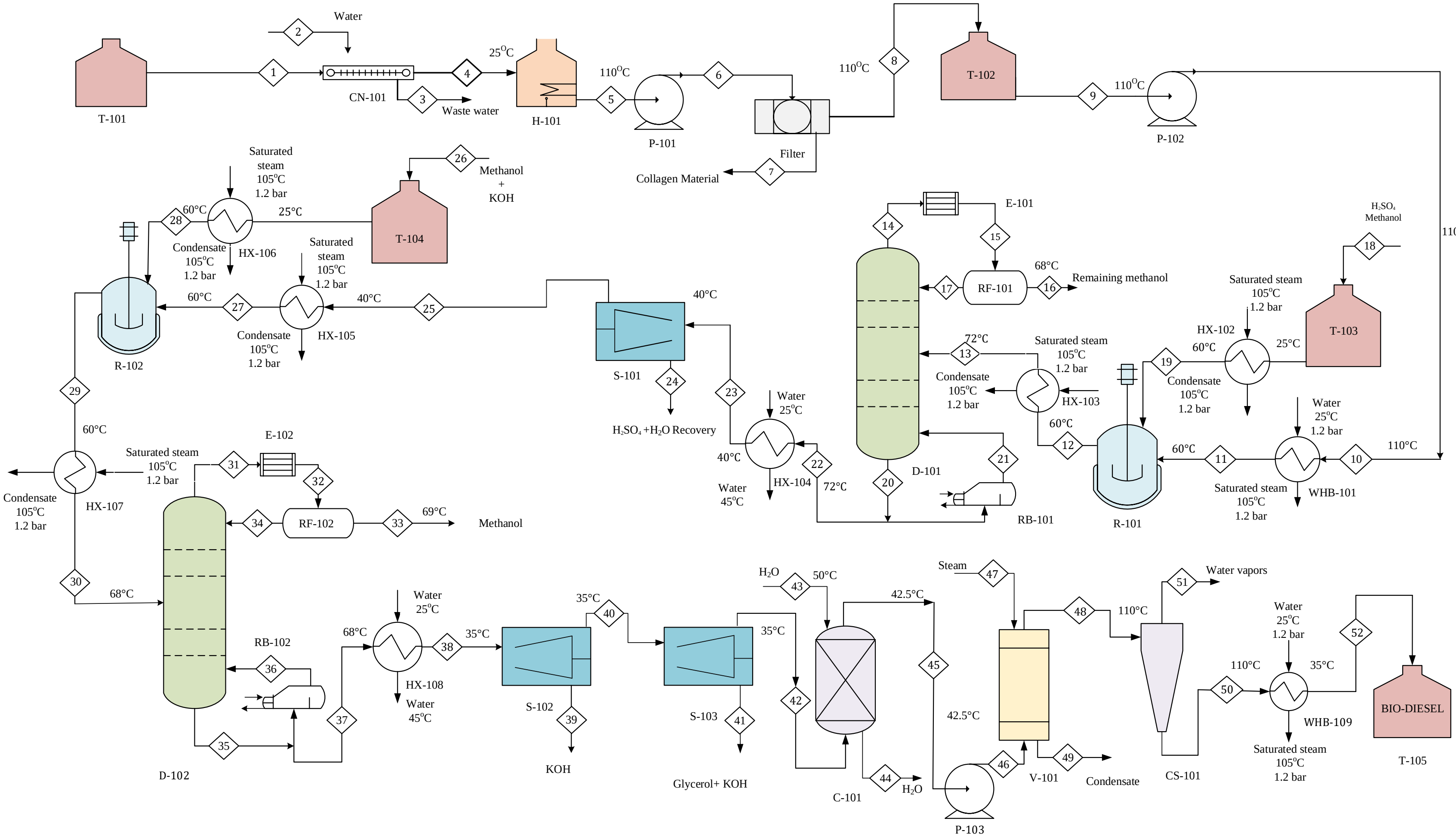
$$= \frac{6000 \times 10^6}{38.5 \times 10^6}$$

$$= 155 \text{ kg/s}$$

$$= \frac{155 \text{ kg}}{\text{s}} \times \frac{60 \text{ sec}}{1\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{1 \text{ day}} \times \frac{1 \text{ ton}}{1000 \text{ kg}}$$

$$= 13{,}392 \approx 13{,}500 \text{ tons/day}$$

Biodiesel required to produce 6000 MW = 13,500 ton/day



T-101…105	WHB-101,109	H-101	RB-101,102	P-101…103	R-101,102	D-101,102	HX-102...107
Tank	Waste Heat Boiler	Heater	Reboiler	Pump	Reactor	Distillation Column	Heat Exchanger
S-101…103	**CN-101**	**C-101**	**V-101**	**CS-101**	**E-101,102**	**RF-101,102**	
Decanter	Conveyor Belt	Column	Evaporator	Cyclone Separator	Condenser	Reflux Drum	

Figure 2.3: Process Flow Diagram

CHAPTER 03

MATERIAL BALANCE

Introduction

Mass of a chemical system is conserved. Mass entering the system will equal mass leaving the system for steady-state conditions. The terms in the material balance are those of the system mass and the streams entering and leaving the system. Material balances for the chemical processes studied were based on data from literature sources with the production scales assumed according to estimated market demand and economy of scale. Material balance simply compares the original volumes at initial reservoir pressure to the current volumes at a lower pressure.

Basic Equation of Material Balance

(Rate of mass input) - (Rate of mass output) ± (Rate of mass generation/consumption) ± (Rate of mass Accumulation/ Depletion) = 0

Basis

1hr of operation

Assumption

Plant is running at Steady state condition

Capacity of Plant

13,500 Tons Per Day

Production Rate

13,500 tons	1000 kg	1 day
day	ton	24 hr.

=562,500 kg/hr

Yield = 94% [15]

Reactant Supplied

$$\text{reactants flowrate} = \frac{\text{biodiesel produced}}{\text{yield}} \quad \textbf{3.1}$$

= 598404.3 kg/hr

Table 3-1: Composition of Raw Material

Composition of raw material	wt%	Mass flow rate (kg/hr)
FFA	15%	89760.6
TG	80%	478723.4
Water	3%	17952.1
Impurities	2%	11968.1

Table 3.2: Molecular Weights

Components	Molecular weights (kg/kmol)
FFA	282.5
TG	885.5
Methanol	32
Methyl ester	296.5
Water	18
Glycerol	92
KOH	56
H_2SO_4	98.1

3.1 Material Balance around Reactor (R-101)

In this reactor esterification of the free fatty acids is done to reduce the free fatty acids to less than 1%. This prevents the soap formation in the biodiesel and maintains the yield.

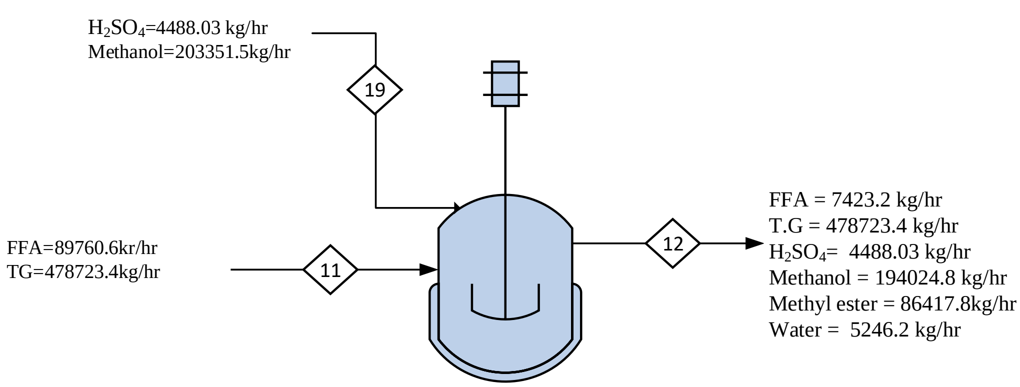


Figure 3.1: Material Balance on R-101

Chemical Reaction

$$\underset{\text{FFA}}{RCOOH} + \underset{\text{alcohol}}{CH_3OH} \xrightarrow{H_2SO_4} \underset{\text{biodiesel}}{RCOOCH_3} + \underset{\text{water}}{H_2O}$$

Conversion

91.7%

H_2SO_4 Required

= 5% of FFA [6]

= 89760.6 x 0.5

=4488.03 kg/hr

Methanol Required

1 FFA: 20 methanol [16]

= 6354 x 32

= 194024.8 kg/hr

FFA Converted

= 89760.6 x 0.917

= 82337.4 kg/hr (291.4 kmol/hr)

FFA Unconverted

= 89760.6 – 82337.4

= 7423.2 kg/hr

Methyl Ester Produced

= 291.4 x 296.5

= 86417.8 kg/hr

Methanol Converted

= 291.4 x 32

= 9326.7 kg/hr

Methanol Unconverted

= 203351.5 – 9326.7

= 194024.8 kg/hr

Water Produced

= 291.4 x 18

= 5246.2 kg/hr

Table 3.3: Mass Flow Rates in Reactor

Components	Input (kg/hr)		Output (kg/hr)
	Stream 11	**Stream 19**	**Stream 12**
FFA	89760.6	0	7423.2
TG	478723.4	0	478723.4
H_2SO_4	0	4488.03	4488.03
Methanol	0	203351.5	194024.8
Methyl ester	0	0	86417.8
Water	0	0	5246.2
Total	**776323.6**		**776323.6**

3.2 Material Balance around Distillation Column (D-101)

It recovers 99% of methanol for reuse

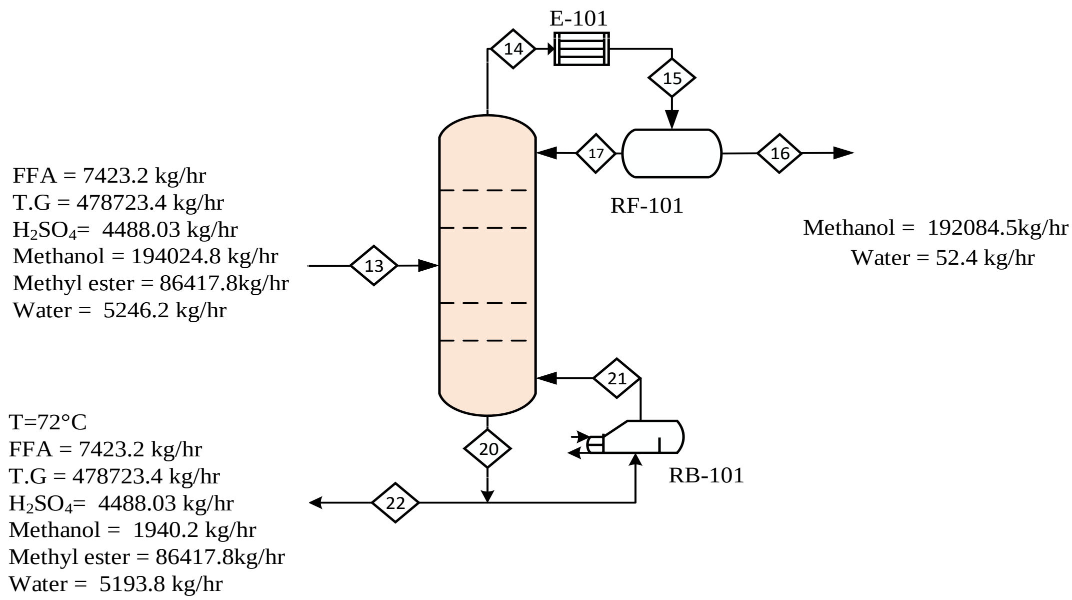


Figure 3.2: Material Balance on D-101

Applying Overall Material Balance

$$F = D + W \quad (3.2)$$

Methanol in Distillate (99%)

= 194024.8×0.99

=192084.5 kg/hr

Methanol in Bottom (1%)

= 194024.8-192084.5

=1940.2 kg/hr

Water in Distillate (1%)

= 5246.2×0.01

=52.4kg/hr

Water in Bottom (99%)

=5246.2-52.4

=5193.8kg/hr

Table 3.4: Mass Flow Rates in Distillation Column

Components	Input (kg/hr)	Output (kg/hr)	
	Stream 13	**Stream 16**	**Stream 22**
FFA	7423.2	0	7423.2
TG	478723.4	0	478723.4
H_2SO_4	4488.03	0	4488.03
Methanol	194024.8	192084.5	1940.2
Methyl ester	86417.8	0	86417.8
Water	5246.2	52.4	5193.8
		192137.03	584186.5
Total	**776323.6**	**776323.6**	

3.3 Material Balance around Decanter (S-101)

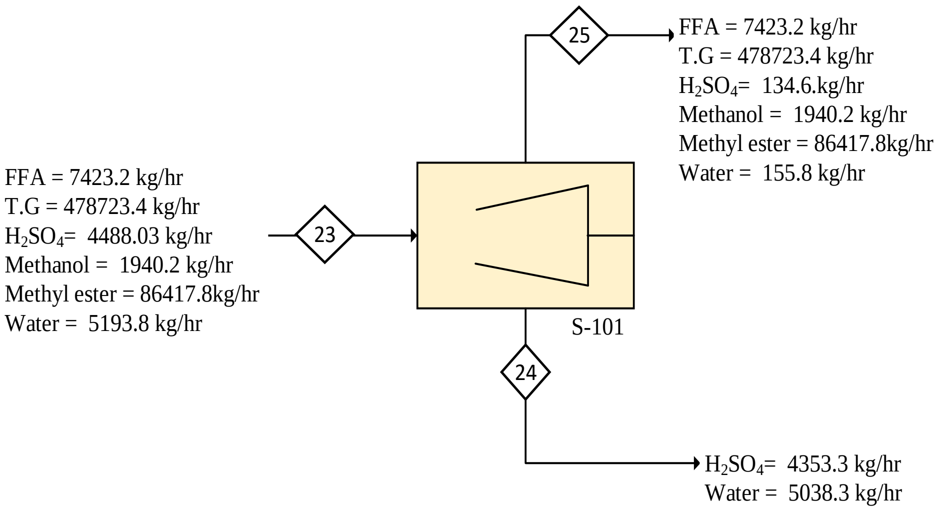


Figure 3.3: Material Balance on S-101

Efficiency

$$= 97\%$$

Water Removed

$$= 5193.8 \times 0.97$$

$$= 5038 \text{ kg/hr}$$

Water Retained

$$= 5193.8 - 5038$$

$$= 155.8 \text{ kg/hr}$$

H_2SO_4 Removed

$$= 4488 \times 0.97$$

$$= 4353.39 \text{ kg/hr}$$

H_2SO_4 Retained

$$= 4488 - 4353.4$$

$$= 134.6 \text{ kg/hr}$$

Table 3.5: Mass Flow Rates in Decanter

Components	Input (kg/hr)	Output (kg/hr)	
	Stream 23	**Stream 25**	**Stream 24**
FFA	7423.2	7423.2	0
TG	478723.4	478723.4	0
H_2SO_4	4488.03	134.6	4353.3
Methanol	1940.2	1940.2	0
Methyl ester	86417.8	86417.8	0
Water	5193.8	155.8	5038.0
		574795.1	9391.3
Total	**584186.5**	**584186.5**	

3.4 Material balance around Reactor (R-102)

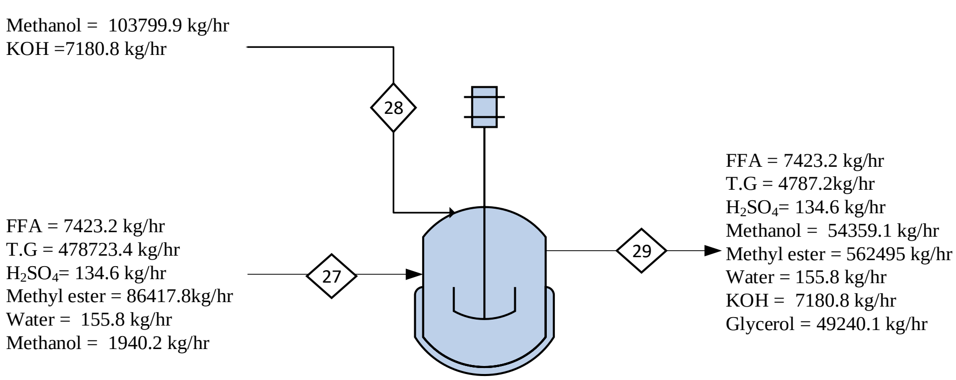


Figure 3.4: Material Balance on R-102

Reactions

$$\text{Triglyceride + Methanol} \xleftrightarrow{\text{KOH}} \text{diglyceride + Biodiesel}$$

$$\text{Diglyceride + Methanol} \xleftrightarrow{\text{KOH}} \text{monoglyceride + Biodiesel}$$

$$\text{Monoglyceride + Methanol} \xleftrightarrow{\text{KOH}} \text{glycerol + Biodiesel}$$

Overall Reaction

$$\text{Triglyceride} + 3\ \text{Methanol} \xleftrightarrow{KOH} 3\ \text{Biodiesel} + \text{Glycerol}$$

As diglyceride and monoglyceride are completely converted, therefore we will consider the overall reaction

Conversion

= 99%

KOH Required

1.5 wt% of T.G [17]

= 478723.4 x 1.5/100

= 7180.8 kg/hr

TG Required

1TG: 6 Methanol [17]

540.6 TG: 3243.6 Methanol

TG Converted

= 478723.4 x 0.99

= 473936.2 kg/hr

= 535.2 kmol/hr

TG Unconverted

= 4788723.4 – 473936.2

= 4787.2 kg/hr

Methyl Ester Produced

1 TG: 3 Methyl esters

= 1605.7 x 296.5

= 4706077 kg/hr

Glycerol Produced

1 TG: 1 Glycerol

= 535.2 x 92

=49240.1 kg/hr

Table 3.6: Mass Flow Rates in Reactor 2

Components	Input (kg/hr)		Output (kg/hr)
	Stream 27	**Stream 28**	**Stream 29**
FFA	7423.2	0	7423.2
TG	478723.4	0	4787.2
H_2SO_4	134.6	0	134.6
Methanol	1940.2	103799.9	1940.2 + 52418.9
Methyl ester	86417.8	0	86417.8 + 476077
Water	155.8	0	155.8
KOH	0	7180.8	7180.8
Glycerol	0	0	49240.1
	574795.2	110980.8	88358.1+ 597417.9
Total	**685776.03**		**685776.03**

3.5 Material Balance around Distillation Column (D-102)

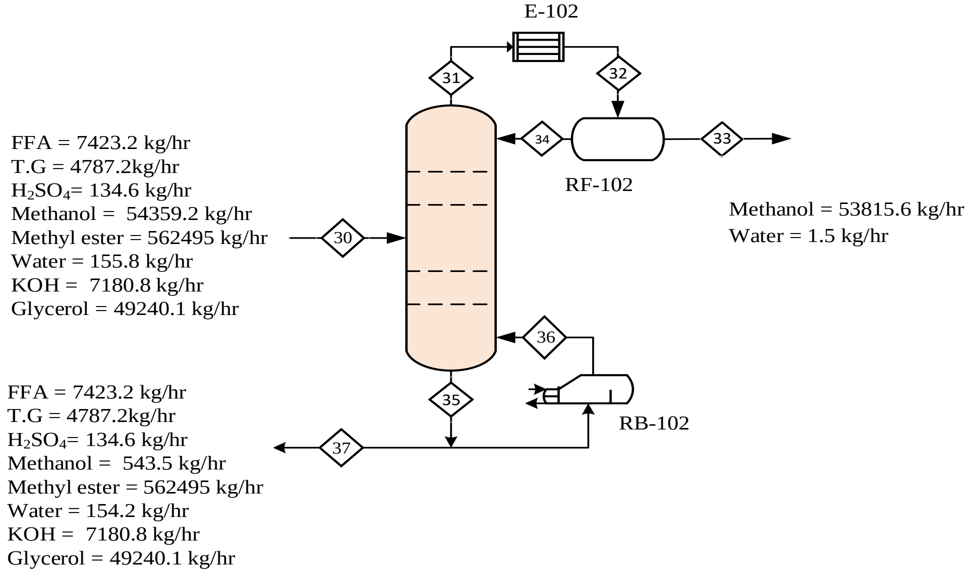


Figure 3.5: Material Balance on D-102

Applying Overall Material Balance

$$F = D + W$$

As methanol recovery from distillation column is 99% (from literature) So, there will be 1% of water in distillate as water has the least boiling point in the mixture

Methanol in Distillate (99%)

= 54359.1×0.99

=53815.6 kg/hr

Methanol in Bottom (1%)

= 54359.1-53815.6

=543.6 kg/hr

Water in Distillate (1%)

= 155.8×0.01

=1.5 kg/hr

Water in Bottom (99%)

= 155.8-1.5

=154.2 kg/hr

Table 3.7: Mass Flow Rates in Distillation Column 2

Components	**Input (kg/hr)**	**Output (kg/hr)**	
	Stream 30	**Stream 33**	**Stream 37**
FFA	7423.2	0	7423.2
TG	4787.2	0	4787.2
H_2SO_4	134.6	0	134.6
Methanol	54359.2	53815.6	543.5
Methyl ester	562494.9	0	562494.9
Water	155.8	1.5	154.2
KOH	7180.8	0	7180.8
Glycerol	49240.1	0	49240.1
		53817.2	631958.8
Total	685776.03	685776.03	

3.6 Material Balance around Decanter (S-102)

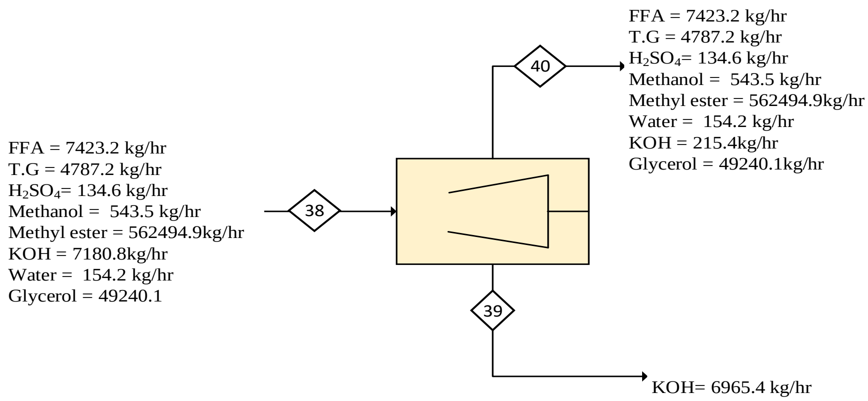


Figure 3.6: Material Balance on S-102

Efficiency =97%

KOH Removed

= 7180.8×0.97 =6965.4 kg/hr

KOH Retained

= 7180.8-6965.4 =215.4 kg/hr

Table 3.8: Mass Flow Rates in Decanter 2

Components	Input (kg/hr)	Output (kg/hr)	
	Stream 38	Stream 40	Stream 39
FFA	7423.2	7423.2	0
TG	4787.2	4787.2	0
H_2SO_4	134.6	134.6	0
Methanol	543.5	543.5	0
Methyl ester	562494.9	562494.9	0
Water	154.2	154.2	0
KOH	7180.8	215.4	6965.4
Glycerol	49240.1	49240.1	0
		624993.3	6965.4
Total	**631958.8**	**631958.8**	

3.7 Material Balance around Decanter (S-103)

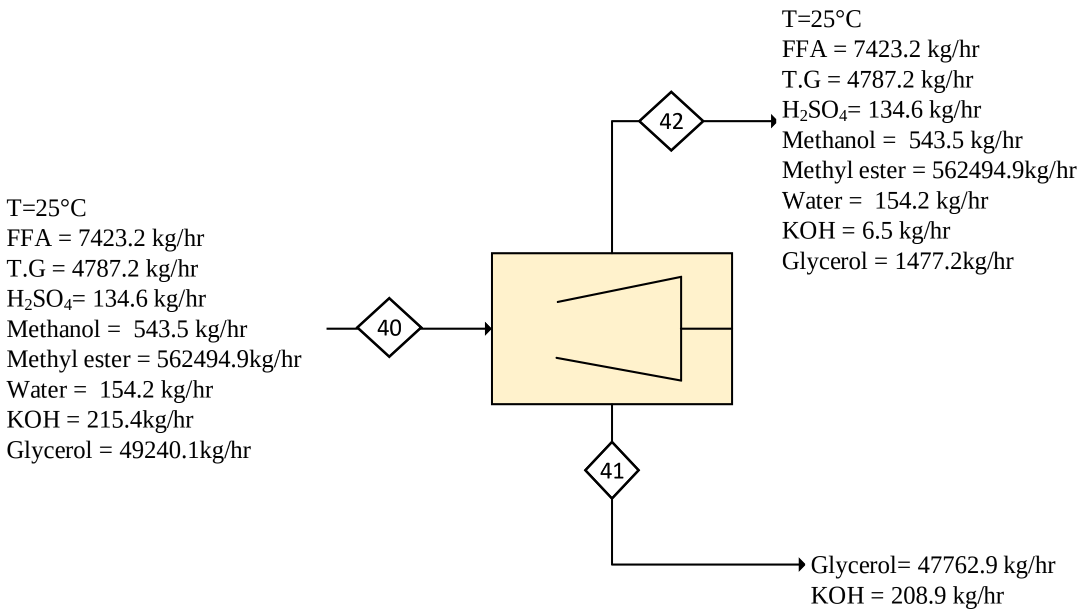


Figure 3.7: Material Balance on S-103

Efficiency

$$= 97\%$$

Glycerol Removed

$$= 49240.1 \times 0.97$$

$$= 47762.9 \text{ kg/hr}$$

Glycerol Unremoved

$$= 49240.1 - 47762.9$$

$$= 1477.2 \text{ kg/hr}$$

KOH Removed

$$= 215.4 \times 0.97$$

$$= 208.9 \text{ kg/hr}$$

KOH Unremoved

$$= 215.4 - 208.9$$

$$= 6.5 \text{ kg/hr}$$

Table 3.9: Mass Flow Rates in Decanter 3

Components	Input (kg/hr)	Output (kg/hr)	
	Stream 40	Stream 42	Stream 41
FFA	7423.2	7423.2	0
TG	4787.2	4787.2	0
H_2SO_4	134.6	134.6	0
Methanol	543.5	543.5	0
Methyl ester	562494.9	562494.9	0
Water	154.2	154.2	0
KOH	215.4	6.5	208.9
Glycerol	49240.1	1477.2	47762.9
		577021.5	47971.8
Total	**624993.3**	**624993.3**	

3.8 Material Balance around Washing Unit (C-101)

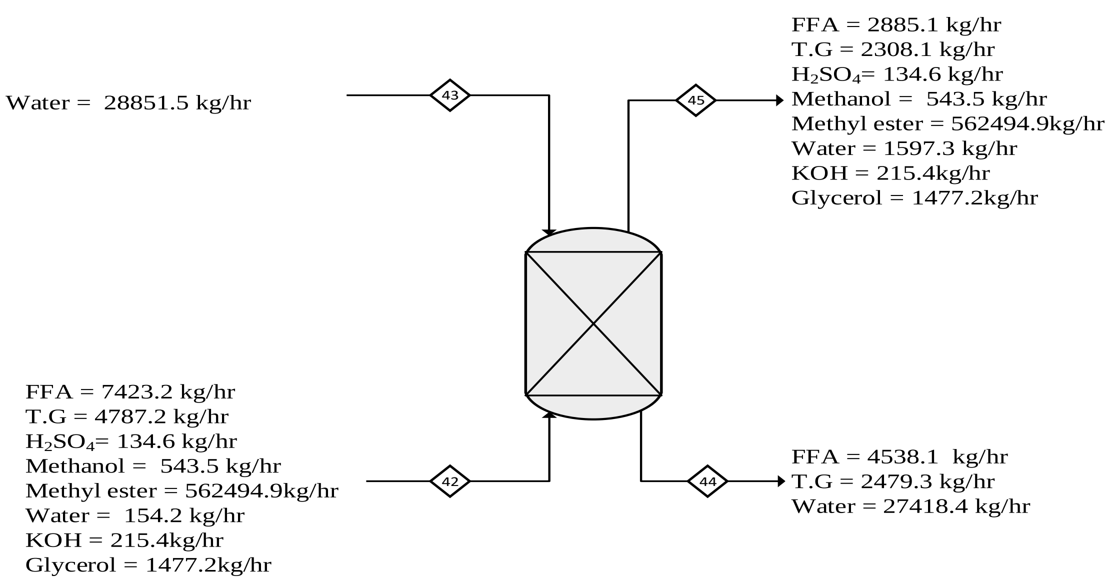


Figure 3.8: Material Balance on C-101

FFA Desired (0.5%) [18]

= 577021.3×0.005

=2885.1 kg/hr

FFA Removed

= 7423.2-2885.1

=4538.1 kg/hr

Water Required for Washing

= 5wt% of biodiesel mixture [16]

= 577021.3×0.05

= 28851.5 kg/hr

Water Dissolved

= 5% of total water

= 28851.5×0.05

=1442.5 kg/hr

Water That Went Out

= 28851.5-1442.5

=27409 kg/hr

T.G Desired (0.4%)

= 577021.3×0.004

=2308.1 kg/hr

T.G Undesired

= 4787.2-2308.1

=2479.14 kg/hr

Table 3.10: Mass Flow Rates in Washing Unit

Components	Mass fraction	Input (kg/hr)		Output (kg/hr)	
	(%)	Stream 42	Stream 43	Stream 45	Stream 44
FFA	1.28	7423.2	0	2885.1	4538.1
TG	0.8	4787.2	0	2308.1	2479.3
H_2SO_4	0.02	134.6	0	134.6	0
Methanol	0.09	543.5	0	543.5	0
Methyl ester	97.5	562494.9	0	562494.9	0
Water	0.026	154.2	28851.5	1597.3	27418.4
KOH	0.001	6.5	0	6.5	0
Glycerol	0.3	1477.2	0	1477.2	0
	100	577021.3	28851.5	571447	34435.8
Total		605883		605883	

3.9 Material Balance around Evaporator (V-101)

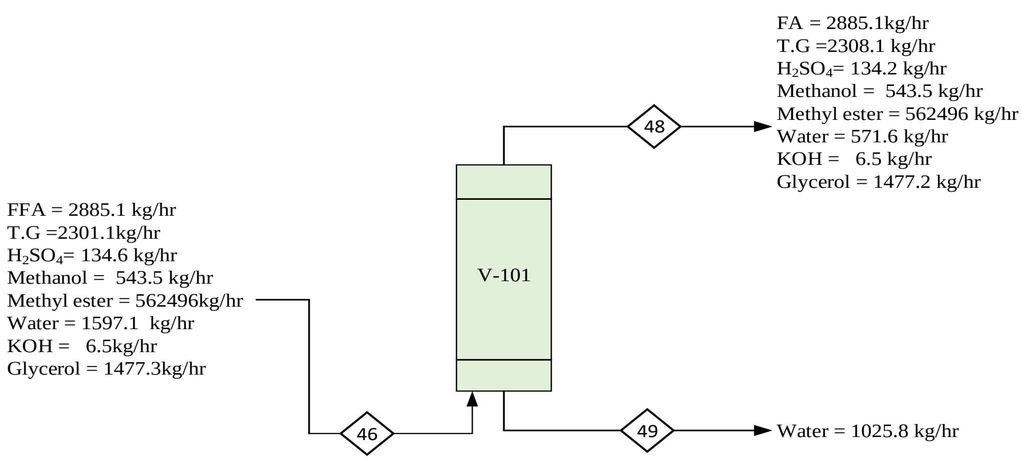


Figure 3.9: Material Balance on V-101

Water Acceptable for Biodiesel

= 0.1 % [16]

= 571499.1×0.001

=571.5 kg/hr

Water Removed

= 1597.3-571.5

=1025.8 kg/hr

Table 3.11: Mass Flow Rates in Evaporator

Components	Mass fraction	Input (kg/hr)	Output (kg/hr)		Mass fraction
	(%)	Stream 46	Stream 49	Stream 48	(%)
FFA	0.5	2885.1	0	2885.1	0.5
TG	0.4	2308.1	0	2308.1	0.4
H_2SO_4	0.02	134.6	0	134.6	0.02
Methanol	0.095	543.5	0	543.5	0.095
Methyl ester	98.4	562494.9	0	562494.9	98.6
Water	0.28	1597.3	1025.8	571.6	0.1
KOH	0.001	6.5	0	6.5	0.001
Glycerol	0.26	1477.2	0	1477.2	0.2
			1025.8	**570421.4**	
Total	**100**	**571497**	**571497**		**100**

CHAPTER 04

ENERGY BALANCE

Introduction

The terms in the energy balance are those of the internal energy, the potential and kinetic energy of the system that is equal to the summation of the enthalpy, potential and kinetic energy of each stream entering and leaving the system along with heat and work terms. In the energy balance, it is important to define the system clearly and to label all streams to correspond with those in the material balance. For systems at steady-state conditions, the time variation of the system energy is equal to zero.

Assumption

Plant is at Steady state operation

Basic Equation of Energy Balance

(Rate of heat input) - (Rate of heat output) ± (Rate of heat generation/consumption) = 0

4.1 Energy Balance around Heater (H-101)

This will melt the fats into fat oil at 110°C

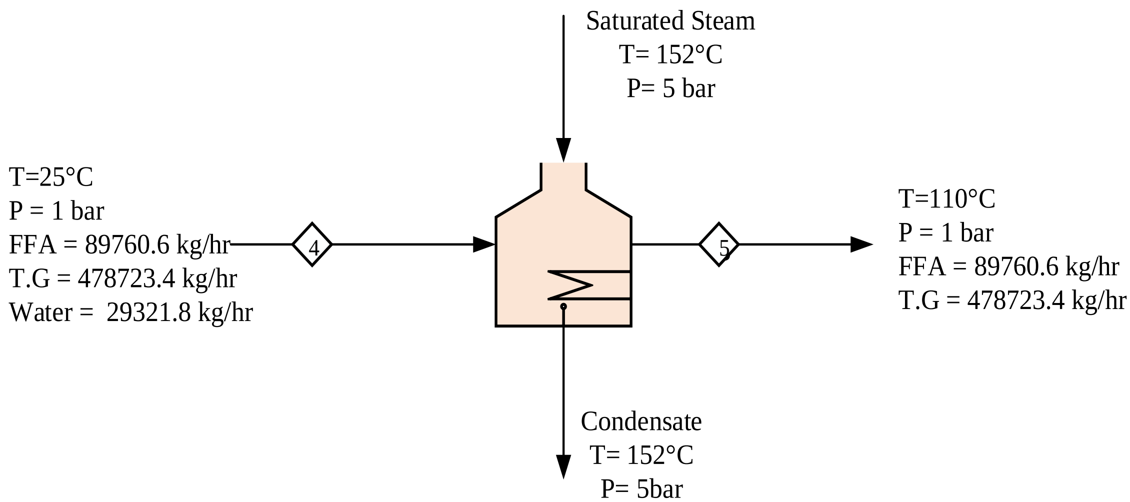


Figure 4.1: Heater (H-101)

Temperatures

$$T_{in} = 25^oC = 298K$$

$$T_{out} = 110^oC = 383\ K$$

$$T_{avg} = 67.5^oC = 340.5\ K$$

Latent Heat of Fusion

$\lambda_{(FFA)}$ = 163KJ/kg [19]

$\lambda_{(TG)}$ = 191KJ/kg [19]

Latent Heat of Vaporization

$\lambda_{(H2O)}$ = 2250.8KJ/kg

Heat Capacities

- **Cp of Water**

a=276300, b= -2090.1, c= 8.125, d= -0.014116

$$Cp = 276300 - 2090.1(T) + 8.125(T)^2 - 0.014116(T)^3$$

$$Cp = 276300 - 2090.1(340.5) + 8.125(340.5)^2 - 0.014116(340.5)^3$$

Cp = 57391.7 J/kmol. K

Cp = 4.18KJ/kg. K

- **Cp of FFA**

$$Cp = 1.9842 + 1.4733\times10^{-3}T - 4.8008\times10^{-6}T^2$$

$$Cp = 1.9842 + 1.4733\times10^{-3}(340.5) - 4.8008\times10^{-6}(340.5)^2$$

Cp = 1.93KJ/kg. K

- **Cp of T.G**

Cp = 2.17KJ/kg. K [20]

Heat Load

$$\Delta T = 383 - 298$$

$$= 85\ K$$

$$Q = (\Sigma mCp)\times\Delta T + (m\lambda_{fusion})_{FFA+TG} + (m\lambda_{vap})_{water} \quad \textbf{4.1}$$

$$Q= \{[89760.64\times163] + [478723.4\times191] + [29321.8\times2250.8] + [(89760.64\times1.93) + (478723.4\times2.1) + (29321.8\times4.18)]\} [383 – 298]$$

$$Q = 288.4\times10^3 \text{ MJ/hr}$$

Saturated Steam Required

$$P = 5 \text{ bar}, T= 150^oC, \lambda= 2107.4 \text{ kJ/kg}$$

$$Q = m\lambda \quad \textbf{4.2}$$

$$m = 136.8\times10^3 \text{ kg/hr}$$

Table 4.1: Energy Balance on Heater

Components	**Specific heat capacity at T_{avg}= 67.5ºC**	**Heat load**
	Cp (KJ/kg.K)	**(MJ/hr)**
FFA	1.97	288.4×10^3
TG	2.1	
water	4.18	

4.2 Energy Balance around Waste Heat Boiler (WHB-101)

This will decrease the temperature from 110 to 60°C of FFA and TG

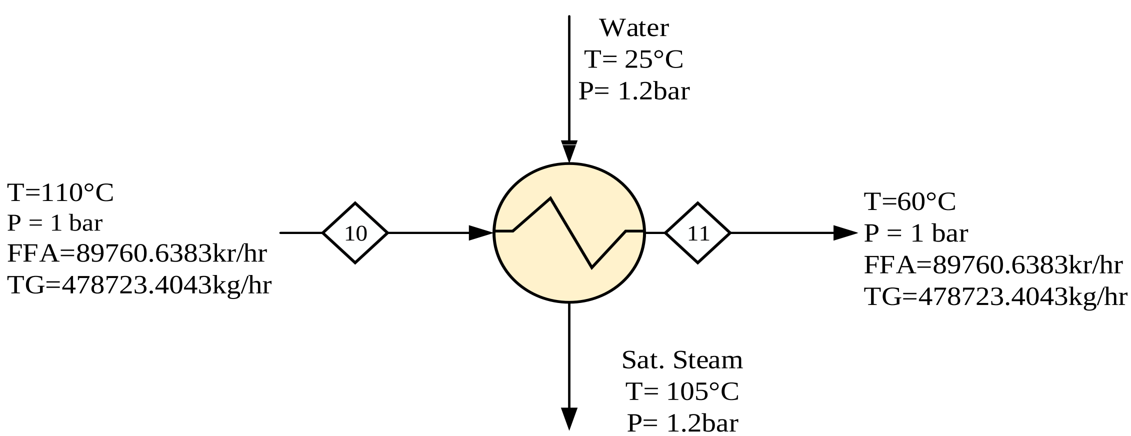


Figure 4.2: Waste Heat Boiler (WHB-101)

Temperatures

$$T_{in} = 110^oC = 383K$$

$$T_{out} = 60^oC = 333\ K$$

Cooling Load

$$\Delta T = T_{out} - T_{in}$$

$$= (333 - 383)\ K$$

$$= -50\ K$$

$$Q = (\Sigma mCp)\Delta T \qquad \textbf{4.3}$$

$$Q = -57.6\times10^3\ MJ/hr$$

Mass flow rate of Steam Produced

$$Q = mCp\Delta T + m\ \lambda$$

$$Cp\ at\ T_{avg}\ (88.5^oC)$$

$$= 4.2\ kJ/kg.\ K$$

Saturated Steam Produced

$$P = 1.2\ bar,\ T = 105^oC,\ \lambda = 2244.1\ kJ/kg$$

$$m = 22.3\times10^3 kg/hr$$

Table 4.2: Energy Balance on Waste Heat Boiler 01

Components	**Specific heat capacity at T_{avg}= 85ºC**	**Heat load**
	Cp (KJ/kg.K)	**(MJ/hr)**
FFA	1.896	57.6×10^3
T.G	2.05	

4.3 Energy Balance around Heat Exchanger (HX-102)

This will increase the temperature from 25 to 60°C of Methanol and H_2SO_4

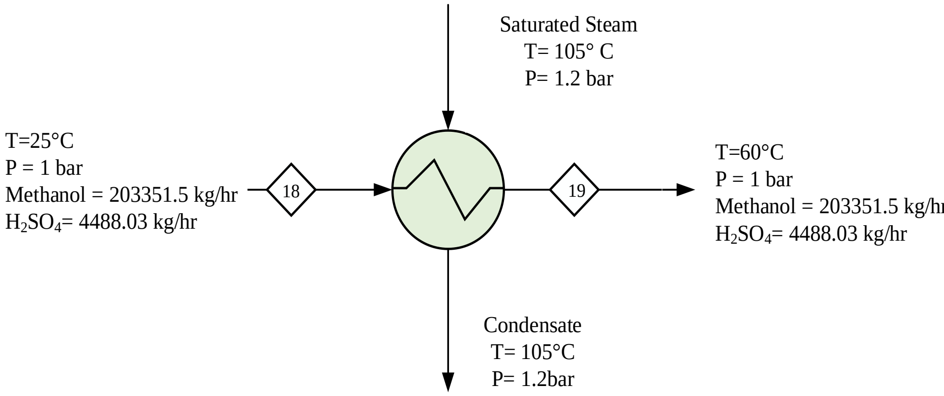


Figure 4.3: Heat Exchanger (HX-102)

Temperatures

$$T_{in} = 25^oC = 298\ K$$

$$T_{out} = 60^oC = 333\ K$$

$$T_{avg}= 42.5^oC = 315.5\ K$$

Saturated Steam Conditions

$$P= 1.2bar\ T= 105^oC,\ \lambda = 2244.1kJ/kg$$

Heat Load

$$\Delta T = (333 - 298)\ K$$

$$= 35K$$

$$Q = (\Sigma mCp)\Delta T$$

$$Q = 18.8\times10^6\ kJ/hr$$

$$= 18.8\times10^3\ MJ/hr$$

Saturated Steam Required

$$Q = m\lambda$$

$$m = 8920.9\ kg/hr$$

Table 4.3: Energy Balance on HX-102

Components	Specific heat capacity at T_{avg}= 42.5ºC	Heat load
	Cp (KJ/kg.K)	**(MJ/hr)**
H_2SO_4	1.917	18.8×10^3
Methanol	2.6	

4.4 Energy Balance around Reactor (R-101)

$$RCOOH + CH_3OH \xrightarrow{H_2SO_4} RCOOCH_3 + H_2O$$

FFA Alcohol Biodiesel Water

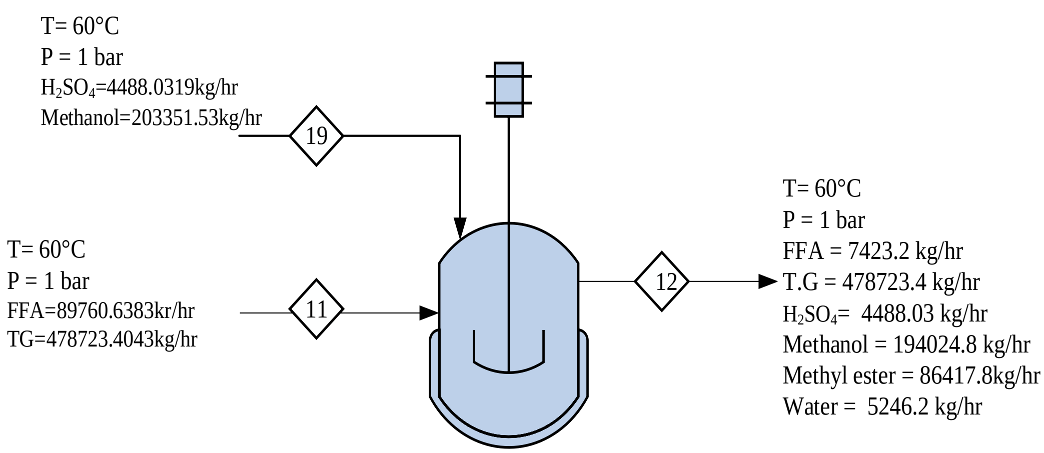


Figure 4.4: Reactor (R-101)

$\Delta H_{r,\,333K}$ = 15.06×10^3 MJ/hr

Temperatures

$$T_{in} = 60ºC = 333\ K$$

$$T_{out} = 60ºC = 333\ K$$

$$T_{ref} = 25ºC = 298\ K$$

Heat Capacities

- **H_2SO_4**

$$a=1.391\times10^{-1},\ b= 1.559\times10\text{-}4$$

$$Cp = 1.391\times10^{-1} +1.559\times10^{-4}T$$

$$Cp = 1.391\times10^{-1} +1.559\times10\text{-}4(315.5)$$

$$Cp= 0.188 KJ/kmol.\ K$$

$$Cp= 1.92 KJ/kg.\ K$$

- **Methanol**

$$a= 105{,}800,\ b= -362.23,\ c= 0.9379$$

$$Cp = 105800 - 362.23(T) + 0.9379(T)^2$$

$$Cp = 105800 - 362.23(315.5) + 0.9379(315.5)^2$$

$$Cp = 2652.35\ J/kg.\ K$$

$$Cp = 2.6 KJ/kg.\ K$$

- **Water**

$$a= 276370,\ b= -2090.1,\ c=8.125,\ d=-0.014116$$

$$Cp = 276370 - 2090.1(T) + 8.125(T)^2 - 0.014116(T)^3$$

$$Cp = 276370 - 2090.1(315.5) + 8.125(315.5)^2 - 0.014116(315.5)^3$$

$$Cp = 75236.6 J/kmol.K. \ = 4.18 KJ/kg.\ K$$

- **FFA**

=1.974 KJ/kg. K

- **T.G**

= 2.1 KJ/kg. K (from graph)

- **Methyl ester**

= 2.99 KJ/kg. K [21]

Total Heat at inlet

$$Q_{in} = (\Sigma mCp)\Delta T$$

$$= 60.2\times10^{6}\ kJ/hr = 60.2\times10^{3}\ MJ/hr$$

Heat of Formation

Heat of Formation of FFA = -822.8×10^{3} KJ/kmol [22]

Heat of Formation of methanol = -238.1×10^{3} KJ/kmol [23]

Heat of Formation of methyl ester = -728.8×10^{3} KJ/kmol [22]

Heat of Formation of water = -285.6×10^{3} KJ/kmol

$$\Delta H_{r,\,298K} = n\Sigma H_f(\text{product}) - n\Sigma H_f(\text{reactants}) \qquad \textbf{4.4}$$

$$= [-285.6 - 728.8] - [238.1 - 822.8]$$

$$= 46.63\times10^{3}\ KJ/kmol$$

Table 4.4: Energy Balance on Reactor R-101

Specific heat capacity	kJ/kg.K	kJ/kmol.K
FFA	1.97	557.65
Methanol	2.6	83.2
Methyl ester	2.99	886.5
Water	4.2	75.24

$$\Delta H_{r,\,333K} = \Delta H_{r,298K} + \int_{T_o}^{T1} (\nabla Cp)dT \qquad \textbf{4.5}$$

$$\Delta H_{r,\,333K} = \Delta H_{r,298K} + \int_{298}^{333} (\nabla Cp)dT$$

$$= 46.63\times10^{3} + \int_{298}^{333} (\nabla Cp)dT$$

$$= 46.63\times10^3\,[(886.5 + 75.24) - (557.65 + 83.2)]\,(333\text{-}298)$$

$$= 57.83\times10^3 \text{ KJ/kmol}$$

$$= 16.85\times10^6 \text{ KJ/hr}$$

$$=16.85\times10^3 \text{ MJ/hr}$$

This shows that the reaction is endothermic.

Total Heat at Outlet

$$Q_{out} = (\Sigma mCp)\Delta T$$

$$= 63.5\times10^6 \text{ kJ/hr}$$

$$= 63.5\times10^3 \text{ MJ/hr}$$

Overall Energy Equation

$$\mathbf{0 = rate\ of\ heat\ out - rate\ of\ heat\ in + (+\Delta H_r)} \qquad \textbf{4.6}$$

$$0 = 63.5\times10^3 \text{ MJ/hr} - 60.2\times10^3 \text{ MJ/hr} + 16.85\times10^3 \text{ MJ/hr}$$

$$0 \neq 20.15\times10^3 \text{ MJ/hr}$$

$$\textbf{Rate of heat in + heat added = rate of heat out + heat of reaction} \qquad \textbf{4.7}$$

$$60.2\times10^3 \text{ MJ/hr} + 20.15\times10^3 \text{ MJ/hr} = 63.5\times10^3 \text{ MJ/hr} + 16.85\times10^3 \text{ MJ/hr}$$

Saturated Steam Required

$$Q = m\lambda$$

$$(P = 1.2\text{bar } T = 105^oC,\ \lambda = 2244.2\text{kJ/kg})$$

$$m = 8979 \text{ kg/hr}$$

Table 4.5: Heat Loads of Reactor 01

Components	Cp (T_{avg}=42.5ºC)	Input		Heat added	Output		Heat of reaction
	(KJ/kg.K)	Mass flow rate (kg/hr)	Q (MJ/hr)	(MJ/hr)	Mass flow rate (kg/hr)	Q (MJ/hr)	(MJ/hr)
FFA	1.97	89760.6	6.2×10^3	20.15×10^3	7423.2	512.8	16.85×10^3
TG	2.1	478723.4	35.2×10^3		478723.4	35.2×10^3	
H_2SO_4	1.919	4488.03	301.4		4488.03	301.4	
methanol	2.6	203351.5	18.5×10^3		194024.8	17.6×10^3	
methyl ester	2.99	0	0		86417.9	9×10^3	
water	4.18	0	0		5246.3	767.5	
Total	-		60.2×10^3			63.5×10^3	

4.5 Energy Balance around Heat Exchanger (HX-103)

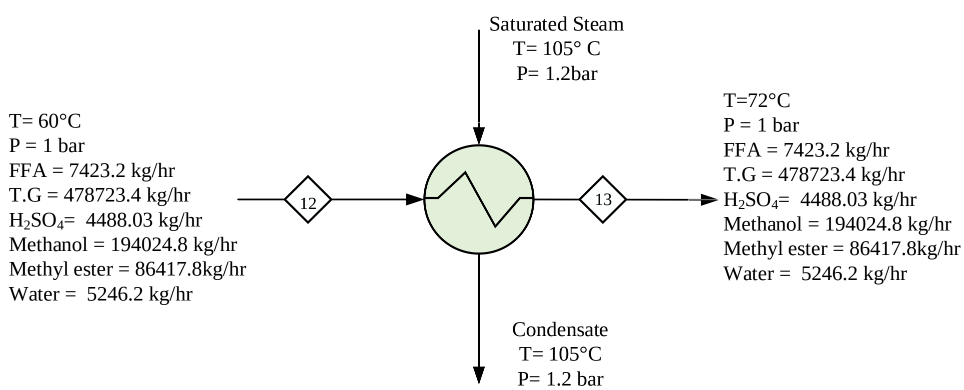


Figure 4.5: Heat Exchanger (HX-103)

Temperatures

$$T_{in} = 60^oC = 333\ K$$

$$T_{out} = 72^oC = 345\ K$$

$$T_{avg} = 66^oC = 339\ K$$

Saturated Steam Conditions

$$P = 1.2\ bar\ T = 105^oC,\ \lambda = 2244.1 kJ/kg$$

Heat Load

$$Q = (\Sigma mCp)\Delta T$$

$$Q = 21.03\times10^6\ kJ/hr$$

$$= 21.03\times10^3\ MJ/hr$$

Saturated Steam Required

$$Q = m\lambda$$

$$m = 9371.2\ kg/hr$$

Table 4.6: Energy Balance on HX-103

Components	Specific heat capacity at T_{avg}= 66 ºC	Heat load
	Cp(KJ/kg.K)	**(MJ/hr)**
FFA	1.93	21.03×10^3
T.G	2.05	
H2SO4	1.937	
Methanol	2.8	
Methyl ester	2.117	
Water	4.19	

4.6 Energy Balance around Distillation Column (D-101)

It is used to recover methanol for reuse

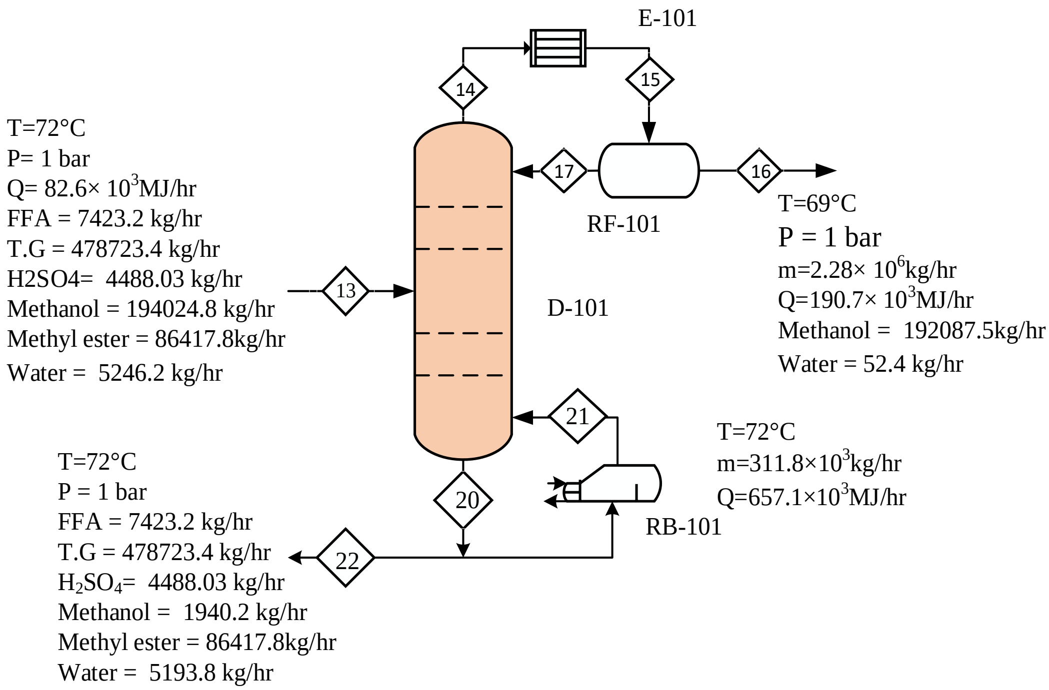


Figure 4.6: Distillation column (D-101)

Temperatures

$$T_{in} = 72^oC = 345\ K$$

$$T_{ref} = 25^oC = 298\ K$$

$$\Delta T = (345\text{-}298)\ K$$

$$= 47\ K$$

Heat Rate at Inlet

$$Q= (\Sigma mCp)\Delta T$$

$$Q= [(7423.2\times1.96) + (478723.40\times2.12) + (4488\times1.93) + (1940.2\times2.7) + (86417.87\times4.18) + (5193.8\times2.068)]\ (47)$$

$$= 82.6\times10^6\ kJ/hr$$

Reboiler Heat Duty

$$\lambda_{weighted} = 846.4 \text{ kJ/hr}$$

$$Q = m\lambda$$

$$= 776323.6 \times 846.4$$

$$= 657.1\times10^{6} \text{ kJ/hr}$$

$$= 657.1\times10^{3} \text{ MJ/hr}$$

Saturated Steam Required

$$P= 1.2 \text{ bar } T= 105^{o}C, \lambda = 2244 \text{kJ/kg}$$

$$Q = m\lambda$$

$$m = 293\times10^{3} \text{ kg/hr}$$

Condenser Heat Duty

$$\lambda_{weighted} = 992.8 \text{ kJ/kg}$$

$$Q = m\lambda$$

$$= -190.7\times10^{6} \text{ KJ/hr}$$

$$= - 190.7\times10^{3} \text{ MJ/hr}$$

Cooling Water Required

$$T_{in}= 25°C, T_{out}= 45°C$$

$$Q = mCp\Delta T$$

$$m = 2.28\times10^{6} \text{ kg/hr}$$

Table 4.7: Energy Balance on Distillation Column 01

Components	**Specific heat capacity at T_{avg}= 48.5°C**	**Mass flow rate (bottom)**	**Reboiler heat duty**	**Mass flow rate (distillate)**	**Condenser heat duty**
	Cp (kJ/kg.K)	**(kg/hr)**	**(MJ/hr)**	**(kg/hr)**	**(MJ/hr)**
FFA	1.96	7423.20		0	
T.G	2.12	478723.40		0	
H2SO4	1.93	4488	657.1×10^3	0	190.7×10^3
Methanol	2.7	1940.2		192084.5	
Methyl ester	4.18	86417.87		0	
water	2..068	5193.8		52.5	

4.7 Energy Balance around Heat Exchanger (HX-104)

This will decrease the temperature from 72 to 40°C

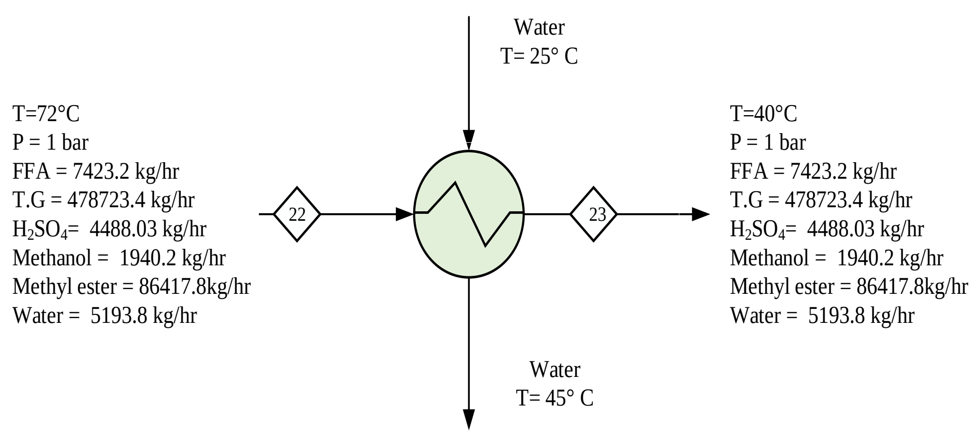


Figure 4.7: Heat Exchanger (HX-104)

Temperatures

$$T_{in} = 72^oC = 345\ K$$

$$T_{out} = 40^oC = 313\ K$$

$$T_{avg} = 56^oC = 329\ K$$

Cooling Load

$$\Delta T = 313 - 345$$

$$= -32\ K$$

$$Q = \Sigma(mCp\Delta T)$$

$$Q = -39.9\times10^3\ MJ/hr$$

Water Required

$$Q = mCp\Delta T$$

$$m = 475\times10^3\ kg/hr$$

Table 4.8: Energy Balance on HX-104

Components	Specific heat capacity at $T_{avg} = 56^oC$	Cooling load
	Cp (KJ/kg.K)	**(MJ/hr)**
FFA	1.96	39.9×10^3
T.G	2.12	
H2SO4	1.93	
Methanol	2.7	
Methyl ester	2.06	
Water	4.19	

4.8 Energy Balance around Heat Exchanger (HX-105)

This will increase the temperature from 40 to 60°C

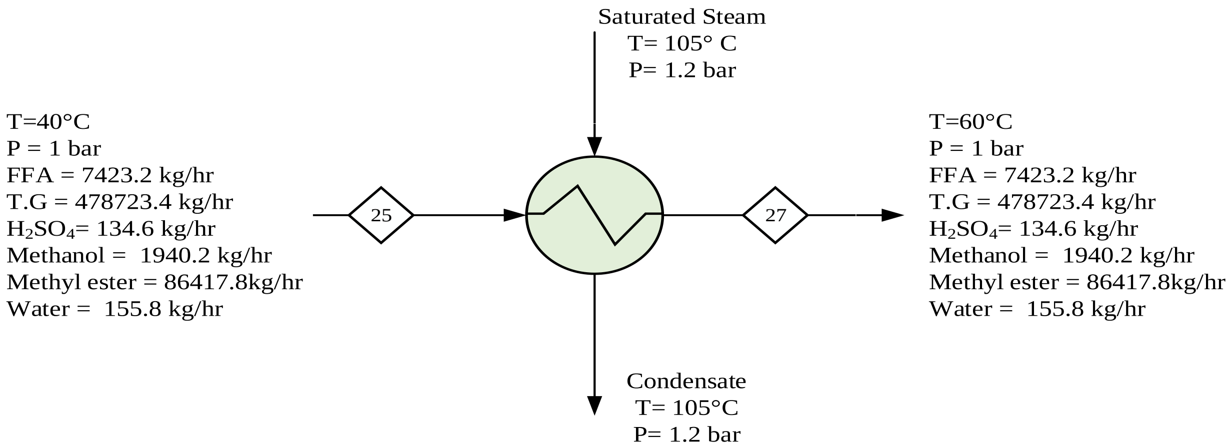


Figure 4.8: Heat Exchanger (HX-105)

Temperatures

$$T_{in} = 40^oC = 313\ K$$

$$T_{out} = 60^oC = 333\ K$$

$$T_{avg} = 50^oC = 323\ K$$

Saturated Steam Conditions

$$P = 1.2\ bar$$

$$T = 105^oC,$$

$$\lambda = 2244.1 kJ/kg$$

Heat Load

$$Q = (\Sigma mCp)\Delta T$$

$$Q = 24.6\times10^6\ kJ/hr$$

$$= 24.2\times10^3\ MJ/hr$$

Saturated Steam Required

$$Q = m\lambda$$

$$m = 10.8\times10^{3} kg/hr$$

Table 4.9: Energy Balance on HX-105

Components	Specific heat capacity at T_{avg}= 42.5°C	Heat load
	Cp (KJ/kg.K)	(MJ/hr)
FFA	1.97	24.2×10^{3}
T.G	1.9	
H2SO4	1.91	
Methanol	2.6	
Methyl ester	2.05	
Water	4.18	

4.9 Energy Balance around Heat Exchanger (HX-106)

This will in the temperature from 25 to 60°C of Methanol and KOH

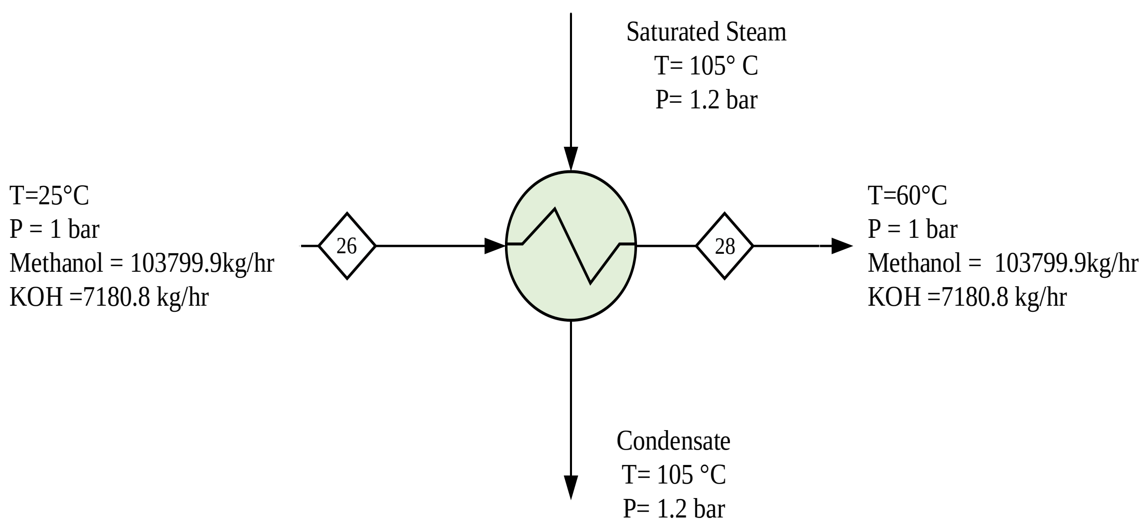


Figure 4.9: Heat exchanger (HX-106)

Temperatures

$$T_{in} = 25^oC = 298\ K$$

$$T_{out} = 60^oC = 333\ K$$

$$T_{avg} = 42.5^oC = 315.5\ K$$

Saturated Steam Conditions

P= 1.2 bar

$T = 105^oC$

$\lambda = 2244.1kJ/kg$

Heat Load

$$Q=(\Sigma mCp)\Delta T$$

$$\mathbf{Q} = 9.817\times10^6\ kJ/hr$$

$$= 9.8\times10^3\ MJ/hr$$

Saturated Steam Required

$$Q = m\lambda$$

$$m = 4367kg/hr$$

Table 4.10: Energy Balance on HX-106

Components	Specific heat capacity at T_{avg}= 67.5ºC	Heat load
	Cp (KJ/kg.K)	(MJ/hr)
KOH	1.48	9.8×10^3
Methanol	2.6	

4.10 Energy Balance around Reactor (R-102)

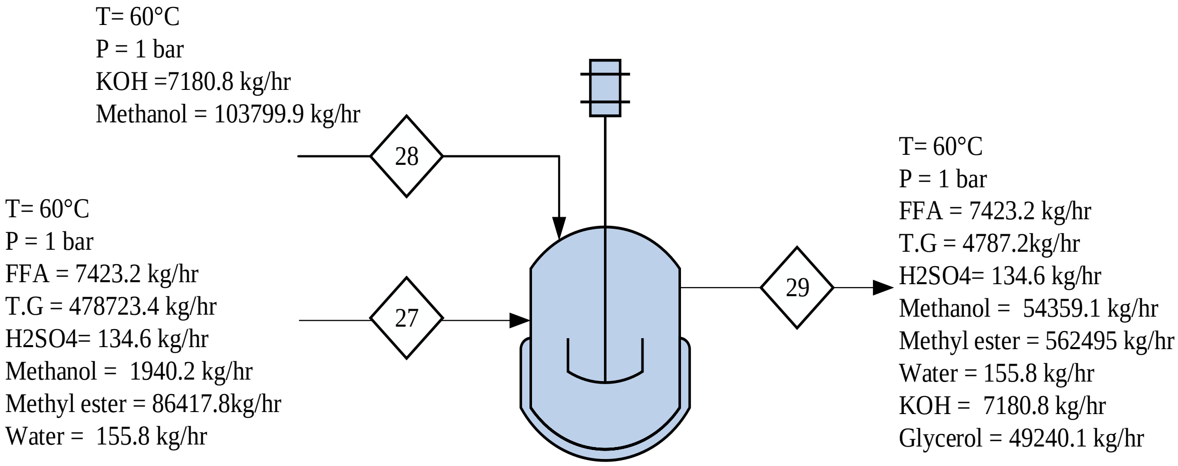


Figure 4.10: Reactor (R-102)

Transesterification Reaction

$$\text{Triglyceride + Methanol} \xleftrightarrow{\text{KOH}} \text{diglyceride + Biodiesel}$$

$$\text{Diglyceride + Methanol} \xleftrightarrow{\text{KOH}} \text{monoglyceride + Biodiesel}$$

$$\text{Monoglyceride + Methanol} \xleftrightarrow{\text{KOH}} \text{glycerol + Biodiesel}$$

Overall Reaction

$$\text{Triglyceride + 3 Methanol} \xleftrightarrow{\text{KOH}} \text{3 Biodiesel + Glycerol}$$

$$\Delta H_{r,\,333K} = -274.4\times10^{3} \text{ MJ/hr}$$

Temperatures

$$T_{in} = 60^{o}C = 333 \text{ K}$$

$$T_{out} = 60^{o}C = 333 \text{ K}$$

$$T_{ref} = 25^{o}C = 298 \text{ K}$$

Heat of Reaction

- **Heat of Formation of T.G**

$= -1601\times10^{3}$ KJ/kmol

- **Heat of Formation of Methanol**

$= -238\times10^{3}$ KJ/kmol

- **Heat of Formation of Biodiesel**

$= -728.8\times10^{3}$ KJ/kmol

- **Heat of Formation of Glycerol**

$= -669.6\times10^{3}$ KJ/kmol [23]

Table 4.11: Specific Heat Capacities of Components

Specific heat capacity	kJ/kg.K	kJ/kmol.K
TG	2.1	1859.6
Methanol	2.6	83.2
Methyl ester	2.99	886.5
Glycerol	2.5	230

$\Delta H_{r,\,298K} = n\Sigma\, H_f(\text{products}) - n\Sigma H_f\,(\text{reactants})$

$= [-669.6\times10^{3} + 3(-728.8\times10^{3})] - [-1601\times10^{3} + 3(-238\times10^{3})]$

$= -555\times10^{3}$ KJ/kmol

$$\Delta H_{r,\,333K} = \Delta H_{r,298K} + \int_{T_o}^{T1} (\nabla Cp)dT$$

$$\Delta H_{r,\,333K} = \Delta H_{r,298K} + \int_{298}^{333} (\nabla Cp)dT$$

$$= -555\times10^3 + \int_{298}^{333}[(230 + 3 * 886.5) - (1859.6 + 3 * 83.2)]\ Dt$$

$$= -528\times10^3 \text{ KJ/kmol}$$

$$= -282.4\times10^6 \text{ KJ/hr}$$

This shows that the reaction is exothermic

Total Heat at Outlet

$$Q_{out} = (\Sigma mCp)\Delta T$$

$$= 69.4\times10^6 \text{ kJ/hr}$$

$$= 69.4\times10^3 \text{ MJ/hr}$$

Overall Energy Equation

0 = rate of heat out – rate of heat in - (-ΔH$_r$)

$$0 = 69.4\times10^3 \text{ MJ/hr} - 54.8\times10^3 \text{ MJ/hr} - 282.4\times10^3 \text{ MJ/hr}$$

$$0 \neq -267.8\times10^3 \text{ MJ/hr}$$

Rate of heat in - rate of heat out + heat of reaction - heat removed = 0

$$54.8\times10^3 \text{ MJ/hr} - 69.4\times10^3 \text{ MJ/hr} + 274.4\times10^3 \text{ MJ/hr} - 259.8\times10^3 \text{ MJ/hr} = 0$$

Cooling Water Required

$$Q = mCp\Delta T$$

$$m = 3.2\times10^6 \text{ kg/hr}$$

Table 4.12: Energy Balance on Reactor 02

Components	**Cp (T_{avg}=42.5°C)**	**Input**		**Heat added**	**Output**		**Heat of reaction**
	Cp (KJ/kg.K)	**Mass flow rate (kg/hr)**	**Q (MJ/hr)**	**(MJ/hr)**	**Mass flow rate (kg/hr)**	**Q (MJ/hr)**	**(MJ/hr)**
FFA	1.97	7423.2	512		7423.2	512	
TG	2.1	478723.4	35.19×10^3		4787.2	351.8	
H_2SO_4	1.919	134.64	9.043		134.64	9.043	
methanol	2.6	105740.1	9.6×10^3		52418.9	4.9×10^3	
methyl ester	2.99	86417.87	9.04×10^3		562494.8	58.8×10^3	
water	4.18	155.8	22.7		155.8	22.7	
KOH	1.48	7180.85	371.9		7180.8	371.9	
Glycerol	2.5	0	0		49240.12	4.3×10^3	
Total	-		54.8×10^3	259.8×10^3		69.4×10^3	274.4×10^3

4.11 Energy Balance around Heat Exchanger (HX-107)

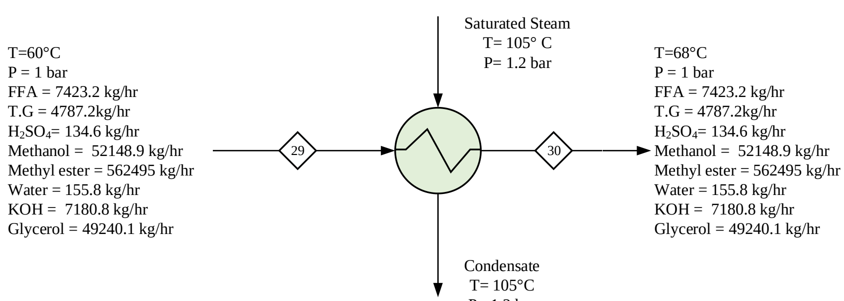


Figure 4.11: Heat Exchanger (HX-107)

Temperatures

$$T_{in} = 60^oC = 333\ K$$

$$T_{out} = 68^oC = 341\ K$$

Saturated Steam Conditions

P= 1.2 bar T= 105^{o}C, λ = 2244.1kJ/kg

Heat Load

$$Q = (\Sigma mCp)\Delta T$$

$$Q = 12\times10^6\ kJ/hr$$

$$= 12\times10^3\ MJ/hr$$

Saturated Steam Required

$$Q = m\lambda$$

$$m = 5347\ kg/hr$$

Table 4.13: Energy Balance on HX-107

Components	**Specific heat capacity at T_{avg}= 64 ^{o}C**	**Heat load**
	Cp (KJ/kg.K)	**(MJ/hr)**
FFA	1.935	12×10^3
T.G	2.11	
H2SO4	1.95	
Methanol	2.8	
Methyl ester	2.117	
Water	4.18	
KOH	1.48	
Glycerol	2.5	

4.12 Energy balance around Distillation Column (D-102)

The feed is saturated liquid at its boiling point

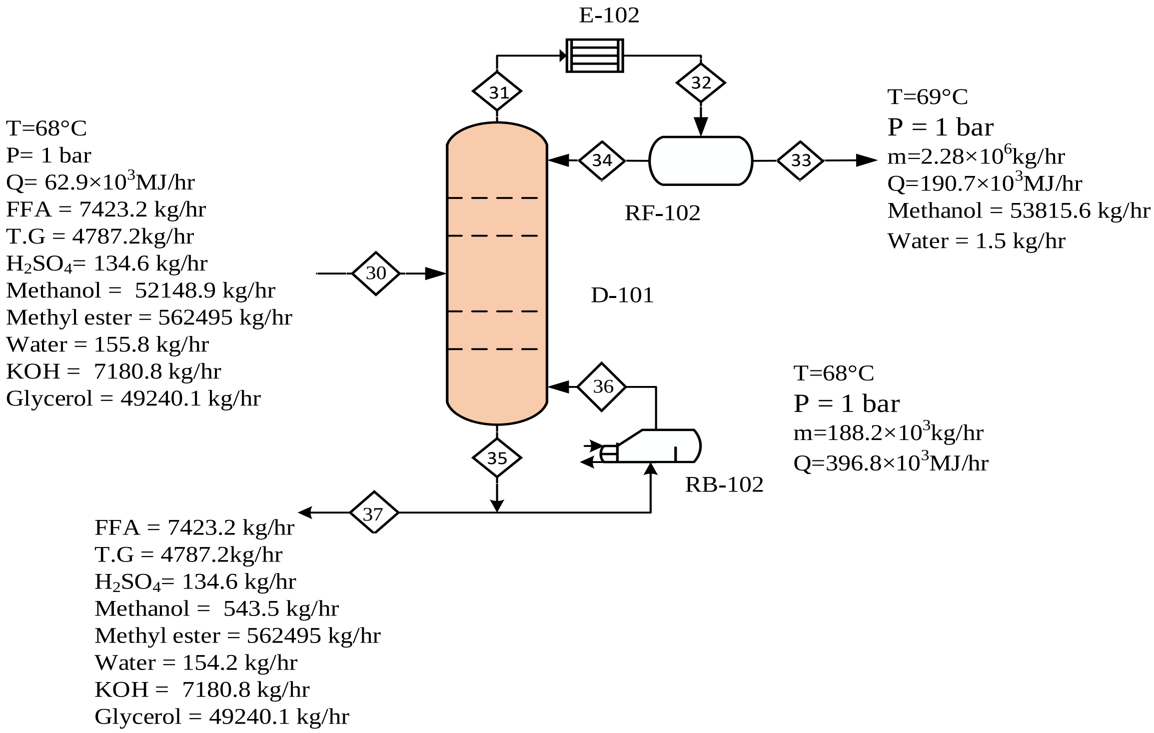


Figure 4.12: Distillation Column (D-102)

Temperatures

$$T_{in} = 68^oC$$

$$T_{ref} = 25^oC$$

Heat Rate of Feed

$$Q= (\Sigma mCp)\Delta T$$

$$=62.9\times10^6 \text{ kJ/hr}$$

$$=62.9\times10^3 \text{ MJ/hr}$$

Reboiler Heat Duty

$$\lambda_{\text{weighted}} = (0.0061\times163) + (0.0013\times191) + (0.00032\times571) + (0.39\times878.2) + (0.4\times250) + (0.002\times2250) + (0.03\times1980) + (0.12\times989.1)$$

$$\lambda_{\text{weighted}} = 628.07 \text{ kJ/kg}$$

$$Q = m\lambda$$

$$= 631958.8 \times 628$$

$$= 396.8 \times 10^{6} \text{ kJ/hr}$$

$$= 396.8 \times 10^{3} \text{ MJ/hr}$$

Saturated Steam Required

$$P = 1.2 \text{bar}$$

$$T = 105^{o}\text{C},$$

$$\lambda = 2244 \text{kJ/kg}$$

$$Q = m\lambda$$

$$m = 177 \times 10^{3} \text{ kg/hr}$$

Condenser Heat Duty

$$\lambda_{\text{weighted}} = 992.8 \text{ kJ/kg}$$

$$Q = m\lambda$$

$$= -190.7 \times 10^{6} \text{ kJ/hr}$$

$$= 190.7 \times 10^{3} \text{ MJ/hr}$$

Cooling Water Required

$$T_{in} = 25°\text{C},$$

$$T_{out} = 45°\text{C}$$

$$Q = mCp\Delta T$$

$$m = 2.28 \times 10^{6} \text{ kg/hr}$$

Table 4.14: Energy Balance on Reactor 02

Components	Specific heat capacity at T_{avg}= 48.5ºC	Mass flow rate (bottom)	Reboiler heat duty	Mass flow rate (distillate)	Condenser heat duty
	Cp (kJ/kg.K)	(kg/hr)	(MJ/hr)	(kg/hr)	(MJ/hr)
FFA	1.96	7423.20	396.8×10^3	0	190.7×10^3
T.G	2.11	4787.23		0	
H2SO4	1.927	134.64		0	
Methanol	2.68	543.59		53815.65	
Methyl ester	2.068	562494.9		0	
Water	4.18	154.25		1.55	
KOH	1.48	7180.85		0	
Glycerol	2.47	49240.12		0	

4.13 Energy Balance around Heat Exchanger (HX-108)

This will decrease the temperature from 68 to 35°C

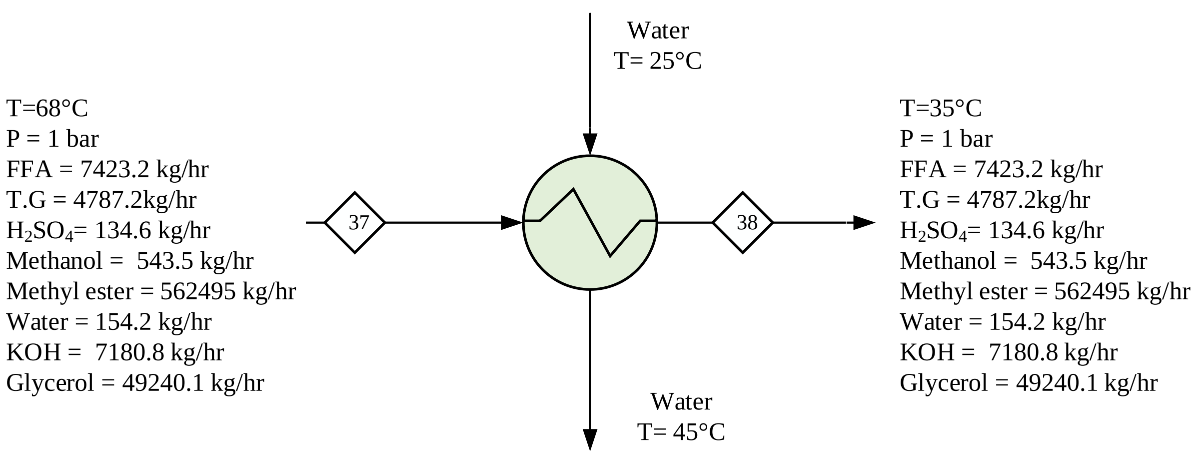


Figure 4.13: Heat Exchanger (HX-108)

Temperatures

$$T_{in} = 68^oC = 341\ K$$

$$T_{out} = 35^oC = 308\ K$$

Cooling Load

$$\Delta T = (308 – 341)\ K$$

$$= -33\ K$$

$$Q = mCp\Delta T$$

$$Q = -43.4 \times 10^6\ kJ/hr$$

$$= -43.4 \times 10^3\ MJ/hr$$

Cooling Water Required

$$Q = mCp\Delta T$$

$$M = 517 \times 10^3\ kg/hr$$

Table 4.15: Energy Balance on HX-108

Components	Specific heat capacity at T_{avg}= 51.5ºC	Heat load
	Cp(KJ/kg.K)	(MJ/hr)
FFA	1.96	43.4×10^3
T.G	2.12	
H2SO4	1.93	
Methanol	2.7	
Methyl ester	2.06	
Water	4.19	

4.14 Energy Balance around Evaporator (V-101)

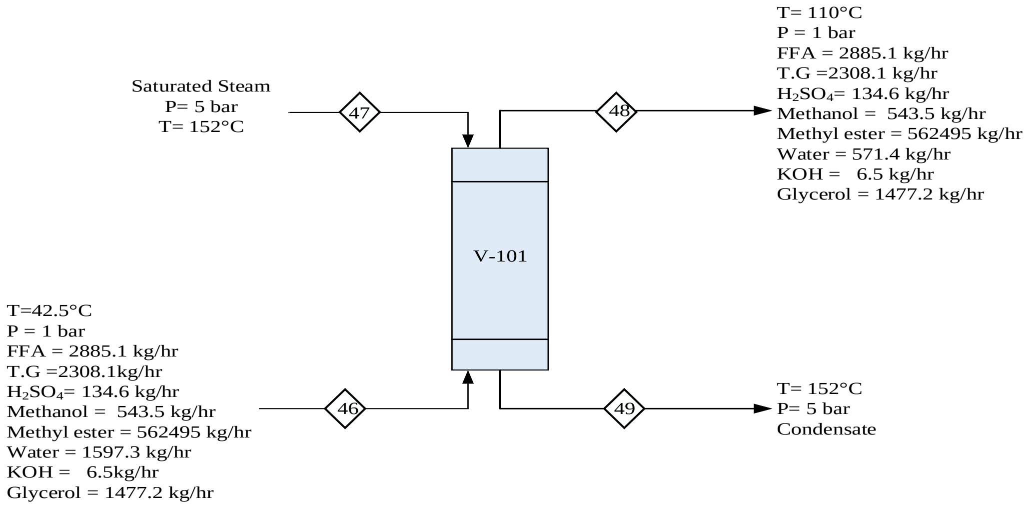


Figure 4.14: Evaporator (V-101)

Temperatures

$$T_{in} = 50^oC = 323\ K$$

$$T_{out} = 110^oC = 383\ K$$

$$T_{avg} = 85^oC = 358\ K$$

Saturated Steam Conditions

$$P = 1.2\ bar\ T = 105^oC,\ \lambda = 2244.1 kJ/kg$$

Total Heat at Inlet and Outlet

$$Q_{in} = 109.2\times10^6\ kJ/hr \quad = 109.2\times10^3\ MJ/hr$$

$$Q_{T(out)} = Q_{out} + m\lambda$$

$$= 121.8\times10^6\ kJ/hr = 121.8\times10^3\ MJ/hr$$

$$Q_{Total} = Q_{out} - Q_{in}$$

$$= 12.6\times10^6\ kJ/hr = 12.6\times10^3\ MJ/hr$$

Saturated Steam Required

$$Q = m\lambda$$

m = 5978.9kg/hr

Table 4.16: Energy Balance on Evaporator

Components	Cp KJ/kg.K	Mass flow rate (kg/hr)	Q_{in} (MJ/hr)	Mass flow rate (kg/hr)	Q_{out} (MJ/hr)	Cp KJ/kg.K
FFA	1.95	2885.1	337.5	337.5×10^6	334	1.93
TG	2	2308.1	276.9	2308.1	318.5	2.3
H_2SO_4	1.94	134.64	15.67	134.64	15.8	1.96
methanol	2.7	543.6	88	543.6	107.6	3.3
methyl ester	2.058	562494.9	69.45×10^3	562494.9	71.45×10^3	2.117
water	4.18	1596.8	400.49	571.4	143.3	4.18
KOH	1.48	6.5	0.577	6.5	0.577	1.48
Glycerol	2.5	1477	221.5	1477	230.4	2.6
Total	-		$\mathbf{109.2\times10^3}$		$\mathbf{121.8\times10^3}$	

4.15 Energy Balance around Waste Heat Boiler (WHB-109)

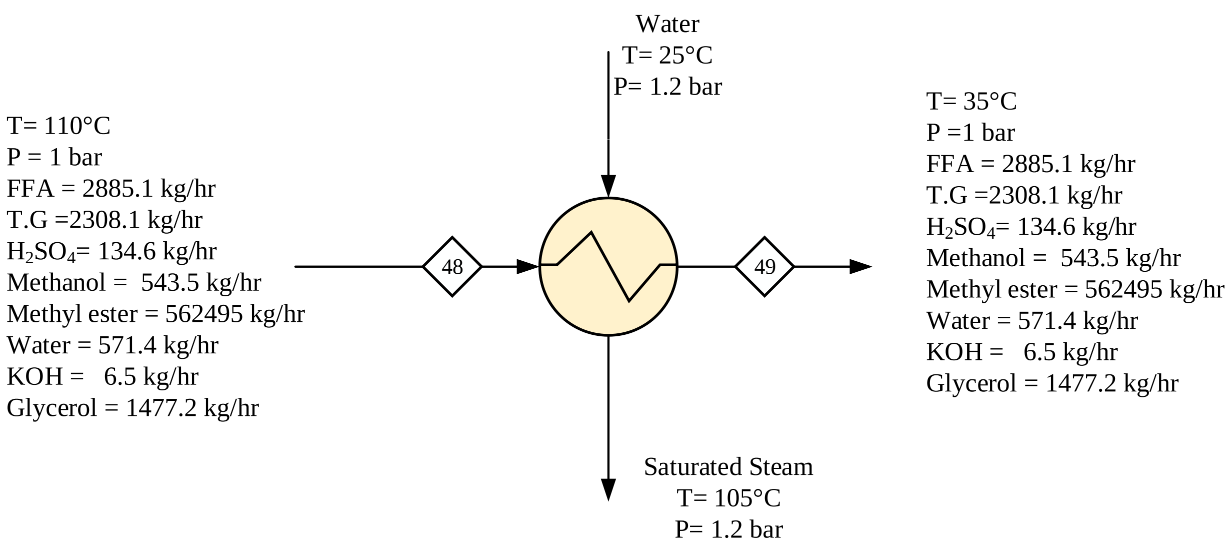


Figure 4.15: Waste Heat Boiler (WHB-109)

Temperatures

$$T_{in} = 110^oC = 383\ K$$

$$T_{out} = 35^oC = 308\ K$$

Cooling Load

$$\Delta T = (308 - 383)\ K$$

$$= -75\ K$$

$$Q = mCp\Delta T$$

$$Q = 90.8 \times 10^6\ kJ/hr = 90.8 \times 10^3\ MJ/hr$$

Saturated Steam Conditions

$$P = 1.2bar,\ T = 105^oC,\ \lambda = 2244.1\ kJ/kg$$

Saturated Steam Produced

$$Q = mCp\Delta T + m\lambda$$

$$Cp \text{ at } T_{avg}\ (88.5^oC) = 4.2\ kJ/kg.\ K$$

$$m = 35.2 \times 10^3\ kg/hr$$

Table 4.17: Energy Balance on WHB-109

Components	**Specific heat capacity at T_{avg}= 67.5°C**	**Heat load**
	Cp (KJ/kg.K)	**(MJ/hr)**
FFA	1.98	90.8×10^3
T.G	2.2	
H2SO4	1.9	
Methanol	2.8	
Methyl ester	2.06	
Water	4.2	
KOH	1.47	
Glycerol	2.5	

CHAPTER 05

EQUIPMENT DESIGN

5.1 Design of CSTR (R-101)

Reactors are vessels used in chemical processing plants to create desired products through chemical reactions.

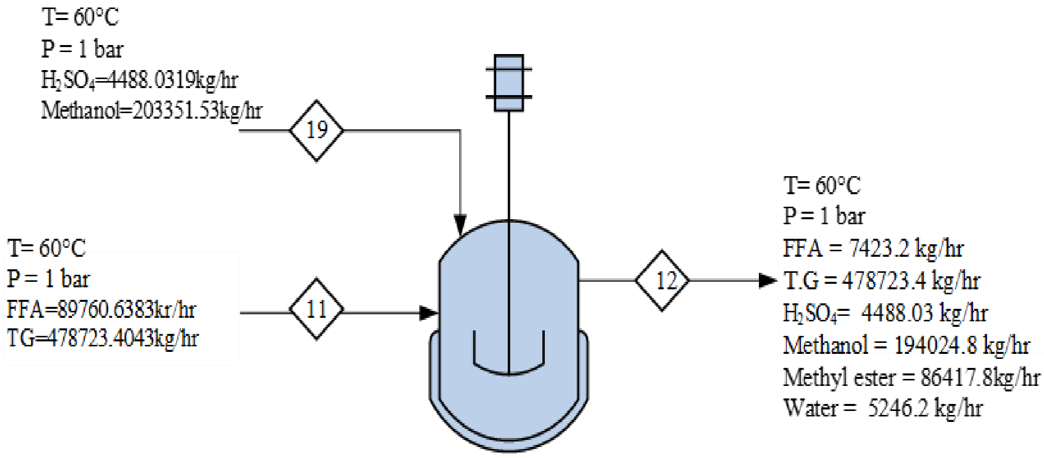


Figure 5.1: Design of Reactor (R-101)

Types of Reactors

There are two main types of reactors.

1. Tubular reactors
2. Stirred tank reactor

The ideal reactor is one in which the attiring is so effective that the inside is uniformly heated and composed. The simple reactors may be operated in numerous models i.e.

- Batch reactors
- Semi batch reactors
- Continuous flow

Reactant elements flow through tubes in a tubular reactor as plugs that are moving parallel to the axis. The flow pattern is also known as a piston or plug flow. It is assumed that there is no axial diffusion or back mixing of the fluid components, and that the velocity profile at a given cross section is flat.

Why I Choose CSTR

We have selected MFR because

The above reaction is

- Moderately endothermic
- Homogenous (liquid)

Design Steps

- Calculating the Volume of the reactor.
- Calculating the length & Diameter of reactor
- Calculating the Power of Impeller.
- Calculating the Cooling jacket Design

Reaction

$$\text{FFA} + \text{methanol} \xrightarrow{k_1} \text{methyl ester} + \text{water}$$

Order = n = 1

Heat of Reaction

$$\Delta H_r = \frac{16.85\times10^6 \text{KJ}}{\text{hr}} \times \frac{0.239\ \text{kcal}}{\text{KJ}} \times \frac{\text{hr}}{317.7\ \text{kmol}} \times \frac{\text{kmol}}{1000\ \text{mol}}$$

= 13 kcal/mol (endothermic)

Temperature and Pressure

- Operating temperature = 60 ^oC
- Operating pressure = 1 bar

Conversion of Reaction

$$X_{FFA} = 92\ \%$$

Design Equation of CSTR

$$\frac{V}{F_{AO}} = \frac{X_A}{-r_A} \quad \textbf{5.1}$$

Rate Equation for the Reaction

$$-r_A = k_1 \times C_{FFA} \ \ [24] \quad \textbf{5.2}$$

$$= k_1 \times C_{FFAO} \times (1 - X_{FFA})$$

Volume of Reactor

$$\frac{V}{F_{AO}} = \frac{X_A}{k_1 \times C_{FFAo} \times (1 - X_{FFA})} \quad \textbf{5.3}$$

F_{FFAO} = molar feed rate of key component

$$F_{FFAo} = \frac{89760.6\ \text{kg/hr}}{282.5\ \text{kg/kmol}}$$

Converting mass to molar flow rate.

$$F_{FFAo} = 317.7\ \text{kmol/hr}$$

Now we will find C_{FFAo}

$$F_{FFAo} = v_o \times C_{FFAo} \qquad \textbf{5.4}$$

To find volumetric flowrate

$$v_o = \frac{m}{\rho}$$

$$= \frac{89760.6\ kg/hr}{867.4\ kg/m^3}$$

$$= 103.5\ m^3/hr$$

Now,

$$C_{FFAo} = \frac{F_{FFAo}}{v_o}$$

$$= \frac{317.7\ kmol/hr}{103.5\ m^3/hr}$$

$$= 3.1\ kmol/m^3$$

From literature kinetic constant is

$$k = 1.81\ min^{-1}$$

$$= \frac{1.81}{min} \times \frac{60\ min}{hr}$$

$$= 108.6\ hr^{-1}$$

Now finding the volume of the reactor

$$\frac{V}{F_{AO}} = \frac{X_A}{k_1 \times C_{FFAo} \times (1 - X_{FFA})}$$

$$\frac{V}{317.7\ \frac{kmol}{hr}} = \frac{0.92}{\frac{108.6}{hr} \times 3.1 \frac{kmol}{hr} \times (1 - 0..92)}$$

V = 11 m^3

For ease of operation we will divide it into two reactors of equal volume

V = 5.5 m^3

Adding safety allowance 5%

V = 5.8 m^3

Length and Diameter of Reactor

$$\frac{L}{D} = 1.15$$

L = 1.15D

Also,

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

D = 1.9 m

L = 2.2 m

Space Time

Space time = τ = $\frac{volume\ of\ reactor}{volumetric\ flow\ rate}$ **5.5**

$$= \frac{5.8 m^3}{103.5\ m^3/hr}$$

= 0.06 hr

= 3.4 min

Impeller Selection

Table 5.1: Types of Impellers

Factors/Types	Propellers	Paddles	Turbine
Viscosity	For Low to Moderate Viscous Liquids	For Moderate Viscous Liquids	For Low to High Viscous Liquids
Flow Pattern	For Axial Flow	For Tangential Flow	For Radial and Tangential Flow, sometimes Axial Flow also.
Types	Square Pitched Marine Propellers	Flat Paddle, Anchor Agitator	Vertical Flat Curved, and Pitched Blade
No. of Blades	3-blade,4-Blade Toothed	2 and 4 bladed Paddles	2-8 Blades
RPM Ranges	400-800, 1150-1750	20-150	50-250

- One can notice that there are no axial flow impellers in the reactors.
- The selected impeller is disk style flat blade turbine which is commonly referred to the as Rushton impeller, which is a radial flow impeller.
- At reaction temperature, the mixture's weighted viscosity is 5.9 cp, which is within the impeller range.
- It can be operated at reasonable speed
- Wide range of applications.
- Maximum radial flow no back mixing.
- Less power requirement.
- Promote heat transfer between the liquid and a coil or jacket
- High mass transfer between phases

Impeller Design

$\frac{Da}{Dt} = 1/3$ Da=0.63m

$\frac{H}{Dt} = 1$ H =1.9 m

$\frac{J}{Dt} = 1/12$ J=0.16 m

$\frac{E}{Dt} = 1/3$ E =0.63 m

$\frac{W}{Da} = 1/5$ W = 0.13 m

$\frac{L}{Da} = 1/4$ L = 0.16 m

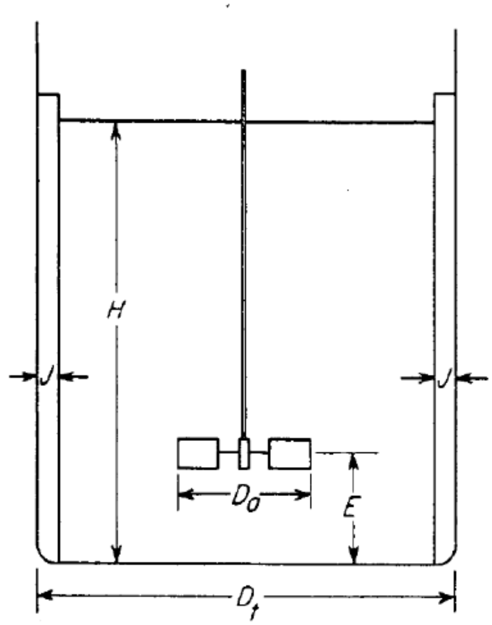


Figure 5.2: Reactor Dimensions

Where,

Da=Diameter of impeller

Dt=Tank diameter

H=Depth of liquid in tank

J =Width of baffles

E =Hight of impeller above vessel flow

W =impeller width

L =length of impeller blade

Reynolds Number

Taking revolutions of impeller

n = 80 rev/min

$$Re = \frac{Da^2 \times n \times \rho}{\mu} \qquad \textbf{5.6}$$

= 6920.1

From fig 10.6 (Chemical Process Equipment by Walas)

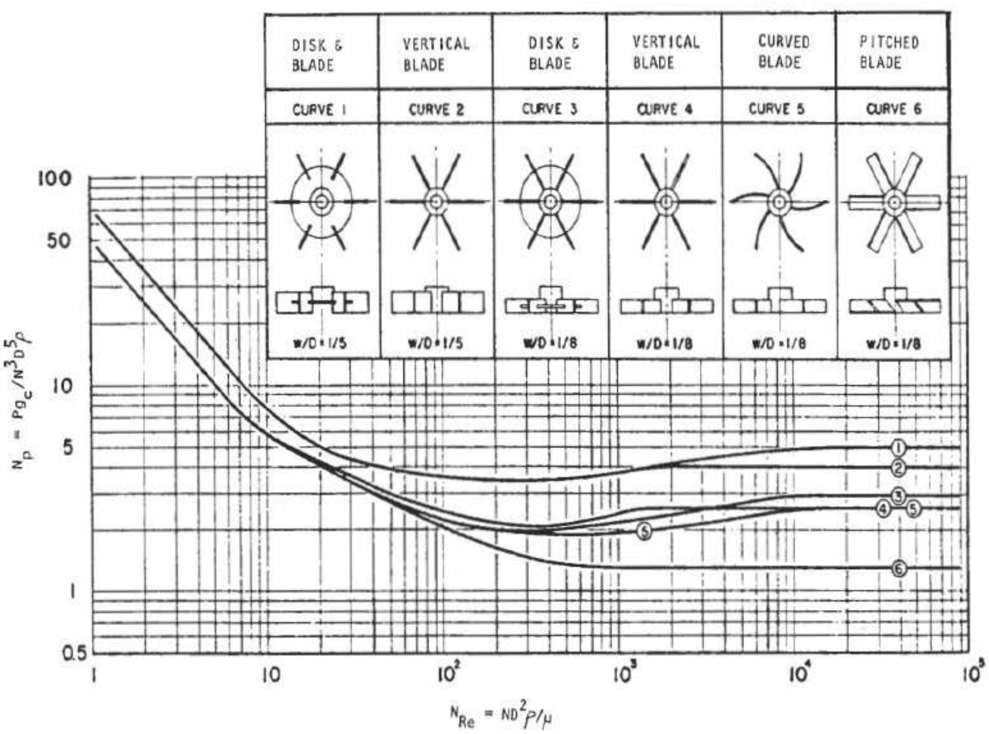


Figure 5.3: Reynolds Number Graph

From Reynolds number

Np = 3.5

Power Calculations

$$Np = \frac{P}{N^3 \rho D^5}$$

P = 473 watt = 0.6 hp

Jacket Selection Criteria

We have selected dimple jacket because

- Suitable for low to moderate heat transfer rates
- Used for circulating steam and hot oil
- It has low pressure drop

Design of Heating Jacket

Following are the cooling arrangements for continuous stirred tank reactors:

- Jackets
- Internal coils
- External coils

Selection of Jacket

In terms of control, effectiveness, and product quality, Jacket offers the best way to heat and cool a process vessel.

There are now three primary categories of jackets.

- Spiral baffle Jacket
- Half pipe coil Jacket
- Dimple jacket

Jacket Selection

The following factors should be taken into account while choosing the sort of jacket to wear:

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. The pressure rating of the designs can be used as a general guide and is as follows:

- Jackets, up to 10bar.
- Half-pipe up to 40bar.
- Dimple jacket up to 70bar.

So, for high pressure, dimple jackets would be employed.

Area of Jacket

Assuming that 95% of area of reactor is covered with jacket

$$A_j = \frac{\pi \times D^2}{2} + \pi \times D \times L \times (0.95) = 15.3\ m^2$$

Tank Side Calculations

- **Reynolds Number**

$$Re = \frac{\rho \times n \times L^2}{\mu} = 84387$$

- **J_H Factor**

From figure 20.2 (Process Heat Transfer by Kern)

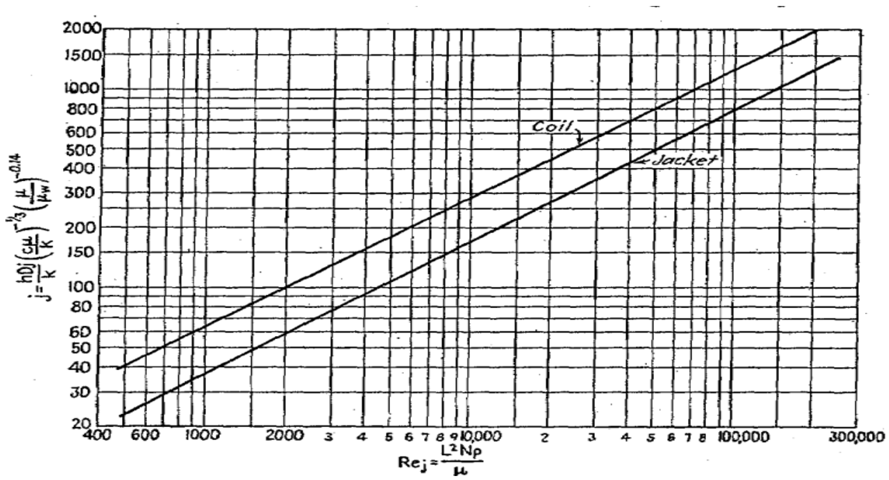


Figure 5.4: Heat Transfer Coefficient Graph

J = 700

$$J = \frac{h_i \times D}{k} \times \left(\frac{C_p \times \mu}{k}\right)^{-0.3} \times \left(\frac{\mu}{\mu_w}\right)^{-0.14}$$

$$h_i = 240\ W/m^2.K$$

$$(\frac{\mu}{\mu_w})^{-0.14} = 1\ (for\ water)$$

Jacket Side Calculations

- **Steam Heat Transfer Coefficient**

$$h_o = 7315.3\ W/m^2.K$$

- **Overall Heat Transfer Coefficient**

$$Uc = \frac{h_i \times h_o}{h_i + h_o} \quad \textbf{5.7}$$

$$= 232.4\ W/m^2.K$$

$$\frac{1}{U_D} = \frac{1}{U_c} + R_d$$

$$U_D = 120\ W/m^2.K$$

SPECIFICATION SHEET					
Identification					
Item			Reactor		
Item no.			R-101		
No. required			2		
Operation			Continuous		
Type			Mixed flow reactor		
Function					
Esterification of Fatty acids					
Chemical reaction FFA + methanol → methyl ester + water					
Reactor		**Impeller**		**Jacket**	
Length	2.2m	**Length**	0.6m	**Area**	15.3 m^2
Diameter	1.9m	**Height**	1.9 m	**Heat transfer coefficient**	7315.3 $W/m^2.K$
Volume	5.8 m^2	**Power**	0.65 hp	**Overall transfer coefficient**	120 $W/m^2.K$

5.2. Design of CSTR (R-102)

Reactors are vessels used in chemical processing plants to create desired products through chemical reactions.

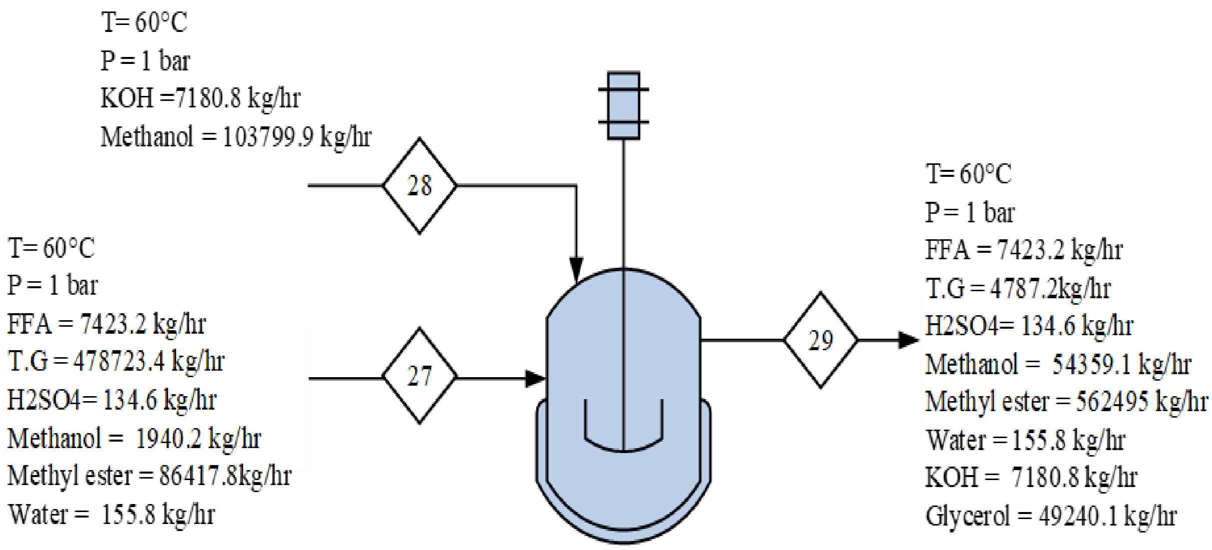


Figure 5.5: Design of Reactor (R-102)

Selection of Appropriate Type

We have selected MFR, because

As the reaction is

- Highly exothermic
- Homogenous (liquid)
- Series reaction (production distribution is to be controlled)

Design Steps

- Calculating the Volume of the reactor.
- Calculating the length & Diameter of reactor
- Calculating the Power of Impeller.
- Calculating the Cooling jacket Design

Reactions

Order = n =2

Conversion = X_{TG}= 99%

$$\text{Triglyceride + Methanol} \underset{k_2}{\overset{k_1}{\longleftrightarrow}} \text{diglyceride + Biodiesel}$$

$$\text{Diglyceride + Methanol} \underset{k_4}{\overset{k_3}{\longleftrightarrow}} \text{monoglyceride + Biodiesel}$$

$$\text{Monoglyceride + Methanol} \underset{k_6}{\overset{k_5}{\longleftrightarrow}} \text{glycerol + Biodiesel}$$

Overall Reaction

$$\text{Triglyceride + 3 Methanol} \underset{k_8}{\overset{k_7}{\longleftrightarrow}} \text{3 Biodiesel + Glycerol}$$

Heat of Reaction

$$\Delta H_r = \frac{-290\times10^6 \text{KJ}}{\text{hr}} \times \frac{0.239 \text{ kcal}}{\text{KJ}} \times \frac{\text{hr}}{535 \text{ kmol}} \times \frac{\text{kmol}}{1000 \text{ mol}}$$

= -190 kcal/mol (exothermic)

Temperature and Pressure

- Operating temperature = 60 ^{o}C
- Operating pressure = 1 bar

Design Equation of CSTR

$$\frac{V}{F_{AO}} = \frac{X_A}{-r_A}$$

Rate Equation for the Reaction

From literature [25]

$$r_A = k_1 \times C_{TG} \times C_m + k_2 \times C_{DG} \times C_m - k_7 \times C_{TG} \times C_m^3 + k_8 \times C_m \times C_{GL}^3 \qquad \textbf{5.8}$$

C_{DG} = 0 (100% conversion)

$$r_A = k_1 \times C_{TG} \times C_m - k_7 \times C_{TG} \times C_m^3 + k_8 \times C_m \times C_{GL}^3$$

Volume of Reactor

- **Concentration of Triglycerides**

$$F_{TGo} = \frac{478723.4 \frac{kg}{hr}}{885.5 \frac{kg}{kmol}}$$

= 540.6 kmol/hr

$$F_{TGo} = v_o \times C_{TGo}$$

$$v_o = \frac{m}{\rho}$$

$$v_o = \frac{478723.4\,\frac{kg}{hr}}{1792\ kg/m^3}$$

= 267.1 m^3/hr

Now,

$$C_{TGo} = \frac{F_{TGo}}{v_o}$$

$$= \frac{540.6\,\frac{kmol}{hr}}{267.1\,\frac{m^3}{hr}}$$

= 2.02 kmol/m^3

$$C_{TG} = C_{TGo}(1 - X_{TG})$$

= 0.02 kmol/m^3

- **Concentration of Methanol**

$$F_{Mo} = \frac{105740.1\,\frac{kg}{hr}}{32\,\frac{kg}{kmol}}$$

= 3304.4 kmol/hr

$$F_{Mo} = v_o \times C_{Mo}$$

$$v_o = \frac{m}{\rho}$$

$$v_o = \frac{105740.1\,\frac{kg}{hr}}{770\,\frac{kg}{m^3}}$$

= 137.3 m^3/hr

Now,

$$C_{Mo} = \frac{F_{Mo}}{v_o}$$

$$= \frac{3304.4\,\frac{kmol}{hr}}{137.3\,\frac{m^3}{hr}}$$

= 24.1 kmol/m^3

$$C_M = C_{mo} - C_{TG}\ X_{TG}$$

= 22.1 kmol/m3

- **Concentration of Glycerol**

$$\mathrm{C_{Gl}} = \frac{\mathrm{F_{GL}}}{\mathrm{v_{GL}}}$$

= 13.7 kmol/m^3

- **Values of Rate Constant, k**

From literature

k_1 = 180 m^3/kmol.hr

k_7 = 0.28 m^3/kmol.hr

k_8 = 6.69×10^{-4} m^3/kmol.hr

So, volume of reactor will be

V = 5 m^3

Safety allowance = 5%

V = 5.6 m^3

Length and Diameter of Reactor

$$\frac{L}{D} = 1.15$$

L = 1.15D

Also,

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

D = 1.8 m

L = 2 m

Impeller Selection

Table 5.2: Characteristics and Types of Impellers

Factors/Types	Propellers	Paddles	Turbine
Viscosity	For Low to Moderate Viscous Liquids	For Moderate Viscous Liquids	For Low to High Viscous Liquids
Flow Pattern	For Axial Flow	For Tangential Flow	For Radial and Tangential Flow, sometimes Axial Flow also.
Types	Square Pitched Marine Propellers	Flat Paddle, Anchor Agitator	Vertical Flat Curved, and Pitched Blade
No. of Blades	3-blade,4-Blade Toothed	2 and 4 bladed Paddles	2-8 Blades
RPM Ranges	400-800, 1150-1750	20-150	50-250

- One can notice that there are no axial flow impellers in the reactors.

- The selected impeller is disk style flat blade turbine which is commonly referred to the as Rushton impeller, which is a radial flow impeller.
- The weighted viscosity of mixture at reaction temperature is 6.5 cp which lies in the range of impeller.
- It can be operated at reasonable speed
- Wide range of applications.
- Maximum radial flow no back mixing.
- Less power requirement.
- Promote heat transfer between the liquid and a coil or jacket
- High mass transfer between phases

Impeller Design

$\frac{Da}{Dt} = 1/3$ Da=0.6 m

$\frac{H}{Dt} = 1$ H =1.8 m

$\frac{J}{Dt} = 1/12$ J=0.15 m

$\frac{E}{Dt} = 1/3$ E =0.6 m

$\frac{W}{Da} = 1/5$ W = 0.12 m

$\frac{L}{Da} = 1/4$ L = 0.15 m

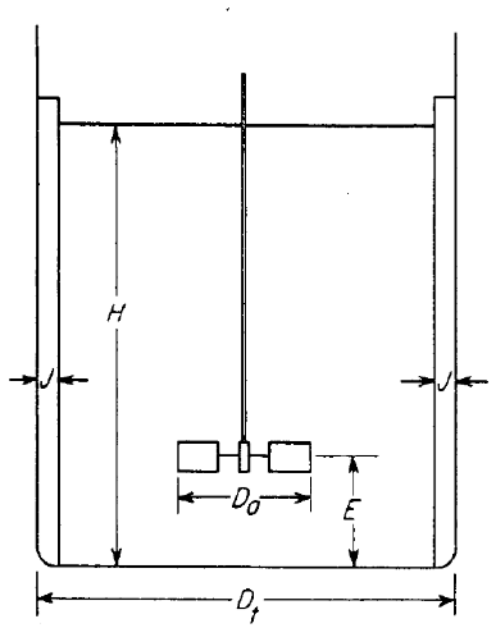


Figure 6.6: Dimensions of Reactor

Where,

Da=Diameter of impeller

Dt=Tank diameter

H=Depth of liquid in tank

J =Width of baffles

E =Hight of impeller above vessel flow

W =impeller width

L =length of impeller blade

Reynolds Number

Taking revolutions of impeller

n = 80 rev/min

$$Re = \frac{Da^2 \times n \times \rho}{\mu}$$

= 129024

From fig 10.6 (Chemical Process Equipment by Walas)

From Reynolds number

Np = 3.5

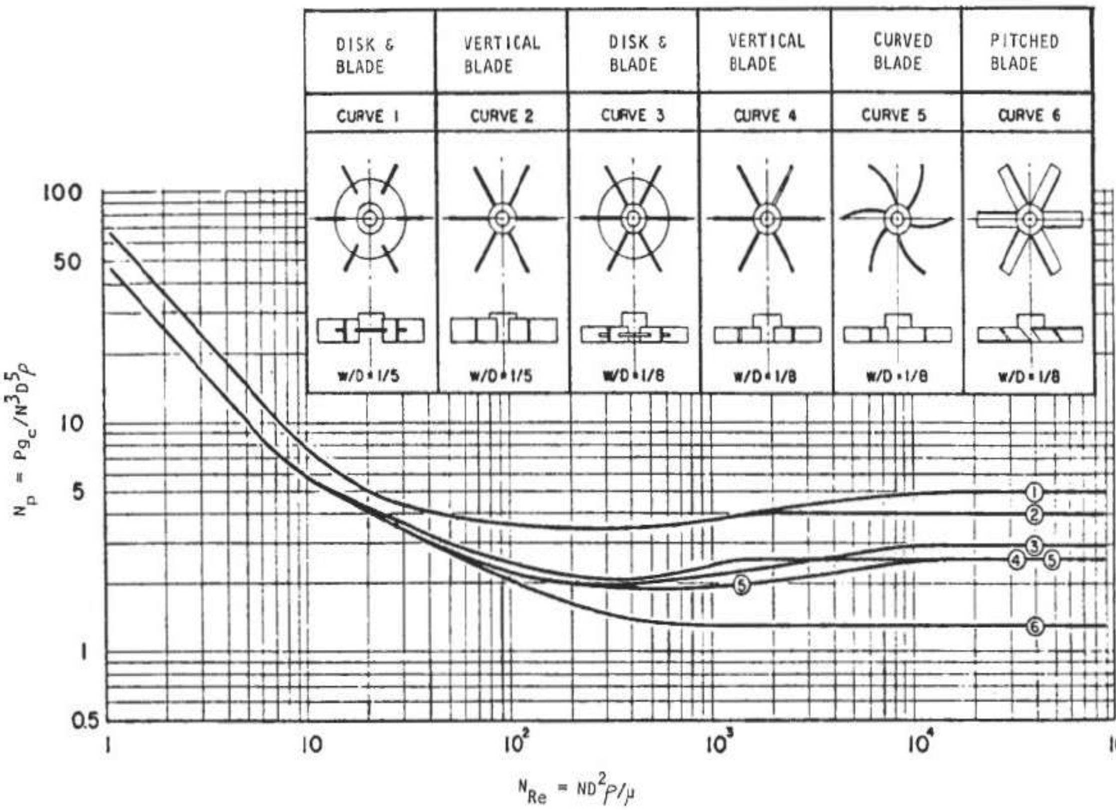


Figure 5.7: Power number and Reynolds number Graph

Power Calculations

$$P = N_p \times n^3 \times \rho \times D_a^5 \quad \textbf{5.9}$$

P = 473 watt = 0.6 hp

Design of Cooling Jacket

The cooling configurations for continuous stirred tank reactors are as follows:

- Jackets
- Internal coils
- External coils

In terms of control, effectiveness, and product quality, a jacket offers the best way to heat and cool a process vessel.

There have been three primary categories of jackets.

- Spiral baffle Jacket
- Half pipe coil Jacket
- Dimple jacket

The following factors should be taken into account while choosing the sort of jacket to wear:

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 significant amount of transfer of heat is necessary, consider a spirally baffled or half-pipe jacket.

3. As a general rule, the pressure rating of the designs can be interpreted as:

- Jackets, up to 10bar.
- Half-pipe up to 40bar.
- Dimple jacket up to 70bar.

So, for high-pressure applications, dimple jackets would be employed.

Jacket Selection

We have selected spiral Jacket because,

- Here high heat transfer rate is required
- The other reason is that it is less costly than other types of jacket
- Suitable for pressure range of 1-10 bar

Jacket Side Calculation

Spacing between jacket and vessel = 50 -300 mm

We have selected 175 mm

Pitch between spirals = 200 mm

Height of jacket = 95% of reactor height

= 1.8 m = 1800 mm

$$number\ of\ spirals = \frac{height\ of\ jacket}{pitch}$$

$$= \frac{1800\ mm}{200\ mm} = 9$$

- **Cross Sectional Area of Channel**

= spacing between jacket and vessel × pitch

= 175 mm × 200 mm

= 35×10^{3} mm^2 = 35×10^{-3} m^2

- **Hydraulic Mean Dia**

$$d_e = \frac{4\times\text{cross sectional area}}{\text{wetted parameter}}$$

$$= \frac{4\times(35\times10^{3})}{2\times(175+200)}$$

= 187 mm

- **Velocity through Channels**

$$= \frac{flow\ rate}{density\times cross\ sectional\ area}$$

$$= \frac{8979\frac{kg}{hr}}{3600}\times\frac{1}{983\frac{kg}{m^3}}\times\frac{1}{35\times10^{-3}m^2}$$

= 0.1 m/s

- **Reynolds Number**

$$Re = \frac{\rho\times v\times D}{\mu}$$

= 39110

- **Prandtl Number**

$$\text{Pr} = \frac{C_p\times\mu}{k} = 3$$

- **Nusselt Number**

$$Nu = C\times R_e^{0.8}\times P_r^{0.33}$$

For non-viscous fluids

$$C = 0.023$$

$$Nu = 156$$

- **Heat Transfer Coefficient Jacket Side**

$$h_j = \frac{N_u \times k}{de} = 534 \text{ W/m}^2\text{.K}$$

Tank Side Calculations

- **Reynolds Number**

$$Re = \frac{\rho \times D2}{\mu} = 89324$$

- **Prandtl Number**

$$Pr = \frac{C_p \times \mu}{k} = 3.7$$

$$h_t D/\lambda = 0.73(\rho D^2/\mu)^{0.33}(C_p\mu/k)^{0.66}(\mu/\mu_s)^{0.1}$$

$$h_t = 574 \text{ W/m}^2\text{.K}$$

- **Overall Heat Transfer Coefficient**

$$U_d = \frac{h_j \times h_t}{h_j + h_t} = 197 \text{ W/m}^2\text{.K}$$

Area of Jacket

Assuming that 95% of area of reactor is covered with jacket

$$A_j = \frac{\pi \times D^2}{2} + \pi \times D \times L \times (0.95) \qquad \textbf{5.10}$$

$$= 13.3 \text{ m}^2$$

SPECIFICATION SHEET	
Identification	
Item	Reactor
Item no.	R-102
No. required	1
Operation	Continuous
Type	Mixed flow reactor

Function
Transesterification for the production of biodiesel
Chemical reactions
Triglyceride + Methanol ⟷ diglyceride + Biodiesel
Diglyceride + Methanol ⟷ monoglyceride + Biodiesel
Monoglyceride + Methanol ⟷ glycerol + Biodiesel

Reactor		**Impeller**		**Jacket**	
Length	2m	**Length**	0.6m	**Area**	13.3 m^2
Diameter	1.8m	**Height**	1.8 m	**Heat transfer coefficient**	574 $W/m^2.K$
Volume	5.6 m^2	**Power**	0.6 hp	**Overall transfer coefficient**	197 $W/m^2.K$

5.3 Design of Evaporator V-101

Falling Film Evaporator

A falling-film evaporator, which lowers its liquid film, operates on similar principles. The most fundamental and popular kind of film evaporator is the falling-film evaporator. In this apparatus, a thin layer of liquid moves through heated, vertical tubes that are gravity-driven, and the produced vapour normally moves with the liquid in the tubes' centers. The evaporator, a separator to separate the vapors from the leftover liquid, and a condenser make up an entire evaporator stage. A portion of the concentrated liquid is recycled back to the evaporator take in when high evaporation ratios are required to make sure the tubes are adequately moistened.

Advantages of Falling Film Evaporator

- high coefficients of heat transfer
- pressure drops are low
- suitability for vacuum operation
- high ratios of evaporation
- wide range of operating
- poor sensitivity to fouling
- minimum cost of operation

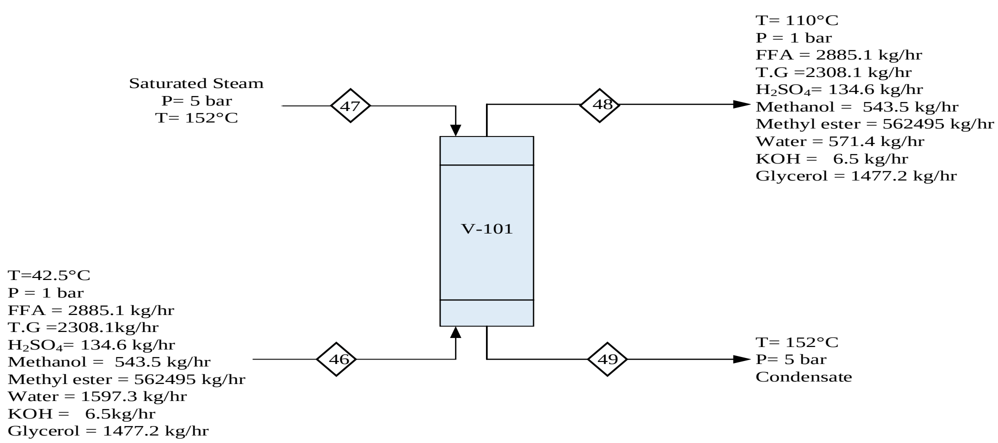


Figure 5.8: Design of Evaporator (V-101)

Heat Load

$$Q = mCp\Delta T$$

$$\Delta T = 383^{o}K - 315.6^{o}K$$

$$\Delta T = 323^{o}K$$

$$C_p = 2.15 KJ/kg.\ K$$

$$m = 0.0004\ kg/s$$

$$Q = 0.001 kg/s$$

Log Mean Temperature Difference (LMTD)

$$LMTD = \frac{\Delta t_2 - \Delta t_1}{\ln \Delta t_2/\Delta t_1} \quad \textbf{5.11}$$

$$\Delta t_2 = T_2 - t_1 = 365^{o}K$$

$$\Delta t_1 = T_1 - t_2 = 297^{o}K$$

$$LMTD = \frac{197 - 75.6}{\ln(197/75.6)}$$

$$LMTD = 325.7^{o}K$$

Correction Factor

$$F_T = 1$$

$$\text{Corrected LMTD} = LMTD \times F_T$$

$$\Delta t = 325.7^{o}K$$

Calculate Area

Assume U_D

$$U_D = 14306\ KJ/hr.m^2.\ K$$

$$A = Q/U_D\Delta t$$

$$A = \frac{7.1\times10^{7}}{700\times126.7}$$

$$A = 74.7 m^2$$

Tube Specifications

$$L = 4.8m$$

$$OD = 0.019\ m$$

$$BWG = 16$$

$$a_t = 0.03m^2$$

No. of Tubes

$$N_t = A/L\times a_t \qquad \textbf{5.12}$$

$$N_t = 153$$

We have selected 1 1/4 in OD, 1 in triangular spacing, 1 tube passes

$$\text{Corrected } N_t = 170$$

$$\text{Area} = N_t\ L\times a_t$$

$$\text{Area} = 170\times16\times0.3271$$

$$\text{Area} = 82.6m^2$$

Flow Area

- **Shell Side (Hot Fluid)**

$$As = (\text{area of shell}) - (\text{area of tube}) \qquad \textbf{5.13}$$

$$a_s = \frac{1}{144}\left[\pi\frac{ID2}{4} - N_t\pi\frac{OD2}{4}\right]$$

$$a_s = 0.18m^2$$

- **Tube Side (Cold Fluid)**

$$a_t = \frac{Nt\times at'}{144\times n} \qquad \textbf{5.14}$$

$$a_t = \frac{170\times 0.985}{144\times1}$$

$$a_t' = 0.09m$$

$$a_t = 0.107m^2$$

Mass Velocity

- **Shell Side (Hot Fluid)**

$$G_s = W/a_s \qquad \textbf{5.15}$$

$$W = 4.63 kg/s$$

$$G_s = 2.55 \frac{kg}{m2.s}$$

- **Tube side (Cold fluid)**

$$G_t = W/a_t$$

$$W = 0.0001 \ kg/s$$

$$G_t = 1334 \frac{kg}{m2.s}$$

Reynolds Number

- **Shell side (Hot Fluid)**

$$Re_s = DeGs/\mu \qquad \textbf{5.16}$$

$$\mu = 0.0004 \ Pa. \ s$$

$$De = \frac{4 \times as}{Nt\pi OD/12}$$

$$De = 0.04m$$

$$Re_s = \frac{0.14 \times 1886}{0.104}$$

$$Re_s = 2538$$

For Steam

$$h_{io} = 8517 \ W/m^2. \ K$$

- **Tube Side (Cold Fluid)**

$$Re_t = DGt/\mu$$

$$\mu = 0.0013 \ Pa. \ s$$

$$D = 0.028m$$

$$Re_s = \frac{0.093 \times 983823}{3.41}$$

$$Re_t = 25966$$

$$j_H = 80$$

$$C_p = 2.15KJ/kg.\ K$$

$$k = 0.56\ \ W/m^2.\ K$$

$$(C_p\mu/k)^{1/3} = 2.6$$

$$h_o = j_H(K/D)\ (C_p\mu/k)^{1/3}\Phi s$$

$$h_o = 1254\ W/m^2.\ K$$

Clean Overall Coefficient Uc

$$U_c = \frac{h_{io} \times ho}{h_{io} + ho}$$

$$U_c = \frac{1500 \times 221}{1500 + 221}$$

$$U_c = 1095\ W/m^2.\ K$$

Design Overall Coefficient U_D

$$1/U_D = 1/Uc + Rd$$

$$R_d = 0.003\ (Assume)$$

$$U_D = 692\ W/m^2.\ K$$

Dirt Factor R_d

$$R_d = \frac{Uc - UD}{Uc \times UD} \quad \textbf{5.17}$$

$$R_d = \frac{193 - 122}{193 \times 122}$$

$$R_d = 0.017\ W/m^2.\ K$$

Pressure Drop

- **Shell Side (Hot Fluid)**

$$De' = 4 \times \frac{Flow\ area}{Wetted\ Parameter} \quad \textbf{5.18}$$

$$De' = 0.036m$$

$$Re'_s = 2176$$

$$f = 0.0004$$

$$s = 0.0931$$

$$\Delta P_s = \frac{fGs^2DeLn}{5.22 \times 10^{\wedge}10De's\Phi s} \quad \textbf{5.19}$$

$$\Delta P_s = 0.0003\ Psi$$

- **Tube Side (Cold Fluid)**

$$Re_t = 25966$$

$$f = 0.00021$$

$$s = 0.143$$

$$\Delta P_t = \frac{fG_t^2Ln}{5.22 \times 10^{\wedge}10Ds\Phi_t}$$

$$\Delta P_t = 4.7\ Psi$$

SPECIFICATION SHEET			
Identification			
Item	Evaporator		
Item no.	V-101		
No. required	1		
Type	Falling Film Evaporator		
Operation	Continuous		
Function			
Evaporate Water			
Heat Duty = **7.56KJ/hr**			
Heat transfer area = **74.7m²**			
Shell side		**Tube side**	
Operating pressure	1 bar	**Operating pressure**	1 bar
Temperature in/out	151ºC	**Temperature in/out**	42 - 110ºC
Shell inner dia	0.63m	**Tube inner dia**	0.02m
Passes	1	**No. of tubes**	170
Pressure Drop	0.0003Psi	**Pressure Drop**	4.7 Psi

5.4. Design of Cyclone (CS-101)

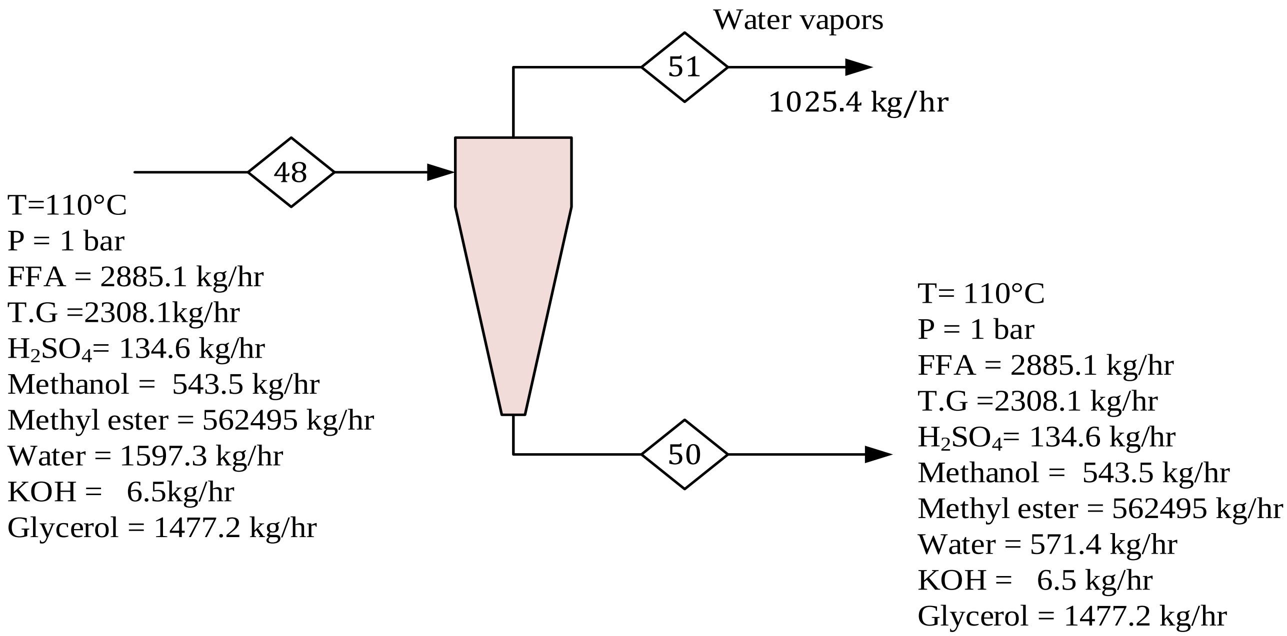


Figure 5.9: Design of Cyclone (CS-101)

Mass flow rate = m = 571446.6 kg/hr

$$\text{Q(volumetric flowrate)} = \frac{571446.8\,\frac{\text{kg}}{\text{hr}}}{910\,\frac{\text{kg}}{\text{m}^3} \times 3600}$$

$$Q = 0.17\ \text{m}^3/\text{sec}$$

Standard velocity taken as

$$v = 9\ \text{-}27\ \text{m/s}$$

we are taking average velocity as

$$v = 18\ \text{m/s}$$

$$\text{inlet duct area} = \frac{\text{volumetric flowrate}}{\text{velocity}}$$

$$= \frac{0.17\,\frac{m^3}{s}}{18\,\frac{m}{s}}$$

$$= 0.009\ m^2 \approx 0.01\ m^2$$

Duct area = 0.5Dc × 0.2Dc

$$0.01 = 0.1\ Dc^2$$

$$Dc = \sqrt{\frac{0.01}{0.1}}$$

Dc = 0.32 m (proposed)

$$no\ of\ cyclones = \frac{Dc\ proposed}{Dc\ standard} \qquad \textbf{5.20}$$

$$\text{No of cyclones} = \frac{0.32}{0.203} = 2$$

Calculation for Single Cyclone

$$flowrate\ of\ liquid = \frac{571446.8\frac{kg}{hr}}{2}$$

$$= 285723.4\frac{kg}{hr}$$

Volumetric flowrate = 0.13 m^3/s

$$inlet\ duct\ area = \frac{volumetric\ flowrate}{velocity}$$

$$= \frac{0.13}{18} = 0.0072\ m^2$$

Duct area = 0.5Dc × 0.2Dc

Dc = 0.27 m

$$\text{Total height} = 1.5Dc + 2.5\ Dc \qquad \textbf{5.21}$$

= 1.1 m

- **Outlet Duct Area**

$$D_o = 0.5\ Dc$$

$$D_o = 0.14 \text{ m}$$

- **Area**

$$A = \frac{\pi \times D_o^2}{4} = 0.02\text{m}^2$$

- **Exit Duct Diameter**

$$D_e = 0.375\ D_c$$

$$= 0.1 \text{ m}$$

Calculation of Scaling Factor

$$\frac{d_2}{d_1} = \left[\left(\frac{D_{c2}}{D_{c1}}\right)^3 \times \frac{Q_1}{Q_2} \times \frac{\Delta\rho_1}{\Delta\rho_2} \times \frac{\mu_2}{\mu_1}\right]^{0.5} \qquad \textbf{5.22}$$

Where

D_{C2} = $Diamerter\ of\ cyclone$ = 0.27m

D_{C1} = $Diamerter\ of\ standard\ cyclone$ = 0.203m

Q_1 = Standard flowrate = 223 m^3/hr

Q_2 = volumetric flowrate per cyclone = 314 m^3/hr

$\Delta\rho_1$ = $Standard$ liquid $fluid$ = 1000 kg/m^3

$\Delta\rho_2$ = particle density = 525 kg/m^3

μ_2 = Gas velocity = 0.03312 mNs $/m^3$

$\mu1$ = $Standard\ viscosity$ = 0.018 mNs/m^3

$$\frac{d_2}{d_1} = 2.4$$

Number of Effective Turns

$$N = \frac{1}{4} \times \left(\frac{L_B + L_C}{2}\right) \qquad \textbf{5.23}$$

$$L_B = 1.5D_c = 0.41\text{m}$$

$$L_C = 2.5\ D_C = 0.675 \text{ m}$$

$$H = 0.5\ D_c = 0.135\ \text{m}$$

$$N = 7$$

Residence Time

$$T = \frac{\text{Path length}}{\text{speed}} = \frac{\pi \times N \times D_c}{v} = \frac{3.14 \times 0.27 \times 7}{18} = 0.33\ sec$$

Drift Velocity

$$V_t = \frac{W}{T} = \frac{0.2D_c}{T} = 0.16\frac{m}{s}$$

Pressure Drop Calculations

$$\Delta P = \frac{\rho_f}{203} \times \left[u_1^2 \times \left(1 + 2\emptyset^2\left(\frac{2r_1}{r_e} - 1\right)\right) + 2u_2^2\right]$$

Where

ΔP = cyclone pressure drop = millibar

ρ_f = Gas density at outlet = 4.69 $kg/m3$

u_1 = $Inlet\ duct\ velocity$ = 18 m/s

$$u_2 = Exit\ duct\ velocity = \frac{volumetric\ flowrate}{area\ of\ exit\ pipe} = \frac{0.13}{0.02} = 6.5\frac{m}{s}$$

$$\frac{r_1}{r_e} = 2.1$$

$$\Delta P = 0.02\ \text{bar}$$

SPECIFICATON SHEET	
Identification	
Item	Cyclone separator
Item no.	CS-101
No. required	1
Operation	Continuous
Function	
To remove water vapors from liquid mixture	
Operating pressure	1 bar
Operating temperature	110 ^oC
Inlet duct area	0.0072m^2
Diameter	0.27m
Total height	1.1m
Outlet duct area	0.02m^2
Outlet duct diameter	0.14m

5.5 Design of Distillation Column (D-102)

Distillation

"Process in which a liquid or vapor mixture of two or more substances is separated into its component fractions of desired purity, by the application and removal of heat".

The column could be packed or trayed. The column is divided into two sections: the striping section is below the feed, and the rectification (or refining) section is above the feed. The feed enters the column at a plate that is halfway up the structure.

The distillate is extracted from the column's top, and the purity is gauged by the tray count and column quality, or the reflux ratio, or R=L/D, of the condensate that is returned to the column.

Plate Selection

The mass transfer of vapors and liquids can be done in a packed column or on a plate. Both of these procedures are very different from one another. Following are the benefits of plate over packed column:

Wide ranges of liquid flow rates can be handled by plate columns without flooding.

When the flow rate of the liquid is lower compared to the flow rate of the gases, dispersion issues are handled in the plate column.

The packed column weighs higher than the plate column with tall columns. In the event that routine cleaning is necessary, manholes will be offered. Before cleaning packed columns, packaging must be removed out.

- The plate column is recommended for non-foaming systems.
- Compared to packed columns, design information for plates columns is more accessible and trustworthy.
- Inter-stage cooling can be offered to remove reaction or solution heat from the plate column.
- When there is a temperature change, packaging may be harmed.

Our processing mixture is "Non-Condensable Gases, Petrol, Diesel." I decided on the plate column because

- The system doesn't foam.
- The temperature fluctuates a much, by 370oC.
- Non-corrosive.

Types of Trays

The trays that are most frequently utilized in commercial distillation columns are

- Bubble cap tray
- Sieve tray
- Valve tray

Selection Criteria of Trays

Table 5.3: Types of Trays

Parameter	Sieve tray	Valve tray	Bubble cap tray
Capacity	High	High to very high	Moderately high
Efficiency	High	High	Moderately high
Entrainment	Moderate	Moderate	High
Pressure drop	Moderate	Moderate	High
Cost	Low	20% higher than sieve tray	2-3 times higher than sieve tray
Maintenance	Low	Moderate	High
Fouling	Low	Low to moderate	High
Effect of corrosion	Low	Moderate	High

Selection of Tray

We decided to use a sieve plate because:

- They are less expensive and lighter in weight. Installing it is simpler and less expensive.
- When compared to bubble cap trays, pressure decrease is less.
- Peak productivity is often high.
- Because cleaning is so simple, maintenance costs are decreased.

Design Steps for Distillation Column and Design Calculations

- Calculation of Bubble point and dew point
- Number of stage calculation.
- Minimum Reflux Ratio Rm Calculation
- Actual Reflux Ratio R Calculation
- Determination of Physical properties of top and bottom product.
- Diameter of the column calculation.
- Weeping point, entrainment etc. calculation
- Pressure drop calculation
- Height of the column calculation
- Iterate the value of temperature till the value of ΣY become 1.

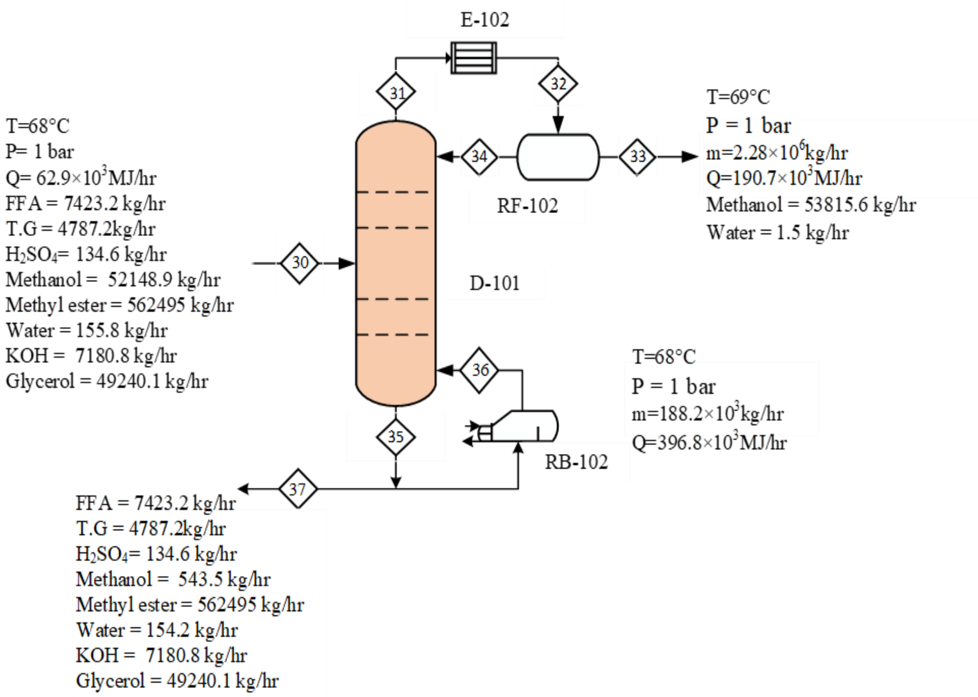


Figure 5.10: Design of Distillation Column (D-102)

Table 5-4: Relative Volatilities of Components

Components	x_f	Relative Volatility	x_d	x_w
FFA	0.006	1	0.99	0.0117
T.G	0.0012	5.61699E+21	0.01	0.0075
H2SO4	0.0003	0.0315		0.00021
Methanol	0.394	2.76		0.00086
Methyl Ester	0.441	0.0345		0.8900
Water	0.0020	1268.02		0.00024
KOH	0.0298	1267.9		0.0113
Glycerol	0.12	0.00342		0.0779

Using equation of minimum reflux ratio

$$\Sigma \frac{\alpha i x i,f}{\alpha i - \theta} = 1 - q, \text{ by trial } \theta = 1.3$$

where q = 1, putting all values

$$\Sigma \frac{\alpha i x i,d}{\alpha i - \theta} = R_m + 1, \quad \textbf{5.24}$$

$$R_m = 0.8$$

Actual Reflux Ratio

The rule of thumb is:

$$R = (1.2 \text{ ------- } 1.5)\, R_{min}$$

$$R = 1.5\, R_{min}$$

$$R = 1.2$$

- **Light Key Component**

Methanol

- **Heavy Key Component**

FFA

The minimum no. of stages N_{min} is obtained from Fenske relation which is

$$N_{min} = \frac{log\left[\frac{xLK}{xHK}\right]_d\left[\frac{xHK}{xLK}\right]_b}{log\alpha_{LK}} \quad \textbf{5.25}$$

$$N_{min} = 5$$

Gilliland correlated the minimal reflux ratio, the amount of equilibrium stages, and the number of equilibrium stages with a scheme that Eduljee turned into a relationship;

$$\frac{N - N_{min}}{N + 1} = 0.75\left[1 - \left((\frac{R - R_{min}}{R + 1})^{0.566}\right)\right]$$

From which the theoretical number of stages to be, N = 13

One plate is removed for reboiler, so, N = 13-1 = 12

Table 5.5: Top and Bottom Conditions

TOP CONDITIONS	BOTTOM CONDITIONS
$L_n = D \times R_{min}$	$L_m = L_n + F$
L_n = 1046 kgmol/hr	L_m = 5981 kgmol/hr
$V_n = L_n + D$	$V_m = L_m – B$
V_n =1046 kgmol/hr	=3069kgmol/hr
Average molecular wt. = 25 Kg/Kgmol	Average molecular wt. = 138.92Kg/Kmol
T = 69^o C	T = 68^o C
ρ_V = 1.25Kg/m^3	ρ_V = 10.72 Kg/m^3
ρ_L = 754.33 Kg/m^3	ρ_L = 959.39 Kg/m^3

Maximum Volumetric Flow Rate of Vapour

- **Top**

$$\frac{Ln \times \text{Avg mol.wt}}{3600 \times \rho v} = 7.47\ m^3s^{-1}$$

- **Bottom**

$$\frac{Vn \times \text{Avg mol.wt}}{3600 \times \rho v} = 10.97\ m^3s^{-1}$$

Maximum Volumetric Flowrate of Liquid

- **Top**

$$\frac{Lm \times \text{Avg mol.wt}}{3600 \times \rho l} = 0.012 m^3s^{-1}$$

- **Bottom**

$$\frac{Vm \times \text{Avg mol.wt}}{3600 \times \rho l} = 0.122 m^3s^{-1}$$

Diameter of Rectifying Section

$$\text{FLV} = \frac{Ln}{Vn}\sqrt{\frac{\rho v}{\rho l}} = 0.017$$

Assume tray Spacing = 0.6m

$C_{sb} = 0.12ms^{-1}$ from Graph between F_{LV} and C_{sb}

Flooding velocity is found by formula as follows,

Surface Tension = $22 dynecm^{-1}$

As a rule of thumb, 80 – 85% of flooding velocity is mostly used so we choose 80%

$$V_{nf} = C_{sb} \times \left(\frac{\sigma}{20}\right)^{0.2} \times \left(\frac{\rho L - \rho v}{\rho v}\right)^{0.5} = 3.18$$

$$U_a = V_n = 0.80 \times 3.50 = 2.54ms^{-1}$$

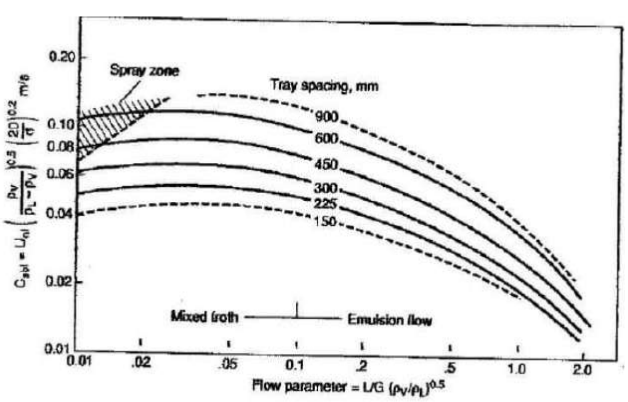


Figure 5.11: Graph Between F_{LV} and C_{sb}

For Tower Dia

Assume that down comer dia is 12% of cross-sectional area

$$A_n = 0.12\ A_c$$

$$A_n = A_d - 0.12\ A_d$$

$$A_c = V_n / U_a = 5.11 m^2$$

$$A_c = 2.94 m^2$$

$$A_c = \frac{\pi D_c^2}{4}$$

$$D_c = 1.9 m$$

Diameter of Stripping Section

$$F_{LV} = \frac{Ln}{Vn}\sqrt{\frac{\rho v}{\rho l}} = 0.204$$

Assume tray Spacing = 0.6m

$C_{sb} = 0.08 ms^{-1}$ from Graph between F_{LV} and C_{sb}

Flooding velocity is found by formula as follows,

Surface Tension = 39.16dynecm^{-1}

As a rule of thumb, 80 – 85% of flooding velocity is mostly used so we choose 80%

$$V_{nf} = C_{sb} \times \left(\frac{\sigma}{20}\right)^{0.2} \times \left(\frac{\rho L - \rho v}{\rho v}\right)^{0.5} = 0.86 ms^{-1} U_a = 0.80 \times 1.28 = 1.02 ms^{-1}$$

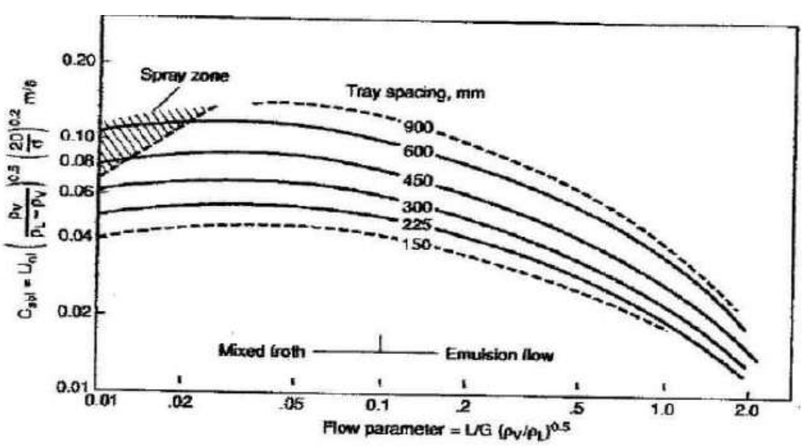


Figure 5.12: Graph Between F_{LV} and C_{sb}

For Tower Dia

Assume that down comer dia is 12% of cross-sectional area

$$A_n = 0.12\ A_c = A_d - 0.12\ A_d$$

$$A_c = V_n / U_a = 0.177 m^2$$

$$A_c = 0.47 m^2$$

$$A_c = \frac{\pi D_c^2}{4}$$

$$D_c = 1.57 m$$

Number of Holes in Rectifying Section

$$A_a = A_c - 2\ A_d = 2.24 m^2$$

Assume 10%-hole area in tray & 6mm hole dia

$$A_h = 0.1\ A_a = 0.224 m^2$$

Area of hole = 2.83 × 10^-5 m^2

Number of holes = A_h /Area of hole = 7879

Number of Holes in Stripping section

$$A_a = A_c - 2\ A_d = 0.134 m^2$$

Assume 10%-hole area in tray & 6mm hole dia

$$A_h = 0.1\ A_a = 0.0134 m^2$$

Area of hole = 2.83×10^{-5} m^2

Number of holes = A_h /Area of hole= 473

Provisional Plate Section

Column dia = 1.9 m

Column Area = 2.94m^2

Down Comer Area = $0.12A_c = 0.352m^2$

Net area = $A_c - 2A_d = 2.23m^2$

Weir Length = $(A_d/A_c) \times 100 = 12$ %

$L_w/D_c = 0.78$ by using graph

$L_w = 2.09 \times 0.78 = 1.5$ m

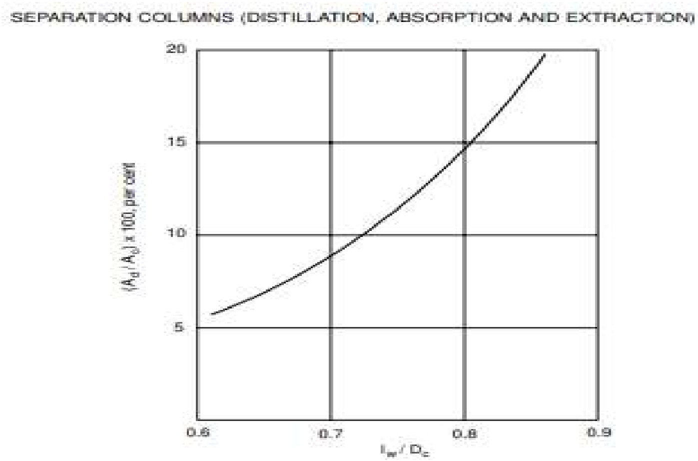


Figure 5.13: Relationship Between Down Comer Area and Weir Length

Number of Actual Stages

E = Number of Theoretical stages / No. Actual stages **5.26**

We Take Colum Efficiency 70%

Actual Stages = 12 /0.70 = 17 plates

Height of Column

((N-1) × tray spacing) + ΔH + Thickness of plate **5.27**

Tray spacing = 0.6m, ΔH = 1m,

Total thickness = 0.102m

Height of column = 10.7 m

Location of Feed Plate

The Kirk bridge method determine the ratio of trays above and below the feed point. From which,

$$\log\left(\frac{N_D}{N_B}\right) = 0.206\log\left[\left(\frac{B}{D}\right)\left(\frac{xHK}{xLk}\right)\left(\frac{(xLK)B}{(xHK)D}\right)^2\right] \quad \textbf{5.28}$$

$N_D/N_B = 0.45$

Number of Plates above the feed tray = $N_D = 5$

Number of Plates below the feed tray = $N_B = 11$

Entrainment

Un=Maximum vapour flow/ Net Area = 7.47/2.23

$= 3.3\ ms^{-1}$

$$uf = K1\sqrt{\frac{\rho L - \rho v}{\rho v}}$$

$= 4.8\ ms^{-1}$

Percent flooding =70 %

Fractional Entrainment = 0.08ms $^{-1}$

Fractional Entrainment is 0.08,

below 0.1 is satisfactory

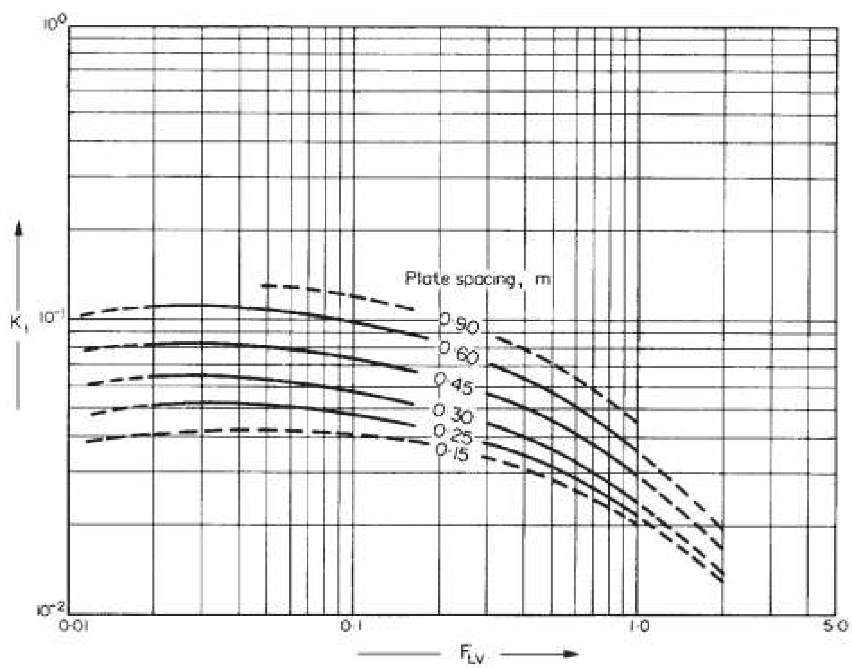


Figure 5.14: Flooding Velocity Sieve Plate

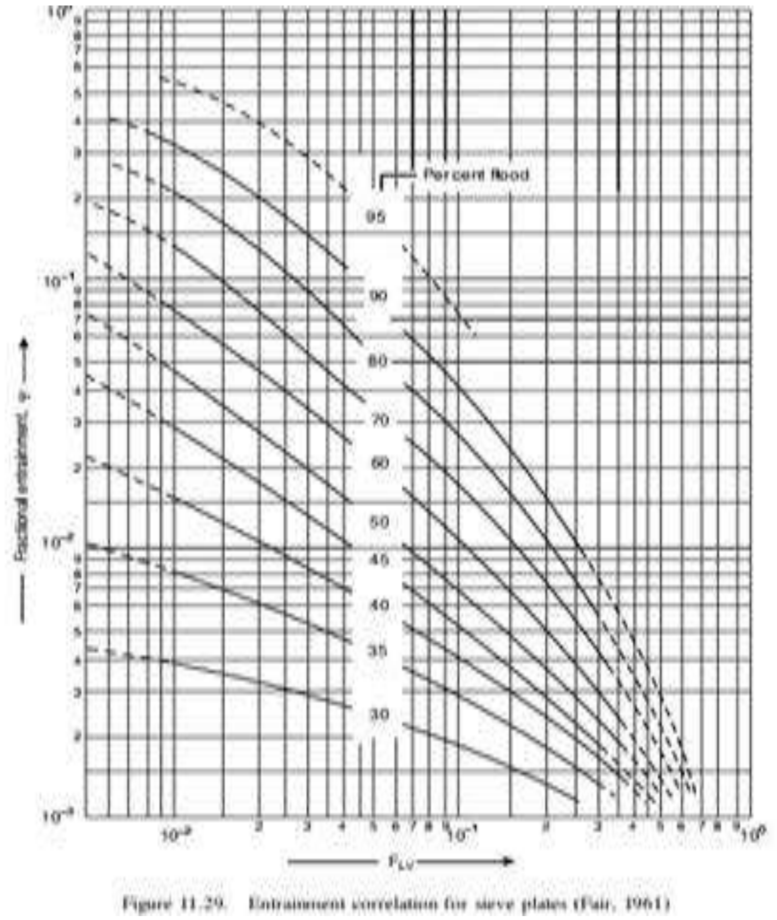


Figure 5.15: Entrainment Correlation for Sieve Plate

Weir Length

l_w = 1.5m

Take weir height = 40 mm

Hole Dia = 6mm

Plate Thickness = 6mm

Weeping

Maximum Liquid Rate = 15.63kg/s

Minimum Liquid Rate at 70% turn down

$$0.7 \times 15.63 = 10.92 \text{ kg/s}$$

$$h_{ow}max = 750\left(\frac{Lw}{\rho L \times lw}\right)^{2/3} = 43\text{mm liquid}$$

$$h_{ow}min = 750\left(\frac{Lw}{\rho L \times lw}\right)^{2/3} = 34\text{mm liquid}$$

We take h_{ow}min

$h_w + h_{ow}$min = 74 mm liquid

$$K_2 = 30.5$$

$$U_h = \left[\left(\frac{K2-0.9(25{,}4-dh)}{(\rho v)^{0.5}}\right)\right] = 12.30\text{m/s}$$

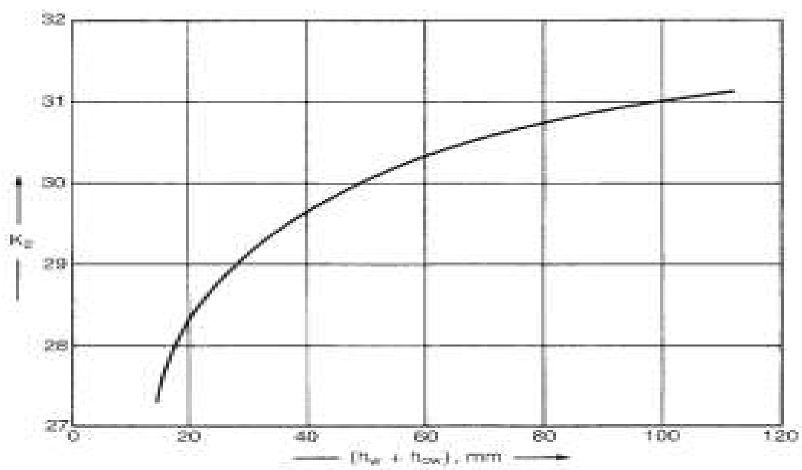


Figure 7.16: Weep Point Correlation

Plate Pressure Drop

U_h = Max vapor volumetric flow rate /Hole Area = 33m/s

$$(A_h/A_p) \times 100 = 12$$

$$Co = 0.85$$

$$hd = 51\left[\frac{Uh}{Co}\right]^2 \frac{\rho v}{\rho l} = 15.36 \text{ mm liquid}$$

Residue Head

$$h_r = \frac{(12.5 \times 10^3)}{\rho l} = 13 \text{ mm liquid}$$

Total Pressure Drop

$$h_t = hd+(h_{ow}+h_w) +h_r \qquad \textbf{5.29}$$

$$= 102.4 \text{ mm liquid}$$

$$P_t = 9.81 \times 10^{-3} ht.\rho L$$

$$= 1952 \text{ Pa}$$

$$P_t = 0.19 \text{ bar} = 0.28 \text{psi}$$

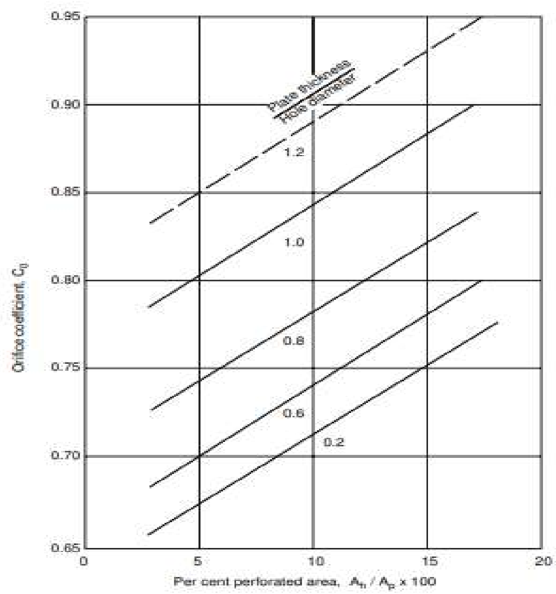


Figure 11.34. Discharge coefficient, sieve plates (Liebson *et al.*, 1957)

Figure 5.17: Discharge Coefficient Correlation

SPECIFICATION SHEET	
Identification	
Item	Distillation Column (D-101)
Type	Sieve Tray
No. of required	2
Operation	Continuous
Function	
Recovery of Methanol	
Material Balance	
Feed In	776323.09 kg/hr
Top Product	192137.031 kg/hr
Bottom Product	584186.051kg/hr
Operating Condition	
No of Trays	18
Pressure	1 bar
Reflux Ratio	1.17
Tray Spacing	0.6 m
Height of Column	11.3 m
Diameter of Column	1.67 m
Tray Thickness	0.006 m
Hole Diameter	0.006 m
Weir Length	1.31 m
Active Area	4.34m
Number of Holes	16171
Percentage Flooding	80 %
Total Pressure drop	0.23psi

SPECIFICATION SHEET	
Identification	
Item	Distillation Column (D-102)
Type	Sieve Tray
No. of required	2
Operation	Continuous
Function	
Recovery of Methanol	
Material Balance	
Feed In	685776.0292 kg/hr
Top Product	53817.21022 kg/hr
Bottom Product	631958.819 kg/hr
Operating Condition	
No of Trays	16
Pressure	1 bar
Reflux Ratio	1.2
Tray Spacing	0.6 m
Height of Column	10.7 m
Column Diamater	1.9 m
Tray Thickness	0.006 m
Hole Diameter	0.006 m
Weir Length	1.5 m
Active Area	2.23m
Number of Holes	8352
Percentage Flooding	70 %
Total Pressure drop	0.28psi

5.6. 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. This also implies that less greenhouse gases enter the atmosphere. A waste heat boiler with a water-tube design is more difficult to construct and install, but it can manage substantially higher steam pressures than a boiler with a fire-tube design. Compared to a fire-tube boiler, this type of boiler has thinner tubes that hold water rather than hot gases. A fire-tube boiler reverses the arrangement so that waste heat surrounds the water-filled tubes in the form of hot gases or furnace flames. To prevent the boiler tubes from flame damage, insulating materials are utilized. A water-tube waste heat boiler can withstand high pressures while also responding swiftly to variations in heat input.

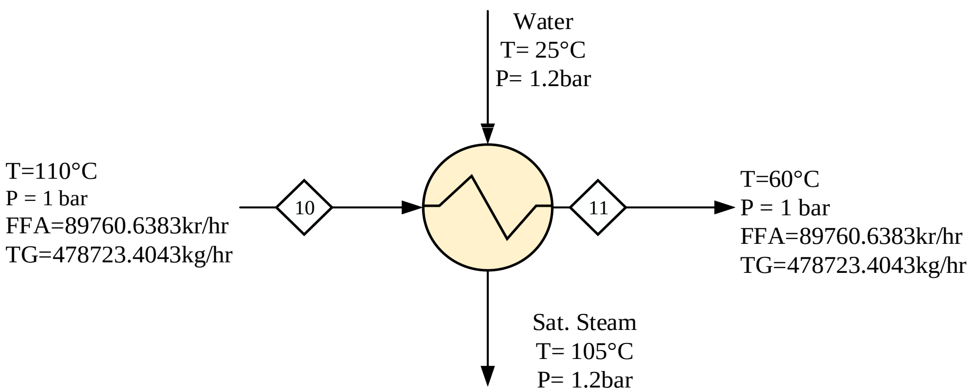


Figure 5.18: Design of WHB-101

Heat Rate

$$Q_u = 57.6\times10^6 \text{ KJ/hr}$$

Mass Flowrate

$$m = 22.3\times10^3 \text{ kg/hr}$$

Taking heat loss at 2% approximately

$$Q_T = Q_u + 0.02\, Q_T \quad \textbf{5.30}$$

$$0.98Q_T = Q_u$$

$$Q_T = 58.8\times10^6 \text{ KJ/hr}$$

Water Required

Mass of feed water = mass of stream + blowdown

$$M_F = M_S + M_B \quad \textbf{5.31}$$

Blowdown up to 10%

$$M_B = 0.1\ M_F$$

$$M_F = M_S + 0.1\ M_F$$

$$0.9\ M_F = M_S$$

$$M_S = 20.1\times10^3 \text{ kg/hr}$$

Overall Heat Transfer Coefficient

$$U_D = 900 \text{ W/m}^2\text{.C}$$

$$U_D = \frac{900\text{ J}}{\text{s}\times\text{m}^2\times\text{K}} \times \frac{1\text{ KJ}}{1000\text{ J}} \times \frac{60\text{ sec}}{1\text{ min}} \times \frac{60\text{ min}}{1\text{ hr}}$$

$$U_D = 3240 \text{ KJ/hr.m}^2\text{.K}$$

Log Mean Temperature Difference (LMTD)

H.F(°C): 110 → 60

C.F(°C): 105 ← 25

$$\Delta t_2 = 60 - 25 = 35^\circ\text{C}$$

$$\Delta t_1 = 110 - 105 = 5^\circ\text{C}$$

$$LMTD = \frac{\Delta t_2 - \Delta t_1}{\ln\left(\frac{\Delta t_2}{\Delta t_1}\right)} = 15.4\ ^\circ\text{C}$$

Correction Factor

$$F = 0.9$$

Estimation of Surface Area

$$A = \frac{Q}{U_D \times \text{LMTD} \times F} \qquad \mathbf{5.32}$$

$$A = \frac{58.8 \times 10^6 \text{KJ/hr}}{3240 \frac{\text{KJ}}{\text{hr. m}^2\text{. K}} \times 286.9 \text{ K}}$$

$$A = 63 \text{ m}^2$$

Tube Dimensions

Length = 16 ft = 4.87 m

Tube outer diameter = d_o = ¾ in = 0.019 m

Tube inner diameter = d_i = 0.652 in = 0.017 m

Tube Side Calculations

Here we placed the fat oil because it causes more scaling and tubes can be replaced easily.

- **Number of Tubes**

$$Nt = \frac{A}{\pi.\ do.\ L} \qquad \mathbf{5.33}$$

$$Nt = 217$$

We have selected ¾ in OD, 1 inch triangular spacing, 2 tube passes, 1 shell pass. From here the number of tubes is:

$$Nt = 250$$

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
39	1377	1330	1258	1248	1212	39	1206	1176	1128	1100	1078
1 in. OD tubes on 1¼-in. triangular pitch						1¼ in. OD tubes on 19/16-in. triangular pitch					

Figure 5.19: *Tube Sheet Layout*

- **Bundle Diameter**

From table 12.4 (Coulson Richardson volume 06)

For triangular pitch and 2 tube passes

$K_1 = 0.249$ $n_1 = 2.207$

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

Figure 5.20: Equation Constants

$$D_b = d_o \times (\frac{N_t}{K_1})^{\frac{1}{n_1}} \quad \mathbf{5.34}$$

$$= 0.019 \times (\frac{250}{0.249})^{\frac{1}{2.207}}$$

$$D_b = 0.44 \text{ m}$$

- **Tube Cross-Sectional Area**

$$= 2.8\times10^{-4} \text{ m}^2$$

- **Area Per Pass**

For 2 passes

Tube per pass = $\frac{250}{2}$

$$= 125$$

Area per pass = tube per pass × cross-sectional area

$$= 0.04 \text{ m}^2$$

- **Volumetric Flow Rate**

$$v = \frac{\text{feed flow rate}}{\text{density}}$$

$$= 0.1 \text{ m}^3/\text{sec}$$

- **Tube Velocity**

$$ut = \frac{\text{volumetric flow rate}}{\text{area per pass}} \qquad \mathbf{5.35}$$

$$= 2.5 \text{ m/s}$$

- **Reynolds Number**

$$Re = \frac{\rho.\ v.\ do}{\mu} \qquad \mathbf{5.36}$$

$$= 14186$$

- **Prandtl Number**

$$Pr = \frac{Cp.\ \mu}{k} \qquad \mathbf{5.37}$$

$$= 139$$

$$\frac{L}{D} = 256$$

From figure 12.23 (Coulson Richardson volume 06)

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

- **Tube Side Coefficient**

$$h_i = \frac{k}{d_o} \times J_H \times Re \times Pr^{0.33} \times \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

$$= 2800 \text{ W/m}^2\text{. K}$$

Shell Side Calculations

Here we have placed water

- **Shell Diameter**

From table 09 (Process Heat Transfer by Kern)

$$\text{Shell dia} = D_s = 19.25 \text{ in}$$

$$= 0.48 \text{ m}$$

Here we will find heat transfer coefficient by Bell's method

$$h_s = h_{oc} \times F_n \times F_w \times F_b \times F_L$$

- **Ideal Cross Flow Coefficient. h_{oc}**

Tube pitch

$$p_t = 1.25 d_o$$

$$= 0.024 \text{ m}$$

Area of shell

$$A_s = \left(\frac{p_t - d_o}{p_t}\right) \times d_s \times L_B \qquad \mathbf{5.38}$$

L_B = baffle spacing or baffle pitch

$$L_B = ds = 0.48\, m$$

$$A_s = 0.04 \text{ m}^2$$

Shell side mass velocity

$$\text{Gs} = \frac{\text{flow rate}}{\text{area of shell}} = 155 \frac{\text{kg}}{\text{m2. s}}$$

Prandtl number

$$\text{Pr} = \frac{\text{Cp} \times \mu}{\text{k}} = 3.5$$

Reynolds number

$$\text{Re} = \frac{\text{Gs} \times do}{\mu} = 5890$$

From figure 12.31(Coulson Richardson volume 06)

$$J_H = = 3.1\times10^{-2}$$

$$h_{oc} = \frac{k}{d_o} \times J_H \times Re \times Pr^{0.33} \times \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

$$\left(\frac{\mu}{\mu w}\right)^{0.14} = 1$$

$$h_{oc} = 8720 \text{ W/m}^2\text{.K}$$

- **Tube Row Correction Factor, F_n**

Tube vertical pitch = $p_t^{'}$ = 0.87 p_t = 0.02 m

Baffle height cut = H_c = baffle cut × D_s

$$= 0.12 \text{ m}$$

Height between baffle cuts = shell inner dia - 2 × H_c

$$= 0.24 \text{ m}$$

$$N_{cv} = \frac{\text{height between baffle cut}}{pt'}$$

$$= 12$$

From figure 12.32(Coulson Richardson volume 06)

$$F_n = 1.02$$

- **Window Correction Factor, F_w**

$$H_b = \frac{Db}{2} - Ds\ (0.5 - Bc)$$

Bc = baffle cut = 25%

= 0.1 m

Bundle cut

$$B_b = \frac{Hb}{Db} = 0.23$$

From figure 12.41(Coulson Richardson volume 06)

$$Ra' = 0.18$$

Tubes in one window area

$$N_w = N_t \times Ra' = 45$$

Tubes in cross flow area

$$N_c = N_t - 2\,N_w = 160$$

$$R_w = \frac{2\,Nw}{Nt} = 0.36$$

From figure 12.33(Coulson Richardson volume 06)

$$F_w = 1.02$$

- **Bypass Correction Factor**

$$A_b = L_b \times (D_s - D_b)$$

$$= 0.0192\ m^2$$

$$F_b = \exp\ \left[-\propto\times\ \frac{Ab}{As}\left(1-\left(\frac{2Ns}{Ncv}\right)0.33\right)\right]$$

$$\propto\ = 1.35 \text{ for turbulent flow}$$

$$F_b = 0.85$$

- **Leakage Correction Factor**

Tube to baffle clearance = c_t = 1/34 in

Baffle to shell clearance = c_s = 3/16 in

$$A_{tb} = \frac{c_t \times \pi \times d_o \times (N_t - N_w)}{2} \quad \mathbf{5.39}$$

$$= 4.9 \times 10^{-3}\ m^2$$

$$Asb = \frac{cs \times Ds\ (2\pi\ -\ Øb)}{2} \quad \mathbf{5.40}$$

From figure 12.41(Coulson Richardson volume 06)

$$\O_b = 2.1$$

$$A_{sb} = 4.7 \times 10^{-3}\ m^2$$

$$A_L = A_{tb} + A_{sb}$$

$$= 9.6 \times 10^{-3}\ m^2$$

$$\frac{AL}{As} = 0.24$$

From figure 12.35 (Coulson Richardson volume 06)

$$\beta_L = 0.22$$

$$F_L = \beta_L \times \left[\frac{A_{tb} + 2A_{sb}}{A_L}\right] \qquad \mathbf{5.41}$$

$$= 0.6$$

- **Shell Side Heat Transfer Coefficient**

$$h_s = h_{oc} \times F_n \times F_w \times F_b \times F_L$$

$$= 4672\ W/m^2.K$$

- **Overall Heat Transfer Coefficient**

$$\frac{1}{\mathrm{UD}} = \frac{1}{\mathrm{ho}} \times \frac{1}{\mathrm{hod}} + \frac{\mathrm{do} \times \ln(\frac{\mathrm{do}}{\mathrm{di}})}{2\mathrm{kw}} + \frac{\mathrm{do}}{\mathrm{di}} \times \frac{1}{\mathrm{hid}} + \frac{\mathrm{do}}{\mathrm{di}} \times \frac{1}{\mathrm{hi}} \qquad \mathbf{5.42}$$

Where,

h_o = outside film coefficient

h_{od} = fouling factor

k_w = thermal conductivity of tube wall material

h_{od} = 3000 W/m^2.K

k_w for stainless steel = 16 W/m^2.K

$$U_D = 810 W/m^2.K$$

Pressure Drop (Tube Side)

Tubes = 250, 2 tube passes, Inner dia of tube = 0.017 m, u_t = 2.5 m/s

$$Re = 14186$$

From figure 12.24(Coulson Richardson volume 06)

$$J_f = 2 \times 10^{-3}$$

$$\Delta Pt = Np \times \left[8 \times J_f \times \frac{L}{di} \times (\frac{\mu}{\mu_w})^{-0.14} + 2.5\right] \times \frac{\rho \times u_t^2}{2} \qquad \mathbf{5.43}$$

$$(\frac{\mu}{\mu_w})^{-0.14} = 0.7$$

$$\Delta Pt = 7 \text{ psi}$$

Pressure Drop (Shell Side)

$$\Delta Ps = 2\Delta Pe + \Delta Pc(Nb - 1) + Nb \times \Delta Pw \qquad \mathbf{5.44}$$

- **Cross Flow Zone, ΔPc**

From figure 12.36(Coulson Richardson volume 06)

$$J_f = 1.5 \times 10^{-1}$$

Shell side velocity = $u_s = \frac{Gs}{\rho}$ = 0.2 m/s

$$\Delta Pi = 8Jf \times \rho \times u_s^2/2$$

$$= 283 N/m^2$$

$$F_b' = \exp\left[-\alpha \times \frac{Ab}{As}\left(1 - \left(\frac{2Ns}{Ncv}\right)0.33\right)\right] = 0.68$$

From figure 12.38 (Coulson Richardson volume 06)

$$\beta_L' = 0.41$$

$$FL' = \beta L \times \left[\frac{Atb + 2Asb}{AL}\right] = 0.4$$

$$\Delta P_c = \Delta P_i \times F_b' \times F_L' \qquad \textbf{5.45}$$

= 77 N/m^2

- **Window Zone, ΔPw**

From figure 12.41(Coulson Richardson volume 06)

baffle cut 25%

R_a = 0.15

$$\mathrm{Aw} = \left(\frac{\pi \times \mathrm{Ds2} \times \mathrm{Ra}}{4}\right) - \left(\frac{\mathrm{Nw} \times \pi \times \mathrm{do2}}{4}\right) \qquad \textbf{5.46}$$

= 0.01m^2

$$uz = \sqrt{uw \times us}$$

= 0.1 m/s

$$Nwv = \frac{Hb}{pt'} = 5$$

$$\Delta Pw = F_L' \times (2 + 0.6N_{wv}) \times \rho \times \frac{u_z^2}{2}$$

= 1.7 N/m^2

- **End Zone, ΔPe**

$$\Delta \mathrm{Pe} = \Delta \mathrm{Pi} \times \left[\frac{\mathrm{Nwv} + Ncv}{\mathrm{Ncv}}\right] \times \mathrm{Fb}' \qquad \textbf{5.47}$$

= 273 N/m^2

Total Pressure Drop

$$\mathrm{N_b} = \frac{\mathrm{L}}{\mathrm{L_B}} - 1 = 8$$

$$\Delta \mathrm{Ps} = 2\Delta \mathrm{Pe} + \Delta \mathrm{Pc}(\mathrm{Nb} - 1) + \mathrm{Nb} \times \Delta \mathrm{Pw}$$

= 0.16 psi

SPECIFICATION SHEET			
Identification			
Item		Waste heat boiler	
Item no.		WHB-101	
No. required		1	
Type		1-2 horizontal heat exchanger	
Operation		Continuous	
Function			
Recovery of excess heat from process stream			
Heat duty = 58.8×10^6 KJ/hr			
Heat transfer area = 63 m^2			
Shell side		**Tube side**	
Operating pressure	1 bar	**Operating pressure**	1 bar
Temperatures in/out	25-105^{o}C	**Temperatures in/out**	110-60^{o}C
Shell inner diameter	0.48m	**Tube inner diameter**	0.017m
Passes	1	**No of tubes**	250
Pressure drop	7 psi	**Pressure drop**	0.16 psi

<table>
<tr><th colspan="4">SPECIFICATION SHEET</th></tr>
<tr><th colspan="4">Identification</th></tr>
<tr><td colspan="2">Item</td><td colspan="2">Waste heat boiler</td></tr>
<tr><td colspan="2">Item no.</td><td colspan="2">WHB-109</td></tr>
<tr><td colspan="2">No. required</td><td colspan="2">1</td></tr>
<tr><td colspan="2">Type</td><td colspan="2">1-2 horizontal heat exchanger</td></tr>
<tr><td colspan="2">Operation</td><td colspan="2">Continuous</td></tr>
<tr><th colspan="4">Function</th></tr>
<tr><td colspan="4">Recovery of excess heat from process stream</td></tr>
<tr><td colspan="4">Heat duty = 92.6×10^6 KJ/hr</td></tr>
<tr><td colspan="4">Heat transfer area = 56 m^2</td></tr>
<tr><th colspan="2">Shell side</th><th colspan="2">Tube side</th></tr>
<tr><td>Operating pressure</td><td>1 bar</td><td>Operating pressure</td><td>1 bar</td></tr>
<tr><td>Temperatures in/out</td><td>25-105°C</td><td>Temperatures in/out</td><td>110-35°C</td></tr>
<tr><td>Shell inner diameter</td><td>0.48m</td><td>Tube inner diameter</td><td>0.017m</td></tr>
<tr><td>Passes</td><td>1</td><td>No of tubes</td><td>196</td></tr>
<tr><td>Pressure drop</td><td>4 psi</td><td>Pressure drop</td><td>0.3 psi</td></tr>
</table>

5.7. Design of Heat Exchanger (HX-102)

Because of the advantages that shell-and-tube heat exchangers have over other types, they are widely used in the chemical process industries, particularly in refineries. On their design and construction, a plethora of information is available. The notes that follow are only meant to serve as a rudimentary introduction. A hot fluid travelling over or around a cooler fluid distributes its heat (and therefore energy) in the direction of the colder fluid. This is how all heat exchangers operate. Think about how you feel on a chilly day when you first put your hands on the wheel.

Advantages

- The tubes or the shell, in either a horizontal or vertical arrangement, can support the heat transmission for condensation or boiling.
- The range of pressures and pressure decreases is very broad.
- Thermal strains can be handled affordably.
- Fins with extended heat transfer surfaces can improve heat transfer.

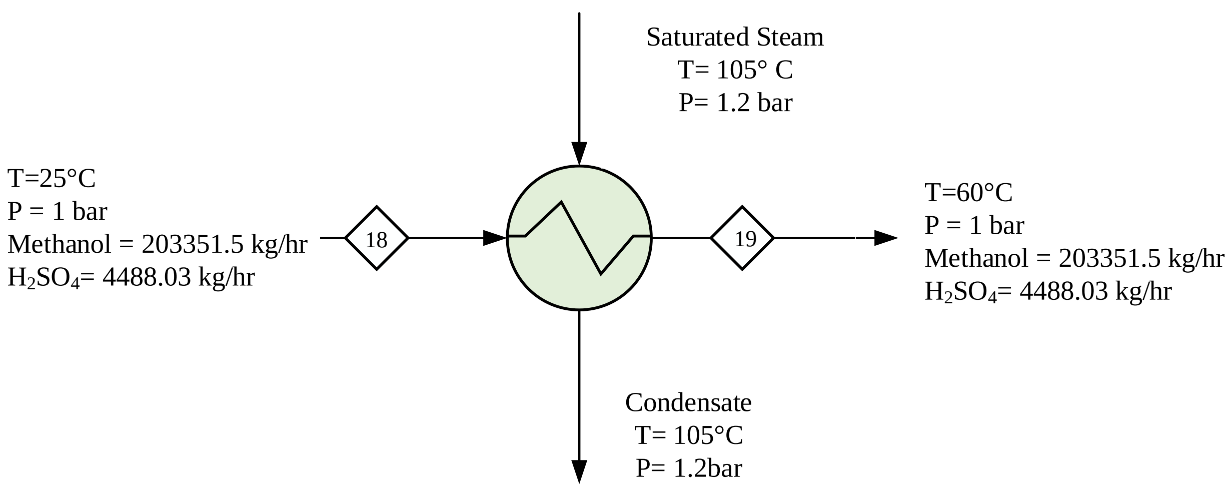


Figure 5.21: Design of Heat Exchanger (HX-102)

Heat Load

$$Q = mc_p\Delta T \quad \textbf{5.48}$$

$$\Delta T = 333^oK - 289^oK$$

$$\Delta T = 290^oK$$

$$C_p = 1.92 KJ/kg.\ K$$

$$m = 0.00056 kg/s$$

$$Q = 0.0001 kg/s$$

Calculate LMTD

$$LMTD = \frac{\Delta t_2 - \Delta t_1}{\ln(\Delta t_2/\Delta t_1)}$$

$$\Delta t_2 = T_2 - t_1 = 335^oK$$

$$\Delta t_1 = T_1 - t_2 = 300^oK$$

$$LMTD = 317^oK$$

Correction Factor

$$F_T = 1$$

$$\text{Corrected LMTD} = LMTD \times F_T$$

$$\Delta t = 317^oK$$

Calculate Area

Assume U_D

$$U_D = 4086\ KJ/hr.m^2.\ K$$

$$A = Q/U_d\Delta t$$

$$A = 55 m^2$$

Tube Specifications

$$L = 4.8 m$$

$$OD = 0.03\ m$$

$$BWG = 16$$

$$a_t = 0.036 m^2$$

a_t = Surface per lin. ft.

No. of Tubes

$$N_t = A/L \times at$$

$$N_t = 94$$

Corrected N_t = 95

We have selected 1 ½ in OD, $1^{7/8}$ triangular spacing, 1 tube passes

Shell ID = 23 ¼ in

Flow Area

- **Shell Side (Hot Fluid)**

$$a_s = ID \times C \times B/144P_T$$

$$C = OD \times 1.25$$

$$B = \text{Shell ID}/5$$

$$a_s = 0.069m^2$$

- **Tube Side (Cold Fluid)**

$$a_t = (N_t \times at')/144 \times n$$

$$a_t' = 1.44m$$

$$a_t = 0.089m^2$$

Mass Velocity

- **Shell Side (Hot Fluid)**

$$G_s = W/a_s$$

$$W = 2.3kg/s$$

$$G_s = 33.3\ kg/s\ m^2$$

- **Tube Side (Cold Fluid)**

$$G_t = W/a_t$$

$$W = 57.7kg/s$$

$$G_t = 647 \text{ kg/s m}^2$$

Reynolds Number

- **Tube Side Reynold Number**

$$Re_t = DeG_s/\mu$$

$$\mu = 0.0005 \text{ Pa. s}$$

$$D = 0.03m$$

$$Re_t = 46055$$

$$j_H = 150$$

$$C_p = 2.59 \text{KJ/kg. K}$$

$$K = 0.653 \text{W/m}^2\text{*K}$$

$$(C_p\mu/k)^{1/3} = 2.67$$

$$h_o = j_H(k/D)\ (C_p\mu/k)^{1/3}\Phi s$$

$$h_o = 1902 \text{W/m}^2\text{*K}$$

- **Shell Side Reynold Number**

$$Re_s = DG_t/\mu$$

$$\mu = 0.00003 \text{ Pa. s}$$

$$De = 0.027m$$

$$Re_s = 30525$$

For Steam

$$h_{io} = 8517 \text{W/m}^2\text{*K}$$

Clean Overall Coefficient Uc

$$U_c = \frac{h_{io} \times ho}{h_{io} + ho}$$

$$U_c = 155 \text{W/m}^2\text{*K}$$

Design Overall Coefficient U_D

$$1/U_D = 1/U_c + R_d$$

$$R_d = 0.003$$

$$U_D = 851 W/m^2*K$$

Dirt Factor R_d

$$R_d = \frac{Uc - UD}{Uc \times U_D}$$

$$R_d = 0.017 W/m^2*K$$

Pressure Drop

- **Shell Side**

$$Re_s = 30525$$

$$f = 0.0019$$

$$s = 0.32$$

$$(N + 1) = 12L/B = 8$$

$$\Delta P_s = \frac{fGs^2De(N+1)}{5.22\times10^{\wedge}10Des\Phi s}$$

$$\Delta P_s = 0.0002 \text{ Psi}$$

- **Tube Side**

$$Re_t = 46055, f = 0.00019, s = 0.042$$

$$\Phi_t = 1.02$$

$$\Delta P_t = \frac{fG_t^2Ln}{5.22\times10^{\wedge}10Ds\Phi_t}$$

$$\Delta P_t = 2.7 \text{ Psi}$$

<table>
<tr><th colspan="4">SPECIFICATION SHEET</th></tr>
<tr><th colspan="4">Identification</th></tr>
<tr><td colspan="2">Item</td><td colspan="2">Heat Exchanger</td></tr>
<tr><td colspan="2">Item no.</td><td colspan="2">HX-102</td></tr>
<tr><td colspan="2">No. required</td><td colspan="2">1</td></tr>
<tr><td colspan="2">Type</td><td colspan="2">Shell and Tube Heat Exchanger</td></tr>
<tr><td colspan="2">Operation</td><td colspan="2">Continuous</td></tr>
<tr><th colspan="4">Function</th></tr>
<tr><td colspan="4">Heating Process Stream</td></tr>
<tr><td colspan="4">Heat Duty = 1.44KJ/hr</td></tr>
<tr><td colspan="4">Heat transfer area = $55m^2$</td></tr>
<tr><th colspan="2">Shell side</th><th colspan="2">Tube side</th></tr>
<tr><td>Operating pressure</td><td>1 bar</td><td>Operating pressure</td><td>1 bar</td></tr>
<tr><td>Temperature in/out</td><td>105ºC</td><td>Temperature in/out</td><td>25 - 60ºC</td></tr>
<tr><td>Shell inner dia</td><td>0.027m</td><td>Tube inner dia</td><td>0.03m</td></tr>
<tr><td>Passes</td><td>01</td><td>No. of tubes</td><td>95</td></tr>
<tr><td>Pressure Drop</td><td>0.0002Psi</td><td>Pressure Drop</td><td>2.7 Psi</td></tr>
</table>

SPECIFICATION SHEET			
Identification			
Item	Heat Exchanger		
Item no.	HX-103		
No. required	1		
Type	Shell and Tube Heat Exchanger		
Operation	Continuous		
Function			
Heating Process Stream			
Heat Duty = $21x10^6$KJ/hr			
Heat transfer area = $81m^2$			
Shell side		**Tube side**	
Operating pressure	1 bar	**Operating pressure**	1 bar
Temperature in/out	105ºC	**Temperature in/out**	60 - 72ºC
Shell inner dia	0.48m	**Tube inner dia**	0.0017m
Passes	01	**No. of tubes**	250
Pressure Drop	3.7Psi	**Pressure Drop**	0.12 Psi

SPECIFICATION SHEET			
Identification			
Item	Heat Exchanger		
Item no.	HX-104		
No. required	1		
Type	Shell and Tube Heat Exchanger		
Operation	Continuous		
Function			
Heating Process Stream			
Heat Duty = $39.9x10^6$KJ/hr			
Heat transfer area = $76m^2$			
Shell side		**Tube side**	
Operating pressure	1 bar	**Operating pressure**	1 bar
Temperature in/out	25-45ºC	**Temperature in/out**	72-40ºC
Shell inner dia	0.48m	**Tube inner dia**	0.0017m
Passes	01	**No. of tubes**	81
Pressure Drop	3.1Psi	**Pressure Drop**	0.14 Psi

SPECIFICATION SHEET			
Identification			
Item		Heat Exchanger	
Item no.		HX-105	
No. required		1	
Type		Shell and Tube Heat Exchanger	
Operation		Continuous	
Function			
Heating Process Stream			
Heat Duty = 24.2×10^6 KJ/hr			
Heat transfer area = $83 m^2$			
Shell side		**Tube side**	
Operating pressure	1 bar	**Operating pressure**	1 bar
Temperature in/out	105ºC	**Temperature in/out**	40-60ºC
Shell inner dia	0.48m	**Tube inner dia**	0.0017m
Passes	01	**No. of tubes**	95
Pressure Drop	5Psi	**Pressure Drop**	0.16 Psi

SPECIFICATION SHEET			
Identification			
Item	Heat Exchanger		
Item no.	HX-106		
No. required	1		
Type	Shell and Tube Heat Exchanger		
Operation	Continuous		
Function			
Heating Process Stream			
Heat Duty = 9.98KJ/hr			
Heat transfer area = 39m^2			
Shell side		**Tube side**	
Operating pressure	1 bar	**Operating pressure**	1 bar
Temperature in/out	105ºC	**Temperature in/out**	25 - 60ºC
Shell inner dia	0.5m	**Tube inner dia**	0.03m
Passes	01	**No. of tubes**	76
Pressure Drop	0.0017Psi	**Pressure Drop**	0.2 Psi

SPECIFICATION SHEET			
Identification			
Item	Heat Exchanger		
Item no.	HX-107		
No. required	1		
Type	Shell and Tube Heat Exchanger		
Operation	Continuous		
Function			
Heating Process Stream			
Heat Duty = 1.74KJ/hr			
Heat transfer area = 29.5m^2			
Shell side		**Tube side**	
Operating pressure	1 bar	**Operating pressure**	1 bar
Temperature in/out	105ºC	**Temperature in/out**	60 - 67ºC
Shell inner dia	0.48m	**Tube inner dia**	0.03m
Passes	01	**No. of tubes**	61
Pressure Drop	0.5Psi	**Pressure Drop**	0.005 Psi

SPECIFICATION SHEET			
Identification			
Item	Heat Exchanger		
Item no.	HX-108		
No. required	1		
Type	Shell and Tube Heat Exchanger		
Operation	Continuous		
Function			
Heating Process Stream			
Heat Duty = 1.98KJ/hr			
Heat transfer area = 69.6m^2			
Shell side		**Tube side**	
Operating pressure	1 bar	**Operating pressure**	1 bar
Temperature in/out	67-35ºC	**Temperature in/out**	60 - 45ºC
Shell inner dia	0.67m	**Tube inner dia**	0.03m
Passes	01	**No. of tubes**	136
Pressure Drop	4.4Psi	**Pressure Drop**	0.3 Psi

CHAPTER 06

MECHANICAL DESIGN

6.1 Introduction

The chemical engineer will be responsible for developing and specifying the basic design information for a particular vessel, and needs to have a general appreciation of pressure vessel design to work effectively with the specialist designer. The basic data needed by the specialist designer will be:

1. Vessel function.
2. Process materials and services.
3. Operating and design temperature and pressure.
4. Materials of construction.
5. Vessel dimensions and orientation.
6. Type of vessel heads to be used.
7. Openings and connections required.
8. Specification of heating and cooling jackets or coils.
9. Type of agitator.
10. Specification of internal fitting

There is no strict definition of what constitutes a pressure vessel, but it is generally accepted that any closed vessel over 150 mm diameter subject to a pressure difference of more than 0.5 bar should be designed as a pressure vessel.

For the purposes of design and analysis, pressure vessels are sub-divided into two classes depending on the ratio of the wall thickness to vessel diameter: thin-walled vessels, with a thickness ratio of less than 1: 10; and thick-walled above this ratio

A torispherical shape, which is often used as the end closure of cylindrical vessels, is formed from part of a torus and part of a sphere. The shape is close to that of an ellipse but is easier and cheaper to fabricate. Under internal pressure a vessel will expand slightly. The radial growth can be calculated from the elastic strain in the radial direction.

6.2 Mechanical Design of CSTR (R-101)

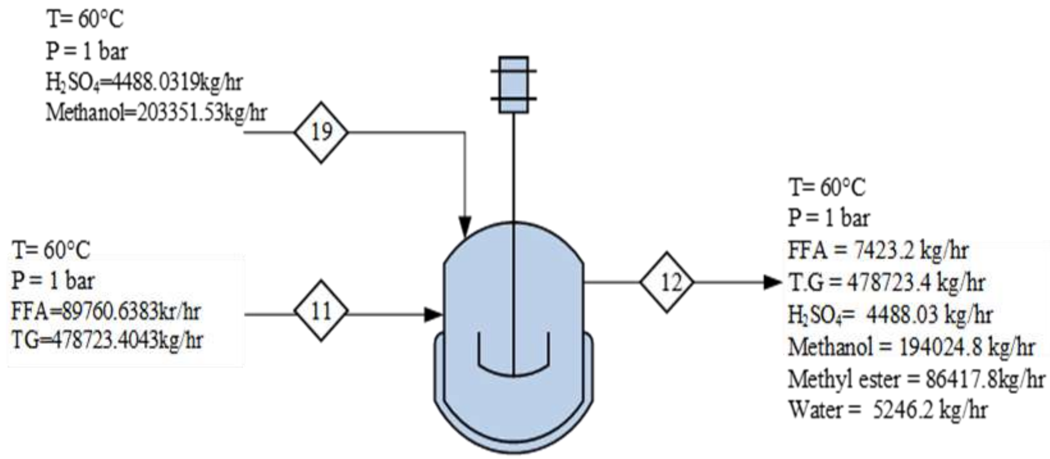


Figure 6.1: Mechanical Design of R-101

Diameter = d =2.3 m

Operating Pressure = 1 bar = 0.1 N/mm^2

Design Pressure

Design pressure is taken as 10% of operating Pressure

$$= 0.1 \times 1.1$$

$$= 0.11\ N/mm^2$$

Material Selection

Stainless steel type 316

- Improve corrosion resistance.
- High strength and resistance to scaling at high temperature.

Cr = 16.5-18.5% , Ni = 10% , C = 0.08%, Mo = 2-3%

Baffle Spacing

4 baffles are used (equally spaced)

$$\pi.D_t/4 = \frac{3.14 \times 1.9}{4} \quad \textbf{6.1}$$

$$= 1.5m$$

Width of Baffle

$$Dt/12 = \frac{1.9}{12}$$

$$= 0.16m$$

Distance from Bottom

$$Dt/2 = \frac{1.9}{2}$$

$$= 0.9m$$

Maximum Practical Thickness

As the vessel dia is between 1-2m, so minimum thickness is 7mm

Material = stainless steel 316

Dia = 1.9m = 1900 mm

Length = 2.2m = 2200 mm

Design Stress = f = 170N/mm (From table 13.2 Coulson Richardson vol 06)

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

Figure 6.2: Design Stress

Joint efficiency = J = 1 (From table 13.3 Coulson Richardson vol 06)

Temperature = 60°C

Maximum Allowable Pressure

$$e = \frac{PD}{2fJ-P} \quad \textbf{6.2}$$

$$= \frac{0.11\times1900}{2\times130\times1-0.11}$$

= 0.6mm+2mm

= 2.6mm

Outer Dia of Shell

$$= D_i + 2e \quad \textbf{6.3}$$

= 1900 + 2(2.64)

Table 13.3. Maximum allowable joint efficiency

Type of joint	Degree of radiography		
	100 per cent	spot	none
Double-welded butt or equivalent	1.0	0.85	0.7
Single-weld butt joint with bonding strips	0.9	0.80	0.65

Figure 6.3: Maximum Allowable Stress

=1905mm

=1.91m

Heads and Closures

Tori-spherical head is also used because it is suitable for pressure range of 1-10 bar

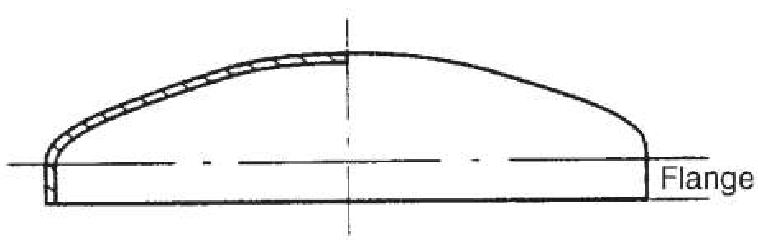


Figure 6.4: Tori Spherical Head

- **Tori Spherical Head**

$$t = \frac{0.885 PiRc}{SE - 0.1Pi} \quad \textbf{6.4}$$

$$t = \frac{0.885 \times 0.11 \times 1800}{130 \times 1 - 0.1 \times 0.11}$$

= 1mm + 2mm

= 3mm

Vessel Support

For the reactor, we use bracket support

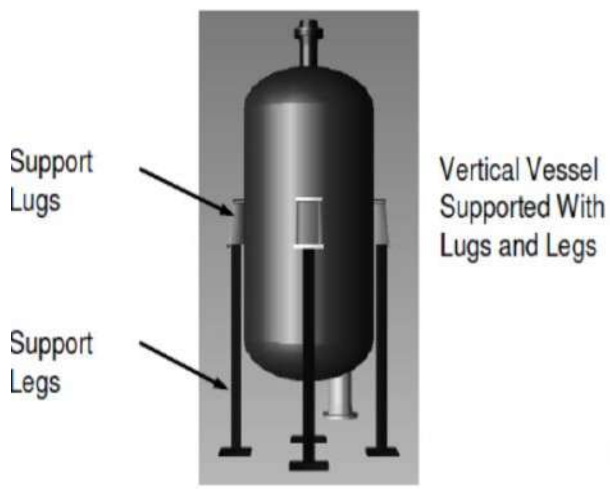


Figure 6.5: Vertical Vessel

Weight Load

$$w = 240 \times Cv \times Dm \times (Hv + 0.8 \times Dm) \times t \quad \textbf{6.5}$$

Dm = Di + t

= 1900 + 2.6

= 1903mm

= 1.9m

$$W = 240 \times 1.08 \times 1.9 \times (2.2 + 0.8 \times 1.9) \times 2.6 \times 10^{-3}$$

= 4.7kN

Wind Load

$$P_w = 1030 N/m^2$$

$$\text{Total dia} = Dt = Di + t \quad \textbf{6.6}$$

$$=1900 + 2.74$$

$$= 1903mm$$

$$F = PD = 1030 \times 1.9$$

$$= 2441N/m$$

$$= 2.4N/mm$$

Stress Calculations

- **Longitudinal Stress**

$$\sigma_H = \frac{PDi}{2t} = \frac{0.11\times1900}{2\times2.63} \quad \textbf{6.7}$$

$$= 35N/mm^2$$

- **Circumferential Stress**

$$\sigma_L = \frac{PDi}{4t} = \frac{0.11\times1900}{4\times3} \quad \textbf{6.8}$$

$$= 17N/mm^2$$

- **Dead Weight Stress**

$$\sigma_W = \frac{W}{\pi(Di+t)\times t} \quad \textbf{6.9}$$

$$= \frac{4700}{\pi(1903)\times2.6}$$

$$= 0.3N/mm^2$$

- **Radial Stress**

$$\sigma_L = \frac{Pi}{2} = 0.05N/mm$$

- **Bending Moment**

$$M = F \times H = 2.4 \times 1109mm = 2640N$$

- **Bending Stress**

$$\sigma_{b}= \frac{Mx}{lv}\left(\frac{Di}{2} + t\right) \quad \textbf{6.10}$$

$$Lv = (Do^4 - Di^4)/\ \pi(Di + t)\ \times t$$

$$= 975 \times 10^3$$

$$\sigma b = 2.3\ N/mm^2$$

CHAPTER 07

PUMPS AND CONVEYER CALCULATIONS

7.1 Pumps

A pump is a mechanical device that is used to move fluids from one place to another. A hydraulic device transports fluid from low to high-pressure locations and elevates fluids from low to high levels. The pump converts the mechanical energy of the fluid into pressure energy (hydraulic energy). A compressor and a pump both work in the same way. The key distinction is that they employ different operating fluids.

7.2 Types of Pumps

Pumps come in a variety of shapes and sizes, but the two most common varieties are shown below:

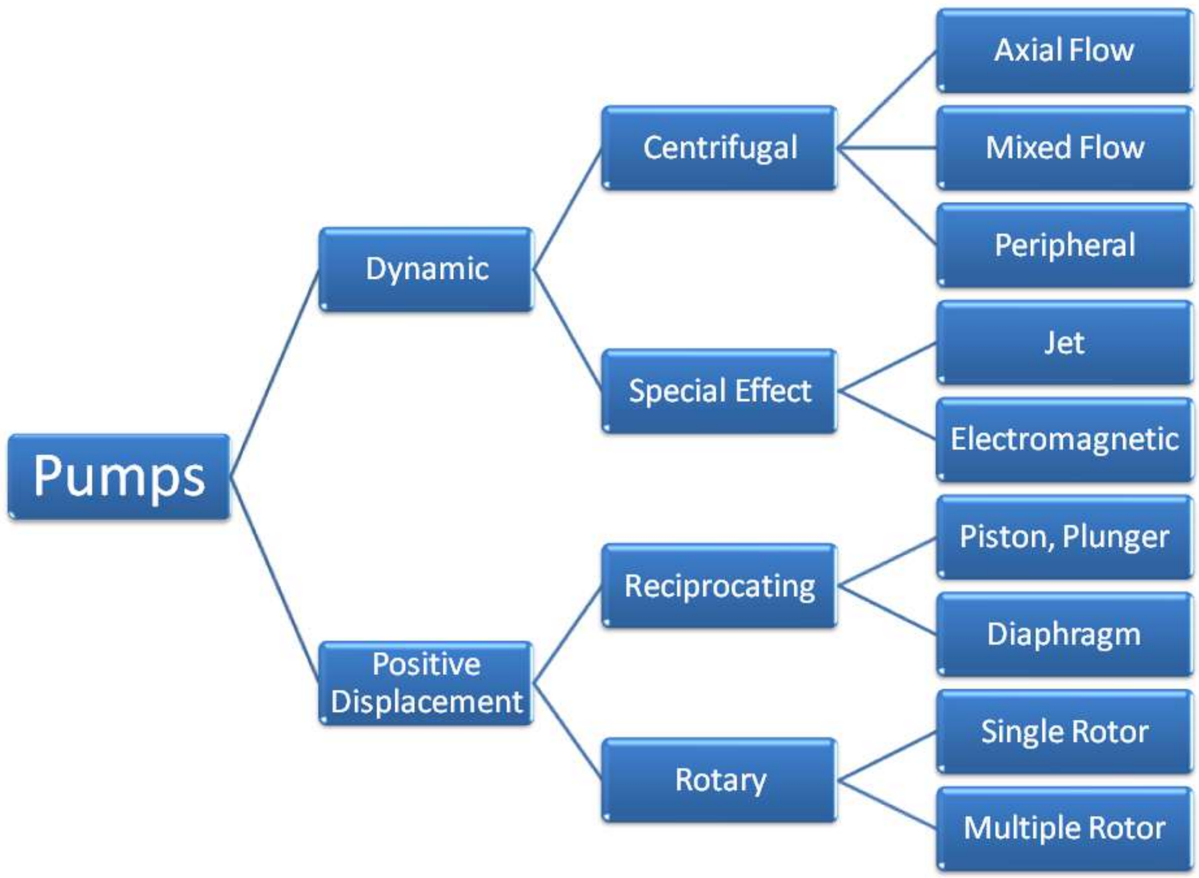


Figure 7.1: Types of Pumps

7.2.1 Positive Displacement Pumps

The liquid is moved through a positive displacement pump by reciprocating, rotational, or pneumatic action. In this case, instead of a steady liquid flow, the fluid is discharged in pulses. These pumps work by allowing a defined volume of fluid to enter the pump chamber through an inlet valve and then releasing it through an output valve. These pumps are used because they can function in high viscosity fluids at high pressures.

7.2.2 Reciprocating Pump

The quantity of water gathered in an enclosed volume is transferred to discharge by providing pressure to reciprocating pumps. With low volume flow at high pressure, reciprocating pumps are employed. A piston rotates back and forth in a stationary cylinder to power this pump. A connecting rod connects the piston to the crankshaft. This piston moves in response to the movement of the connecting rod, which is caused by the crankshaft. This crankshaft is connected to a motor and aids in its rotation.

7.2.3 Dynamic Pump

The plunger or piston in these kinds of pumps travels both downward and upward. Fresh liquid is pumped into the cylinder during the suction stroke. The inlet valve closes and the discharge stroke begins when the cylinder has been filled. Pressurized liquid discharges from the outlet valve when the outlet opens during the discharge stroke. A check valve is present on the liquid's intake and outflow sides to stop the liquid from flowing backward.

7.2.4 Centrifugal Pump

Centrifugal pumps work by providing centrifugal force to fluids, which is often done with the use of impellers. These pumps are commonly used in chemical process industries for moderate to high flow applications with low pressure head. Radial, mixed, and axial flow centrifugal pumps are the three types of centrifugal pumps.

7.2.5 Special Effect Pump

Special effects pumps are another name for kinetic pumps. This sort of pump still uses kinetic and velocity energy to provide energy, but it does it in a different way than centrifugal pumps.

7.3 Selection Criteria of Pumps

A variety of factors might impact the ultimate pump selection for a given operation. The following is a summary of the most important elements to consider while choosing a pump.

- The volume of liquid that needs to be pushed.
- The fluid's characteristics.

- The fluid concentration rises as a result of the pump's action.
- Different types of flow distributions
- Different types of power supplies.
- The pump's cost and mechanical efficiency. We chose centrifugal pumps for a procedure because of the advantages listed below.

7.4 Advantages

- They are easy to use and inexpensive.
- Fluid is given at a constant pressure with no pulsation or shocks.
- Pumping does not need the use of any valves.
- They run at a high speed (up to 4000 rpm), therefore they may be directly linked to an electric motor
- Without altering the pump, the discharge line can be partially or totally shut off.
- They are a lot smaller than other pumps with the same capacity.
- Maintenance is less expensive compared with other types of pumps.

7.5 Reciprocating Pump (P-101)

Due to pipe losses entry pressure is taken as

P_i = 0.8 bar

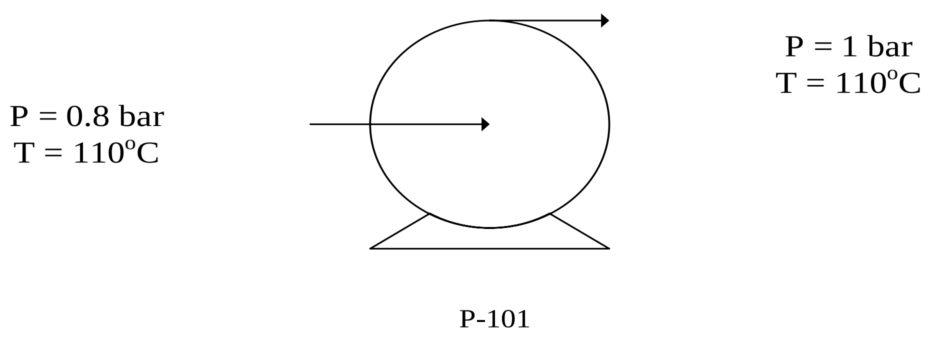


Figure 7.2: Pump (P-101)

$$\Delta P = P_f - P_i$$

= 1-0.8 = 0.2 bar

Calculating Head

$$\Delta H = \frac{\Delta P}{\rho g} \qquad \mathbf{7.1}$$

$$= \frac{20 \times \frac{10^3 kg}{m.s^2}}{910\frac{kg}{m^3} \times \frac{9.8m}{s}}$$

$$\Delta H = 2.24\ m$$

Water Horsepower

$$P_f = Q \times \gamma \times \Delta H \qquad \mathbf{7.2}$$

Where,

$$\gamma = \rho g$$

$$Q(volumetric\ flowrate) = \frac{568484\frac{kg}{hr}}{910\frac{kg}{m^3}}$$

$$= \frac{625\ m^3}{hr} \times \frac{1\ hr}{60\ min} \times \frac{1\ min}{60\ sec}$$

$$= \frac{0.17m^3}{s}$$

$$P_f = \frac{0.17m^3}{s} \times \frac{910kg}{m^3} \times \frac{9.8m}{s^2} \times 2.2\ m$$

= 3532 watts

Brake Horsepower

$$P_B = \frac{P_f}{\eta}$$

Efficiency is taken as

η= 72%

$$P_B = \frac{3532}{0.72}$$

= 4905 watts = 6.5 hp

7.6 Reciprocating Pump (P-102)

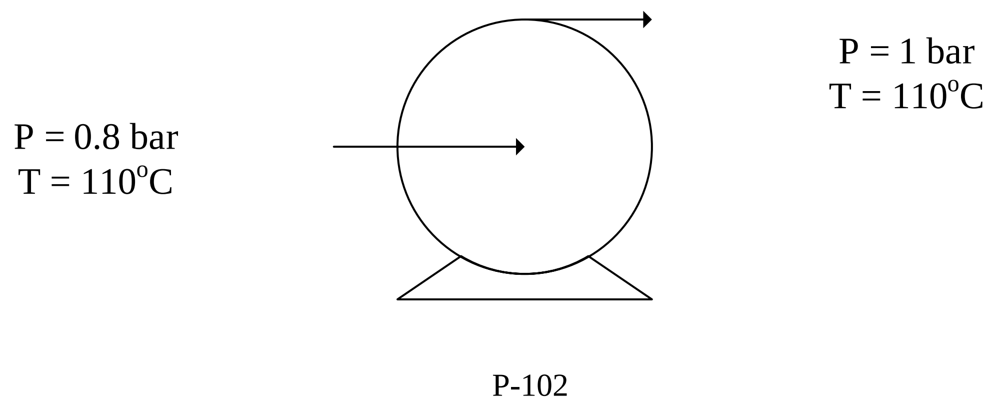


Figure 7.3: Pump (P-102)

Due to pipe losses entry pressure is taken as

P_i = 0.8 bar

$$\Delta P = P_f - P_i \qquad \mathbf{7.3}$$

= 1-0.8 = 0.2 bar

Calculating Head

$$\Delta H = \frac{\Delta P}{\rho g}$$

$$= \frac{20 \times \frac{10^3 kg}{m.s^2}}{1123 \frac{kg}{m^3} \times \frac{9.8m}{s}}$$

$$\Delta H = 1.8\, m$$

Water Horsepower

$$P_f = Q \times \gamma \times \Delta H$$

Where,

$$\gamma = \rho g$$

$$Q(\text{volumetric flowrate}) = \frac{605873 \frac{kg}{hr}}{1123 \frac{kg}{m^3}}$$

$$= \frac{539.5\ m^3}{hr} \times \frac{1\ hr}{60\ min} \times \frac{1\ min}{60\ sec}$$

$$= \frac{0.15 m^3}{s}$$

$$P_f = \frac{0.15 m^3}{s} \times \frac{1123\ kg}{m^3} \times \frac{9.8 m}{s^2} \times 1.8\ m$$

= 2971 watt

Brake Horsepower

$$P_B = \frac{P_f}{\eta}$$

Efficiency is taken as

η= 72%

$$P_B = \frac{2971}{0.72}$$

= 4127 watts = 5.5 hp

7.7 Centrifugal Pump (P-103)

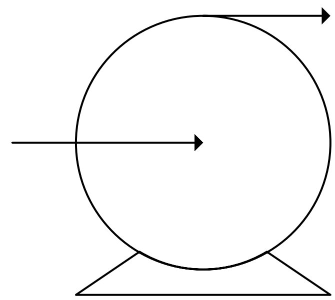


Figure 7.4: Pump (P-103)

Due to pipe losses entry pressure is taken as

$$P_i = 0.8 \text{ bar}$$

$$\Delta P = P_f - P_i$$

$$= 1\text{-}0.8 = 0.2 \text{ bar}$$

Calculating Head

$$\Delta H = \frac{\Delta P}{\rho g}$$

$$= \frac{20 \times \frac{10^3 kg}{m.s^2}}{1051 \frac{kg}{m^3} \times \frac{9.8m}{s}}$$

$$\Delta H = 1.9\ m$$

Water Horsepower

$$P_f = Q \times \gamma \times \Delta H$$

Where,

$$\gamma = \rho g$$

$$Q(volumetric\ flowrate) = \frac{571446.8\,\frac{kg}{hr}}{1051\,\frac{kg}{m^3}}$$

$$= \frac{543.7\ m^3}{hr} \times \frac{1\ hr}{60\ min} \times \frac{1\ min}{60\ sec}$$

$$= \frac{0.15m^3}{s}$$

$$P_f = \frac{0.15m^3}{s} \times \frac{1051\ kg}{m^3} \times \frac{9.8m}{s^2} \times 1.9m$$

= 2935 watt

Brake Horsepower

$$P_B = \frac{P_f}{\eta} \qquad \mathbf{7.4}$$

Efficiency is taken as

η= 72%

$$P_B = \frac{2935}{0.72}$$

= 4076 watts = 5.4 hp

SPECIFICATION SHEET	
Identification	
Item	Pump (P-101)
Type	Reciprocating
head	1.24 m
Function To increase pressure from 0.8 bar to 1 bar	
Mass flow rate	568484 kg/hr
density	910 kg/m^3
Pump work	6.5 hp

SPECIFICATION SHEET	
Identification	
Item	Pump (P-102)
Type	Reciprocating
head	1.8 m
Function To increase pressure from 0.8 bar to 1 bar	
Mass flow rate	605873 kg/hr
density	1123 kg/m^3
Pump work	5.5 hp

SPECIFICATION SHEET	
Identification	
Item	Pump (P-103)
Type	Centrifugal
head	1.9 m
Function To increase pressure from 0.8 bar to 1 bar	
Mass flow rate	571446.8 kg/hr
density	1051 kg/m^3
Pump work	5.4 hp

7.8. Conveyers

A conveyor system is a mechanical handling device that moves loads and materials automatically within a place swiftly and efficiently. This method minimizes human error, reduces workplace dangers, and lowers labor costs, among other benefits. They are being handy when moving bulky or heavy goods from one location to another. A conveyor system may use a belt, wheels, rollers, or a chain to transfer objects.

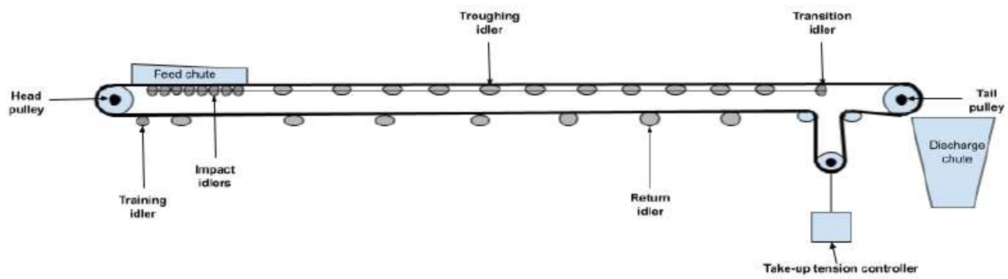


Figure 7.5: Conveyer

7.9 Types of Conveyers

Following are the type of conveyers

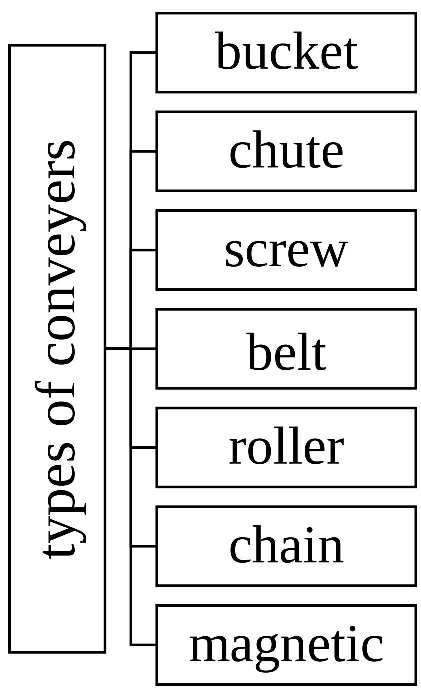


Figure 7.6: Types of Conveyer

7.9.1 Chute Conveyers

One of the least expensive means of material conveyance is the chute conveyor. The most straightforward gravity-operated conveyor is this one. A spiral chute can be utilized to move products between floors with the least amount of space needed, whereas a chute conveyor is used to supply accumulation in shipping areas. The lack of control over the material being delivered is the fundamental drawback of chute conveyors, notwithstanding its affordability. The packages may have a propensity to shift and turn, causing jams and blockages.

7.9.2 Screw Conveyers

By rotating a "fighting," or helical screw blade, usually inside of a tube, a screw conveyor, also known as an auger conveyor, conveys liquid or granular materials. They are used in many bulk handling industries. Screw conveyors are widely employed in modern industry to move semi-solid materials such as food waste, wood chips, aggregates, cereal grains, animal feed, boiler ash, meat and bone meal, municipal solid waste, and many others horizontally or at a little slope.

7.10. Screw Conveyer (CN-101)

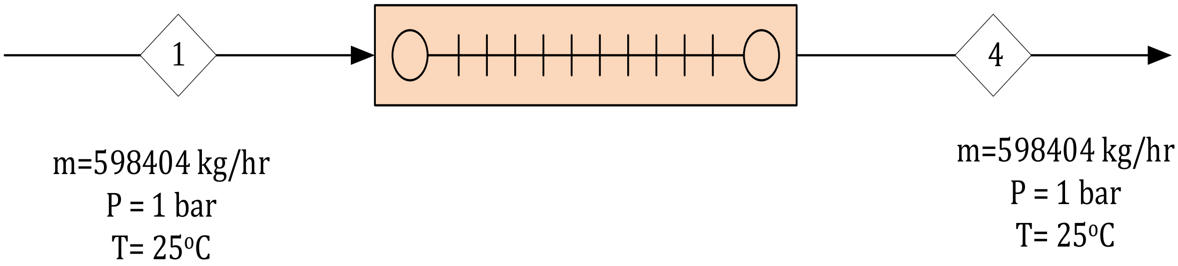


Figure 7.7: Screw Conveyer (CN-101)

Initial size of fat = 50.8 mm = 0.05 m

Final size of fat = 14.5 mm = 0.0145 m

Work Index

As fat is very soft material, therefore

$$Wi = 0.3 \text{ kWh/ton}$$

Power

$$\frac{P}{m} = K_B \times \left[\frac{1}{\sqrt{D_2}} - \frac{1}{\sqrt{D_1}}\right] \quad \mathbf{7.5}$$

$K_B = 0.3162Wi$

$$m = 598404\,\frac{kg}{hr} \times \frac{1\ ton}{1000\ kg}$$

= 598.4 ton/hr

P = 598.4×0.3162×0.05×0.12

P = 6.8 kW = 9.1 hp

SPECIFICATION SHEET	
Identification	
Item	Conveyer (CN-101)
type	Screw conveyer
Operation	Continuous
Function To transport the fat to the heater and also reduce its size	
Mass flow rate	598404 kg/hr
Work index	0.3 kWh/ton
Power	9.1 hp

CHAPTER 08

COST ESTIMATION

8.1 Cost estimation

Any industrial process necessitates a capital expenditure, and determining the required investment is an important aspect of the plant design project. Although there are many names for these estimations, the five categories listed below capture the classification and accuracy range that are frequently employed in design.

- Order of magnitude calculations
- Estimate from the study (factorial estimate)
- Budget authorization estimate for preliminary estimations
- Final cost estimation (project control cost estimation)
- Exact estimate (estimate from the contractor)

8.2 Working Capital

Working capital refers to the money needed to keep the plant running. The following items should be considered when calculating working capital:

- Stockpiles of raw materials and supplies
- Semi-finished items in the manufacturing process and final products in stock.
- Receivables (accounts receivable)
- Cash is maintained on hand to cover monthly operational costs including salaries, wages, and raw material purchases.
- Accounts receivable
- Taxes payable

8.3 Fixed Capital Investment

Long-term asset investments and upkeep are included in fixed capital investments. Investments in physical assets, such as property, plant, and equipment, are included (PP&E). The difference between capital expenditures on property, plant, and equipment (PP&E) and the sale of fixed assets is used to compute it. Fixed capital investment is a key component in calculating the firm's free cash flow (FCFF). Fixed capital investment for FCFF computation is computed using one of the following formulae if a firm's long-term assets are not sold during the financial year:

$$FC_{INV} = \text{closing gross value of PP\&E} - \text{opening gross value of PP\&E}$$

Or

$$FC_{INV} = \text{closing net value of PP\&E} - \text{opening net value of PP\&E} + \text{Depreciation}$$

8.4 Depreciation

Depreciation is an accounting term that describes a method of dispersing the cost of a physical item over the course of its useful life. The term "depreciation" refers to the amount of an asset's value that has been used up. It enables companies to purchase assets over time and generate income from them. If depreciation is not taken into account, it could significantly affect a company's profitability. For tax and accounting reasons, long-term investments might also be written off as expenses.

8.5 Cost Indexes

A cost is similar to an index value for a particular moment in time that shows the cost at that point in time in relation to a base time. As a result, the current cost is approximated using the cost index as follows:

$$\frac{\text{Present cost}}{\text{Index at present time}} = \frac{\text{Original cost}}{\text{Index value at original cost}}$$

Various forms of cost indices are released on a regular basis. Some may be used to estimate the cost of equipment, some are more pertinent to the labor, building, materials, or other specialized industries. These indicators' most popular measurements are

- Equipment for various industries and processes, Marshal-and-Swift
- Engineering news contraction cost index records

8.6 Assumptions

We have taken following assumptions

- Plant is 100% equity financed
- Plant initiates operation in 5-8 years
- Plant life is 20 years
- Plant availability is 330 days per year
- Zero salvage value for general plant

- MACRS depreciation method will be used
- Working capital is 15% of fixed capital investment

8.7 Purchased Cost of Equipment 2003

Agitator (A-101)

$$C = 1.218 \exp [a + b \ln HP + c(\ln HP)^2 \quad \textbf{8.1}$$

Type SS-316

Speed : 2

HP = 0.6hp

C = 5986$

Agitator (A-102)

$$C = 1.218 \exp [a + b \ln HP + c(\ln HP)^2$$

- Type: Carbon Steel

Speed : 2

HP = 1.6hp

C = 5416$

Conveyer (CN-101)

Screw Conveyer (SS)

$$C = 0.85\ L^{0.78} \quad \textbf{8.2}$$

C = 18.9K$

Filter (F-101)

- Type: Rotary drum scraper discharge

$$C = 1.218 \exp [11.27 + 1.3408 (\ln A) + 0.0709 (\ln A)^2] \quad \textbf{8.3}$$

C = 3024360$

Cooling Tower (CT-101)

$$C = 164fQ^{0.61} \quad \textbf{8.4}$$

Q = 37916.6gal/min

C = 203958$

Pump (P-101)

- Type: Reciprocating

$$C = 1407\ F\ Q^{0.52} \quad \textbf{8.5}$$

Q = 2463.4gal/min

C = 69827$

Pump (P-102)

- Type: Reciprocating

$$C = 1407\ F\ Q^{0.52}$$

Q = 2463.4gal/min

C = 9885$

Pump (P-103)

- Type: Centrifugal

$$C = F_M\ .F_T\ .C_b \quad \textbf{8.6}$$

$$F_T = \exp\ [b_1 + b_2\ (\ln Q\sqrt{H}) + b_3\ (\ln Q\sqrt{H})^2]$$

Q = 2476 gal/min

$b_1 = 5.103$

$b_2 = -1.2217$

$b_3 = 0.0771$

$F_T = 1.75$

$$C_b = 3 \exp [8.83 - 0.6019 (\ln Q\sqrt{H}) + 0.0519(\ln Q\sqrt{H})^2]$$

$$C_b = 7321.8$$

$$C = 17298\$$$

Reactor (R-101)

$$C = F_M C_b + C_a \quad \textbf{8.7}$$

$$C_a = 480 \text{ x } D^{0.74} \text{ x } L^{0.7066}$$

$$C_a = 7522$$

$$C_b = 1.672 \exp[9.1 + 0.2889 (\ln W) + 0.04576 (\ln W)^2]$$

$$C_b = 918620$$

$$C = 1936624\$$$

Reactor (R-102)

$$C = F_M C_b + C_a$$

$$C_a = 480 \text{ x } D^{0.74} \text{ x } L^{0.7066}$$

$$C_a = 6767.9$$

$$C_b = 1.672 \exp[9.1 + 0.2889 (\ln W) + 0.04576 (\ln W)^2]$$

$$C_b = 987393$$

$$C = 994161\$$$

Evaporator (V-101)

$$A = 805 ft^2$$

$$C = 1.218 \exp[3.24 - 0.0126 (\ln A) + 0.0244 (\ln A)^2] \quad \textbf{8.8}$$

$$C = 84700\$$$

Washing Unit (C-101)

- Type: Packed Column

Packing type = Ceramic rashing rings

$$C = 1.218\ [f_1\ C_b + V_p\ C_p + C_{p1})$$ **8.9**

$$C_b = 1.218\ \exp[6.63 + 0.18\ (\ln W) + 0.023\ (\ln W)^2]$$

$$C_b = 10272$$

$$C_{p1} = 300 \times D^{0.74} \times L^{0.7068}$$

$$C_{p1} = 4231.5$$

$$C = 28687\$$$

Kettle Type Heater(H-101)

$$C = 1.218\ .fd.fm.fp.Cb$$ **8.10**

$$A = 506ft^2$$

$$C_b = \exp[8.821 - 0.3086\ (\ln A) + 0.0681\ (\ln A)^2]$$

$$C_b = 5666$$

$$f_d = 1.35,\ f_p = 1$$

$$f_m = g_1 + g_2(\ln A)$$

$$f_m = 2.3$$

$$C = 21428\$$$

Waste Heat Boiler (WHB-101)

$$C = 1.218\ .fd.fm.fp.Cb$$

$$A = 678ft^2$$

$$C_b = \exp[8.821 - 0.3086\ (\ln A) + 0.0681\ (\ln A)^2]$$

$$C_b = 16317$$

$$f_d = 0.64,\ f_p = 1$$

$$f_m = g_1 + g_2(\ln A)$$

$f_m = 2.4$

$C = 30527\$$

Waste Heat Boiler (WHB-109)

$C = 1.218 .fd.fm.fp.Cb$

$A = 603ft^2$

$C_b = \exp[8.821- 0.3086 (\ln A) + 0.0681 (\ln A)^2]$

$C_b = 14765$

$f_d = 0.64,\ f_p = 1$

$f_m = g_1 + g_2(\ln A)$

$f_m = 1.84$

$C = 21177\$$

Heat Exchanger (HX-102)

- Type: Shell and Tube

$C = 1.218 .fd.fm.fp.Cb$

$C_b = \exp[8.821- 0.3086 (\ln A) + 0.0681 (\ln A)^2]$

$C_b = 15229.6$

$f_d = 0.58,$

$f_p = 1$

$f_m = g_1 + g_2(\ln A)$

$f_m = 2.3$

$C = 24745\$$

Heat Exchanger (HX-103)

- Type: Shell and Tube

$$C = 1.218.fd.fm.fp.Cb$$

$$A = 871.8ft^2$$

$$C_b = \exp[8.821 - 0.3086 (\ln A) + 0.0681 (\ln A)^2]$$

$$C_b = 19359.6$$

$$f_d = 0.66, f_p = 1$$

$$f_m = g_1 + g_2(\ln A)$$

$$f_m = 1.9$$

$$C = 29569\$$$

Heat Exchanger (HX-104)

- Type: shell and tube

$$C = 1.218. fd.fm.fp. Cb$$

$$A = 818ft^2$$

$$C_b = \exp[8.821 - 0.3086 (\ln A) + 0.0681 (\ln A)^2]$$

$$C_b = 18108.7$$

$$f_d = 0.65, f_p = 1$$

$$f_m = g_1 + g_2(\ln A)$$

$$f_m = 1.819$$

$$C = 27096\$$$

Heat Exchanger (HX-105)

$$C = 1.218 .fd.fm.fp.Cb$$

$$A = 893.4ft^2$$

$$C_b = \exp[8.821 - 0.3086 (\ln A) + 0.0681 (\ln A)^2]$$

$$C_b = 19310.4$$

$$f_d = 0.66,$$

$$f_p = 1$$

$$f_m = g_1 + g_2(\ln A)$$

$$f_m = 1.9$$

$$C = 29494\$$$

Heat Exchanger (HX-106)

- Type: shell and tube

$$C = 1.218 .fd.fm.fp.Cb$$

$$A = 423ft^2$$

$$C_b = \exp[8.821- 0.3086 (\ln A) + 0.0681 (\ln A)^2]$$

$$C_b = 12647.9$$

$$f_d = 0.62,$$

$$f_p = 1$$

$$f_m = g_1 + g_2(\ln A)$$

$$f_m = 1.78$$

$$C = 17001\$$$

Heat Exchanger (HX-107)

$$C = 1.218 .fd.fm.fp.C_b$$

$$A = 318ft^2$$

$$C_b = \exp[8.821- 0.3086 (\ln A) + 0.0681 (\ln A)^2]$$

$$C_b = 10938$$

$$f_d = 0.6,$$

$$f_p = 1$$

$$f_m = g_1 + g_2(\ln A)$$

$$f_m = 1.7$$

$$C = 25855\$$$

Storage Tank (T-101)

$$C = 1.218.F_M \exp[2.631+1.3673(\ln V) + 0.0631\ (\ln V)^2] \quad \textbf{8.11}$$

$$F_M = 2.7$$

$$Q = 2593 gal/min$$

$$C = 36095\$$$

Storage Tank (T-102)

$$F_M = 2.7$$

$$V = 2463 gal/min$$

$$C = 1.218 \times F_M \times \exp[2.631+1.367(\ln v)-0.0631(\ln v)^2]$$

$$C = 44087\ \$$$

Storage Tank (T-103)

$$F_M = 2.7$$

$$V = 901 gal/min$$

$$C = 1.218 \times F_M \times \exp[2.631+1.367(\ln v)-0.0631(\ln v)^2]$$

$$C = 26740\ \$$$

Storage Tank (T-104)

$$F_M = 2.4$$

$$V = 481 gal/min$$

$$C = 1.218 \times F_M \times \exp[2.631+1.367(\ln v)-0.0631(\ln v)^2]$$

$$C = 17924\ \$$$

Storage Tank (T-105)

$$F_M = 2.4$$

$$V = 2472/min$$

$$C = 1.218 \times F_M \times \exp[2.631 + 1.367(\ln v) - 0.0631(\ln v)^2]$$

$$C = 39963\ \$$$

Decanter (S-101)

$$C = F_M .C + C_a \quad \textbf{8.12}$$

$$F_M = 2.1\ (SS\text{-}316)$$

$$C_b = 1.672 \exp[8.571 - 0.233(\ln w) + 0.043(\ln w)^2] \quad , w = 5300N = 1191.5lb$$

$$C_b = 15291$$

$$C_a = 2291 \times D^{0.203} \quad , D = 2.6m = 8.5ft$$

$$C_a = 3537.5$$

$$C = F_M C_b + C_a$$

$$C = 35649\ \$$$

Decenter(S-102)

$$C = F_M .C + C_a$$

$$F_M = 1.7$$

$$C_b = 1.672 \exp[8.571 - 0.233(\ln w) + 0.043(\ln w)^2]$$

$$C_b = 15291$$

$$C_a = 2291 \times D^{0.203} \quad , D = 2.7m = 8.6ft$$

$$C_a = 3545.9$$

$$C = F_M C_b + C_a$$

$$C = 29541\ \$$$

Decanter(S-103)

$$C = F_M .C + C_a$$

$$F_M = 1.7$$

$$C_b = 1.672 \exp [8.571-0.233(\ln w)+0.043(\ln w)^2]$$,

$$C_b = 14545$$

$$C_a = 2291 \times D^{0.203}$$, $D = 2.5m = 8.2ft$

$$C_a = 3511$$

$$C = F_M C_b + C_a$$

$$C = 28238 \$$$

Cyclone

- Standard duty

$$C = 1.05 Q^{0.91}$$, $Q = ft^3/min$

$$Q = 368.4 ft^3/min$$

$$C = 227k\$$$

Distillation Column(D-101)

$$C = [f_1 C_b + Nf_2f_3f_4C_b+C_{pt}]$$,SS-316 , $f_1 = 2.2$

$$f_2 = 1.401 + 0.0724D = 1.54$$

$$f_3 = 0.95$$

$$D = 1.9m = 6.2ft$$,

$$L = 11.3m = 37.4ft$$

$$f_4 = \frac{2.25}{(10414)^N} = 1.08 \times 10^{-72}$$. $N = 18$

, wall thickness = T_p = 0.5in ,bottom thickness = T_b=0.75in

$$C_{pt} = 249.6 \times D^{0.6332} \times L^{0.8016} = 14448$$

$$C_t = 457.7\exp(0.1739D) = 1345$$

$$W = 32129lb$$

$$C_b = 1.218 \exp [7.123+0.1478(\ln w)+0.025(\ln w)^2 +0.0158\ L/D \times \ln T_b /T_p]$$

$$= 98602$$

$$C = 1.218 \exp [2.1 \times 98602+18 \times 0.95 \times 1.1 \times 10^{-72} \times 1345+14448]$$

$$= 253968\$$$

Distillation Column(D-102)

$$C = [f_1 C_b + Nf_2f_3f_4C_b+C_{pt}] \quad ,SS\text{-}304\ ,\ f_1 = 1.7$$

$$f_2 = 1.189 + 0.058D = 1.5$$

$$f_3 = 0.95 \quad (sieve)$$

$$D = 1.67m = 5.5ft\ ,\ L = 10m = 32.8ft$$

$$f_4 = \frac{2.25}{(10414)^N} = 1.2 \times 10^{-64} \quad ,\ N = 16$$

, wall thickness = T_p = 0.5in ,bottom thickness = T_b=0.75in

$$C_{pt} = 249.6 \times D^{0.63} \times L^{0.802} = 11878.6$$

$$C_t = 457.7\exp(0.1739D) = 1195$$

$$W = 32129lb$$

$$C_b = 1.218 \exp [7.123+0.1478(\ln w)+0.025(\ln w)^2 +0.0158\ L/D \times \ln T_b /T_p]$$

$$= 98440.7$$

$$C = [f_1 C_b + Nf_2f_3f_4C_b+C_{pt}] = 218299\$$$

Reboiler (RB-101)

$$A = 51m^2 = 549ft^2$$

$$C = 1.218.f_d.f_m.C_b$$

$$f_d = 1.35$$

$$f_p = 1$$

$$f_m = g_1 + g_2(\ln A) \;, \text{(SS-316)}$$

$$= 2.3$$

$$C_b = \exp[8.821 - 0.3086(\ln A) + 0.0681(\ln A)^2]$$

$$= 14764.7$$

$$C = 1.218.f_d.f_m.C_b$$

$$= 55840\$$$

Reboiler (RB-102)

$$A = 54 m^2 = 581 ft^2$$

$$C = 1.218.f_d.f_m.C_b$$

$$f_d = 1.35$$

$$f_p = 1$$

$$f_m = g_1 + g_2(\ln A) = 1.8 \text{ (SS-304)}$$

$$C_b = \exp[8.821 - 0.3086(\ln A) + 0.0681(\ln A)^2]$$

$$= 14058.7$$

$$C = 1.218.f_d.f_m.C_b$$

$$= 41610\$$$

Condenser (RF-101)

$$A = 49 m^2 = 527.4 ft^2 \text{, u-tube}$$

$$f_d = \exp[-0.9816 + 0.83(\ln A)] = 0.6$$

$$f_p = 1$$

$$f_m = g_1 + g_2(\ln A) \ , (SS\text{-}316)$$

$$= 2.3$$

$$C_b = \exp[8.821 - 0.309(\ln A) + 0.0681(\ln A)^2]$$

$$= 14486.8$$

$$C = 1.218.f_d.f_m.C_b$$

$$= 24350\$$$

Condenser (RF-102)

$$A = 52m^2 = 559.7ft^2$$

$$f_d = \exp[-0.9816 + 0.83(\ln A)]$$

$$= 0.6$$

$$f_p = 1$$

$$f_m = g_1 + g_2(\ln A) \ , (SS\text{-}304)$$

$$= 1.8$$

$$C_b = \exp[8.821 - 0.309(\ln A) + 0.0681(\ln A)^2]$$

$$= 14342.7$$

$$C = 1.218.f_d.f_m.C_b$$

$$= 18866.9\$$$

8.8 Total purchased cost 2022

Cost Index

Cost index 2003 = 402

Cost index 2022 = 808.7

Cost in 2020 = cost in 2003 × $(cost\ index\ 2022)/(cost\ index\ 2003)$

Table 8.1: Purchased Cost 2022

PURCHASED COST 2022	
EQUIPMENT	**COST ($)**
AGITATORS	
A-101	1.2×10^4
A-102	1×10^4
CONVEYER	
CN-101	3.8×10^4
FILTER	
F-101	6×10^6
COOLING TOWER	
CT-101	4.1×10^5
PUMPS	
P-101	1.4×10^5
P-102	1.9×10^4
P-103	3.4×10^4
REACTORS	
R-101	7.7×10^6
R-102	1.9×10^6
EVAPORATOR	
V-101	1.7×10^5
WASHING UNIT	
C-101	5.7×10^4
KETTLE TYPE EXCHANGER	
H-101	4.3×10^4
WASTE HEAT BOILER	
WBH-101	6.1×10^4
WHB-102	4.2×10^4
HEAT EXCHANGERS	

HX-102	4.9×10^4
HX-103	5.9×10^4
HX-104	5.4×10^4
HX-105	5.9×10^4
HX-106	3.4×10^4
HX-107	2.7×10^4
HX-108	5.2×10^4
STORAGE TANKS	
T-101	7.2×10^4
T-102	8.8×10^4
T-103	5.3×10^4
T-104	3.6×10^4
T-105	8×10^4
DECANTER	
S-101	7.1×10^4
S-102	5.9×10^4
S-103	5.6×10^4
CYCLONE	
CS-101	4.5×10^5
DISTILLATION COLUMN	
D-101	5.1×10^5
D-102	4.3×10^5
REBOILERS	
RB-101	1.1×10^5
RB-102	8.3×10^4
CONDENSORS	
RF-101	4.8×10^4
RF-102	3.7×10^4
TOTAL	
1.9×10^7	

8.9 Direct Cost

Table 8.2: Direct Cost

Items	% of Total purchased cost	%	Cost ($)
Purchased equipment	-	100	19.4×10^6
Installation	25-55	40	7.8×10^6
Instrumentation and control	6-30	18	3.5×10^6
Piping	40-80	60	11.7×10^6
Electricity	10-15	12.5	2.4×10^6
Building	15	15	2.9×10^6
Land	4-8	6	1.1×10^6
Service facility	30-80	55	10.7×10^6
Yard Improvement	10-20	15	2.9×10^6
Insulation Cost	8-9	8.5	1.6×10^6
Total			64.2×10^6

8.10 Indirect Cost

Table 8.3: Indirect Cost

Items	Range (%)	%	Cost ($)
Engg and supervision	25% of Direct cost	25	16×10^6
Contractor fees	2-8% of Direct cost	5	3.2×10^6
Construction expenses	10% of Direct cost	10	6.4×10^6
Contingencies	8% of Direct cost	8	5.1×10^6
Total			30.8×10^6

Fixed Capital Investment

$$FCI = \text{direct cost} + \text{indirect cost} \quad \textbf{8.13}$$

$$= 95\times10^6\ \$$$

Working Capital

$$\textbf{WCI =}\ 15\%\ \text{of FCI} \quad \textbf{8.14}$$

$$= 14.3\times10^6\$$$

Total Capital Investment

$$TCI = FCI + WCI \quad \textbf{8.15}$$

$$= 1.1\times10^8\ \$$$

8.11 Variable Cost

Raw Material Cost

- **Chicken Fat**

Price per kg = 0.09 $/kg

Flowrate = 4.7×10^9 kg/yr

Total price = 423×10^6 $/yr

- **Methanol**

Price per kg = 0.25 $/kg

Flowrate = 2.4×10^9 kg/yr

Total price = 600×10^6 $/yr

- **Sulphuric Acid**

Price per kg = 0.62 $/kg

Flowrate = 35.5×10^6 kg/yr

Total price = 22×10^6 $/yr

- **KOH**

Price per kg = 0.52 \$/kg

Flowrate = 57×10^6 kg/yr

Total price = 29×10^6 \$/yr

- **Total Raw Material Cost**

= 1.1×10^9 \$/yr

Miscellaneous Cost

Maintenance cost = 7% of FCI **8.16**

= 7.7×10^6 \$/yr

Miscellaneous material = 10% of maintenance cost **8.17**

= 770×10^3 \$/yr

Utilities Cost

- **Steam Cost**

Price per kg = 0.02 \$/kg

Flowrate = 4.8×10^9 kg/yr

Total price = 96×10^6 \$/yr

- **Water Cost**

Price per kg = 1.8×10^{-5} \$/kg

Flowrate = 6.9×10^{10} kg/yr

Total price = 1.2×10^6 \$/yr

- **Total Utility Cost**

= steam cost + water cost

= 97.2×10^6 \$/yr

Variable cost = raw material cost + miscellaneous cost + utility cost = 1.2×10^9 \$/yr

8.12 Fixed Operating Cost

Table 8.4: Fixed Operating Cost

Type	%FCI	Cost (\$)
Maintenance cost	7	6.65×10^6
Operating cost of labor	10	9.5×10^6
Laboratory cost	20	19×10^6
Supervision cost	15	14.3×10^6
Plant overhead	50	47.5×10^6
Capital Charges	10	9.5×10^6
Insurance	1	950×10^3
Local Taxes	2	1.9×10^6
Royalties	1	950×10^3
Total		110.2×10^6

Direct Production Cost

= variable cost + fixed operating cost **8.18**

= 1.21×10^9 \$/yr

Overhead Charges

= 30% of direct production cost

= 390×10^6 \$/yr

Manufacturing Cost

= overhead cost + direct production cost

$= 1.3\times10^9$ \$/yr

General Expenses

Table 8.5: General Expenses

Function	% of manufacturing cost	Cost($)
Administration	2	33.8×10^6
Distribution and marketing	2	33.8×10^6
Research and development	5	84.5×10^6
Total		152×10^6

Total Production Cost

= manufacturing cost + general expense

$= 1.7\times10^9$ \$/yr

8.13 Profitability analysis

Production Cost

Total production rate $= 4.5\times10^9$ kg/yr

$$\text{Production cost} = \frac{\text{total production cost}}{\text{total production rate}} \quad \textbf{8.19}$$

= 0.3$/kg

Selling Price

Price of biodiesel in Market = 0.8 \$/kg

Selling price of product = 0.4 \$/kg

Profit

Profit = Selling price - production cost

= 0.1 \$/kg

Profit per year = 4.5×10^{8} \$/yr

Total Income

Selling Price = 0.4 \$/kg

Total Production rate = 4.5×10^{9} kg/yr

Total Income = 1.78×10^{9} \$/yr

Gross Profit

= Total Income - Total Production Cost

= 80×10^{6} \$/yr

Depreciation

Machinery and equipment = 20% of FCI

= 19×10^{6} \$/yr

Building = 4% of Building cost

= 113×10^{3}\$/yr

Total Depreciation = Machinery and equipment + Building

= 19.1×10^{6} \$/yr

Taxes

Let the tax rate is 40%

Taxes = 0.4×Gross Profit

$$= 32\times10^6\ \$/yr$$

Net Profit

$$\text{Net Profit before Taxation} = \text{Gross profit} - \text{Depreciation}$$

$$= 60.9\times10^6\ \$/yr$$

$$\text{Net Profit} = \text{Net Profit before Taxation} - \text{Taxes}$$

$$= 28.9\times10^6\ \$/yr$$

Rate of Return

$$\text{rate or return} = \frac{\text{net profit}}{\text{total capital investment}}\times100 \qquad \textbf{8.20}$$

$$= 26\%$$

Payback Period

$$\text{Payback period} = \frac{1}{rate\ or\ return} = 3.8\ \text{years}$$

8.14 Discounted Cashflow

- Total Capital Cost

$$= C_{FC} + C_L + C_{WC} \qquad \textbf{8.21}$$

C_{FC} = Fixed Capital

C_L = Land Cost

C_{WC} = Working Capital

- Annual Expense

= Cost of manufacturing

$$COM = 0.304FCI+2.73C_{OL}+1.23(C_{UT}+C_{RM}) \qquad \textbf{8.22}$$

C_{OL} = Cost of Labor

C_{UT} = Utilities Cost

C_{RM} = Raw Material Cost

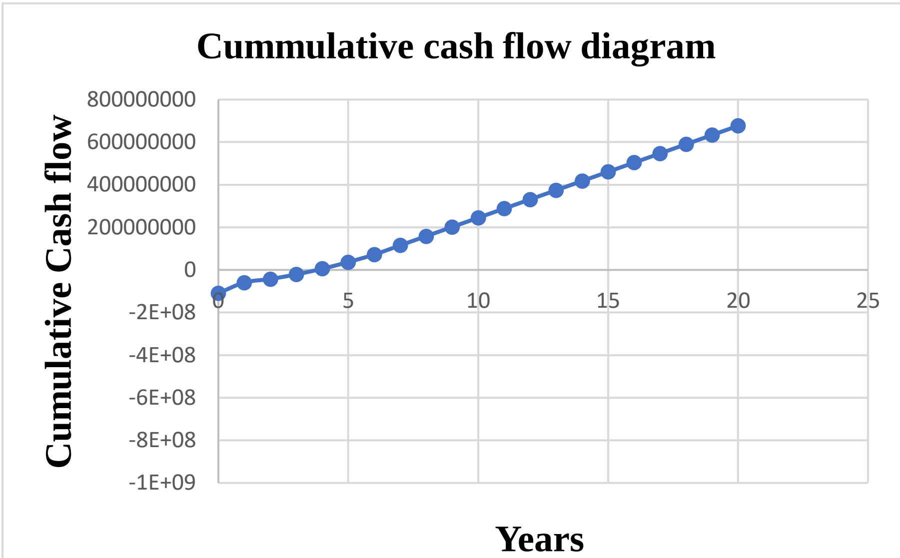


Figure 8.1: Cumulative Cash Flow Chart

8.15 Net Present Worth

Minimum Acceptable Rate of Return

(MARR) = 15%

Internal Rate of Return = I %

$$NPV = \frac{Net\ Profit((1+i)^n - 1)}{i(1+i)^n} - TCI = 0 \qquad \mathbf{8.23}$$

By hit and trial method

IRR = 0.6

NPV = $\$1\times10^9$

This shows that

IRR > MARR

So, project is profitable and acceptable. Also

NPV > 0,

So, the investment is economically feasible

Table 8.6: Net Present Worth

years	Gross income ($)	Annual Expense	Investment and salvage value	Cashflow before tax	Depreciation	Taxable income	Taxes	Cashflow after tax	Cumulative cash flow
0	-	-	-95100000	-95100000					-95100000
0	-	-	-1170000	-1170000					-96270000
0	-	-	-14200000	-14200000					-109300000
1	1780000000	145490000		1634510000	62111380	83378620	33351448	50027172	-59272828
2	1780000000	145490000		1634510000	117684720	27805280	11122112	16683168	-42589660
3	1780000000	145490000		1634510000	109512170	35977830	14391132	21586698	-21002962
4	1780000000	145490000		1634510000	101339620	44150380	17660152	26490228	5487266
5	1780000000	145490000		1634510000	93167070	52322930	20929172	31393758	36881024
6	1780000000	145490000		1634510000	86629030	58860970	23544388	35316582	72197606
7	1780000000	145490000		1634510000	73552950	71937050	28774820	43162230	115359836
8	1780000000	145490000		1634510000	73552950	71937050	28774820	43162230	158522066
9	1780000000	145490000		1634510000	73552950	71937050	28774820	43162230	201684296
10	1780000000	145490000		1634510000	73552950	71937050	28774820	43162230	244846526
11	1780000000	145490000		1634510000	73552950	71937050	28774820	43162230	288008756
12	1780000000	145490000		1634510000	73552950	71937050	28774820	43162230	331170986
13	1780000000	145490000		1634510000	73552950	71937050	28774820	43162230	374333216
14	1780000000	145490000		1634510000	73552950	71937050	28774820	43162230	417495446
15	1780000000	145490000		1634510000	73552950	71937050	28774820	43162230	460657676
16	1780000000	145490000		1634510000	73552950	71937050	28774820	43162230	503819906
17	1780000000	145490000		1634510000	73552950	71937050	28774820	43162230	546982136
18	1780000000	145490000		1634510000	73552950	71937050	28774820	43162230	590144366
19	1780000000	145490000		1634510000	73552950	71937050	28774820	43162230	633306596
20	1780000000	145490000		1634510000	73552950	71937050	28774820	43162230	676468826
			9.51×10^6						

CHAPTER 09

PROCESS DESIGN SIMULATION

9.1 Introduction

Process simulation is used for the design, development, analysis, and optimization of technical processes such as: chemical plants, chemical processes, environmental systems, power stations, complex manufacturing operations, biological processes, and similar technical functions.

Process simulation software describes processes in flow diagrams where unit operations are positioned and connected by product or duct streams. The software solves the mass and energy balance to find a stable operating point on specified parameters. The goal of a process simulation is to find optimal conditions for a process. This is essentially an optimization problem which has to be solved in an iterative process.

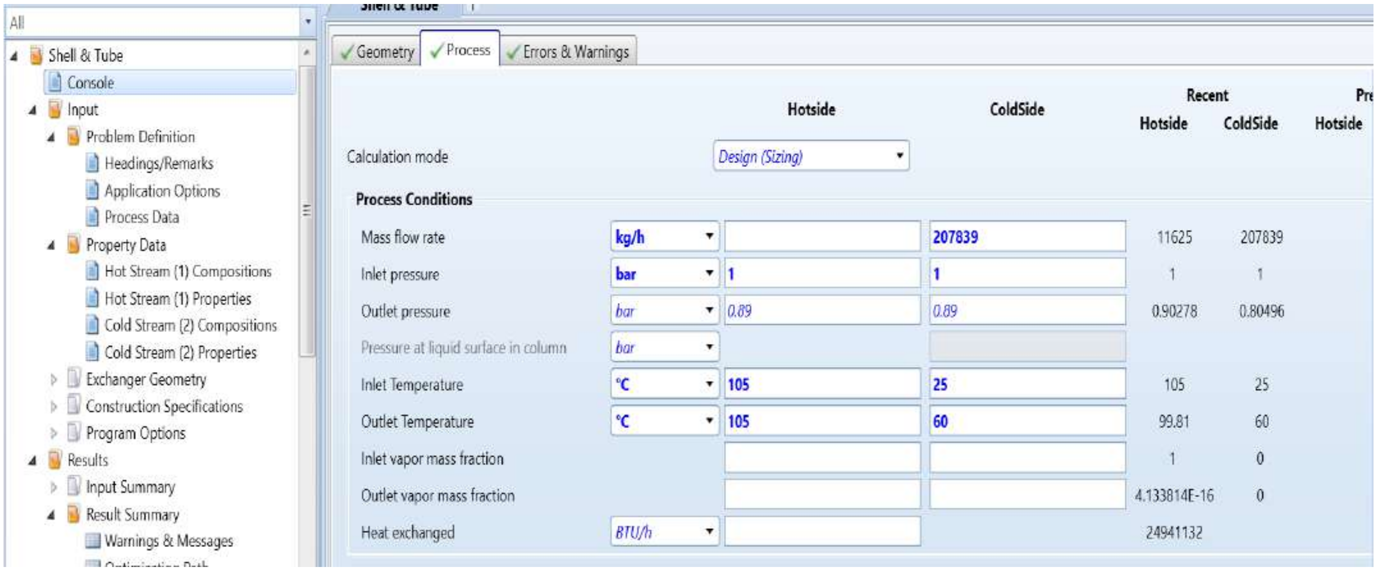
Process simulation uses models which introduce approximations and assumptions but allow the description of a property over a wide range of temperatures and pressures which might not be covered by available real data. Models also allow interpolation and extrapolation - within certain limits - and enable the search for conditions outside the range of known properties.

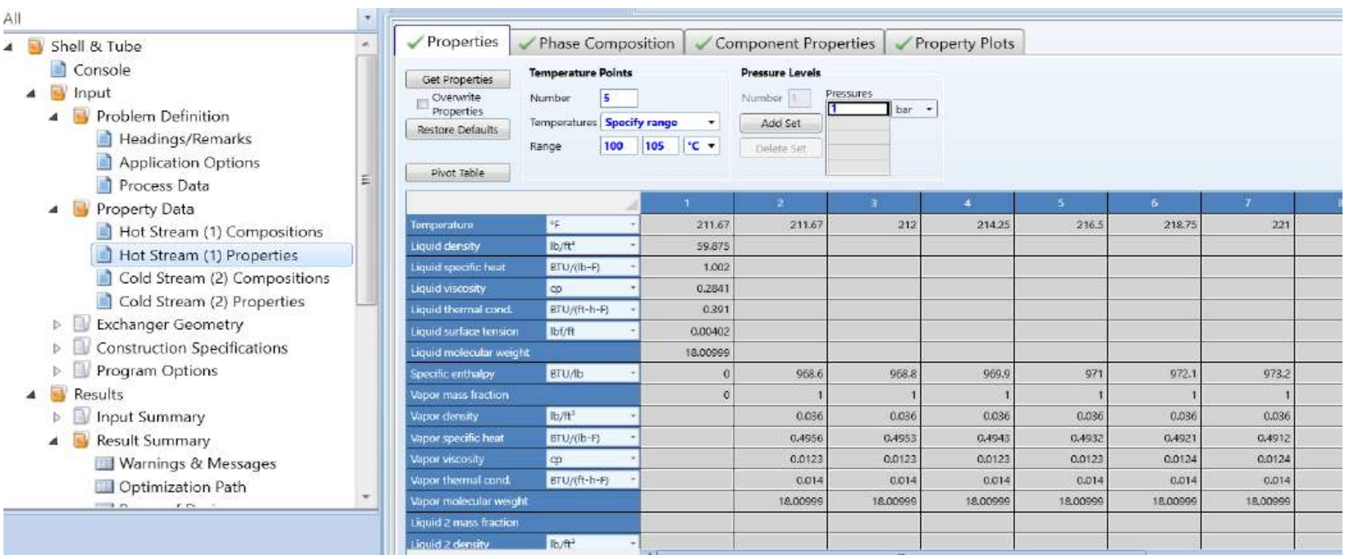
Aspen HYSYS (or simply HYSYS) is a chemical process simulator currently developed by Aspen Tech used to mathematically model chemical processes, from unit operations to full chemical plants and refineries. HYSYS is able to perform many of the core calculations of chemical engineering, including those concerned with mass balance, energy balance, vapor-liquid equilibrium, heat transfer, mass transfer, chemical kinetics, fractionation, and pressure drop.[2] HYSYS is used extensively in industry and academia for steady-state and dynamic simulation, process design, performance modeling, and optimization.

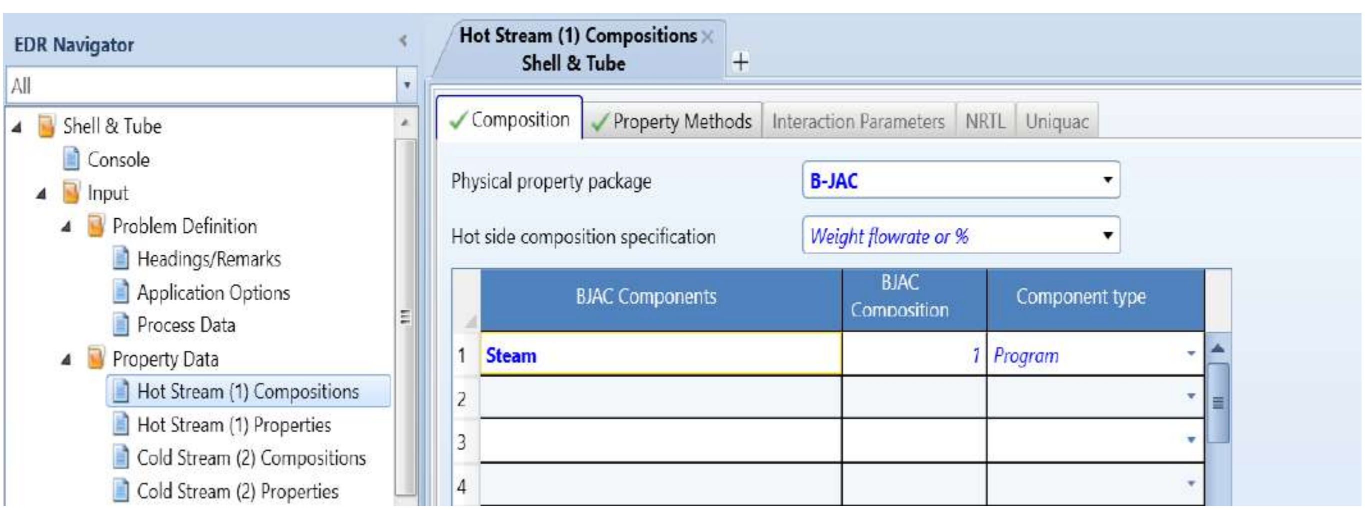
It can also handle very complex processes, such as:

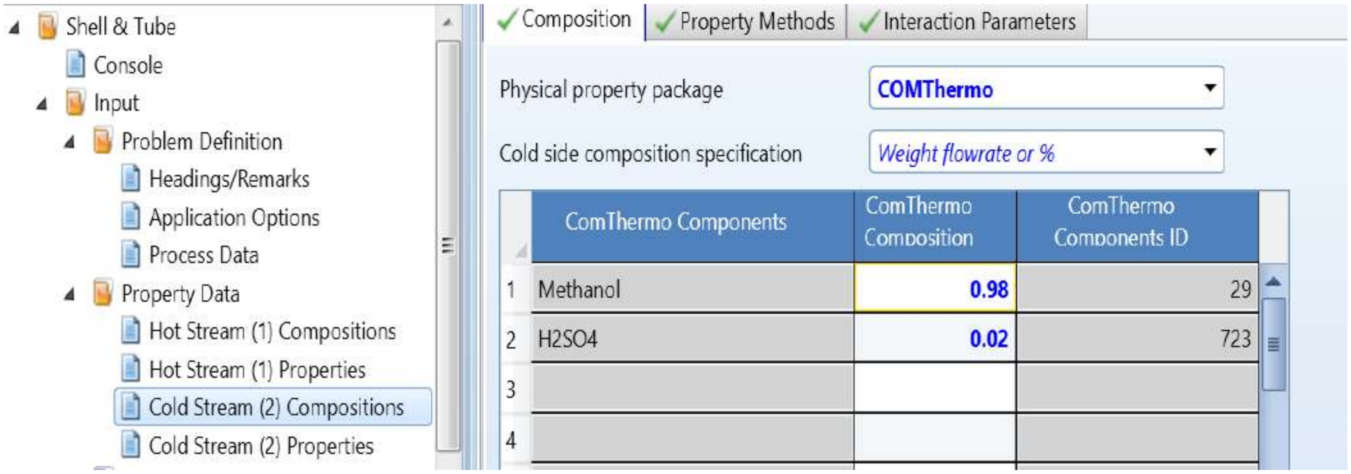
- Dedicated Unit Operations for the Refinery Industry (Crackers, Coker, Reformer, FCC Unit, etc.)
- Multiple-column separation systems
- Chemical reactors
- Simulation of Petroleum Crude Oils (based on their properties)
- Complex Recycle – Bypass Stream in Processes

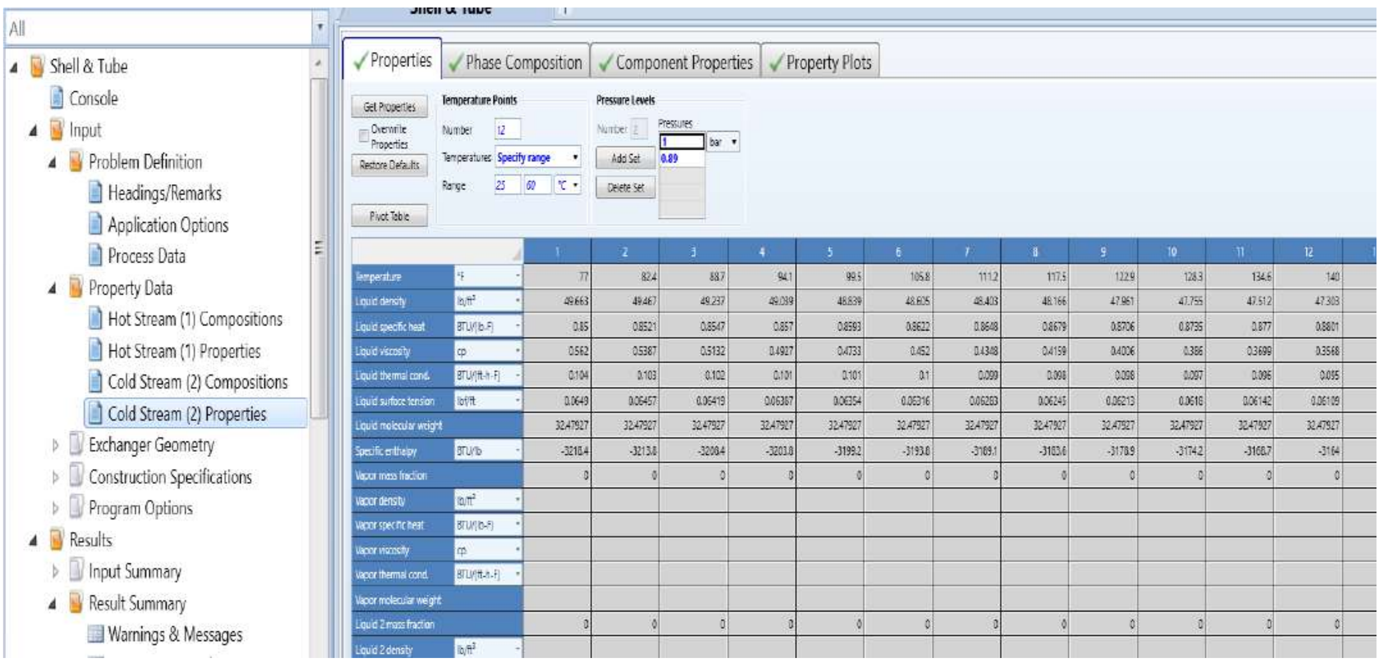
9.2. Simulation of Heat Exchanger (HX-102)

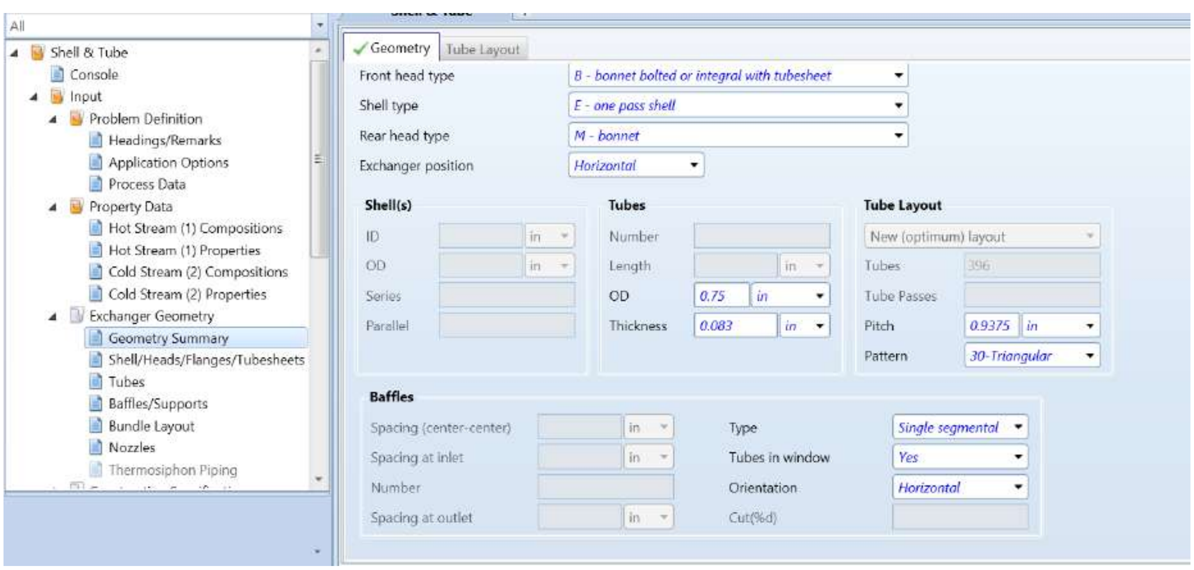


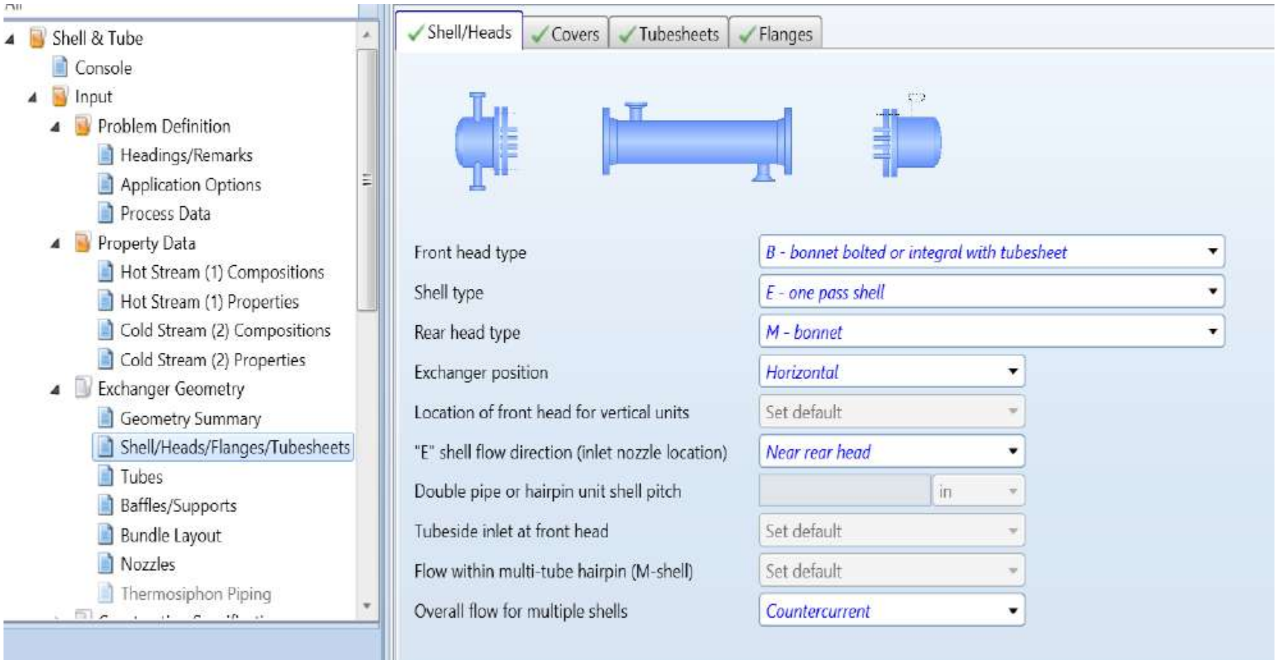


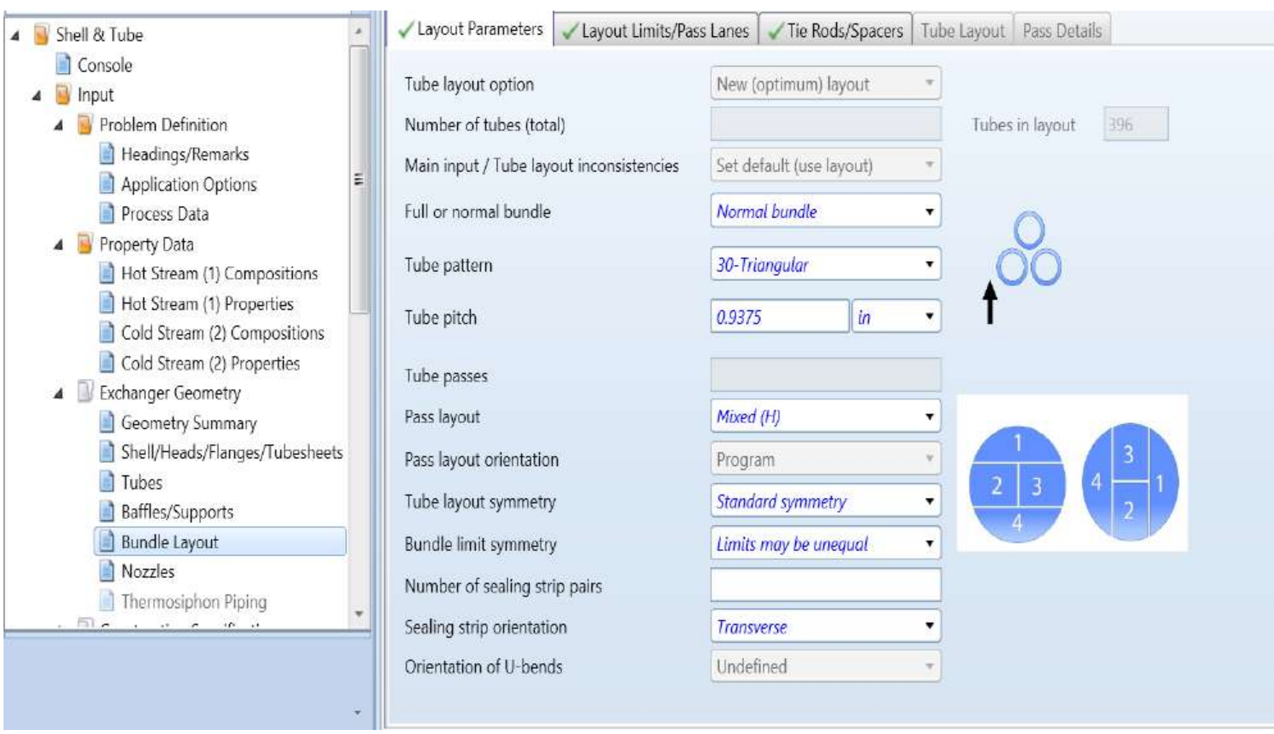


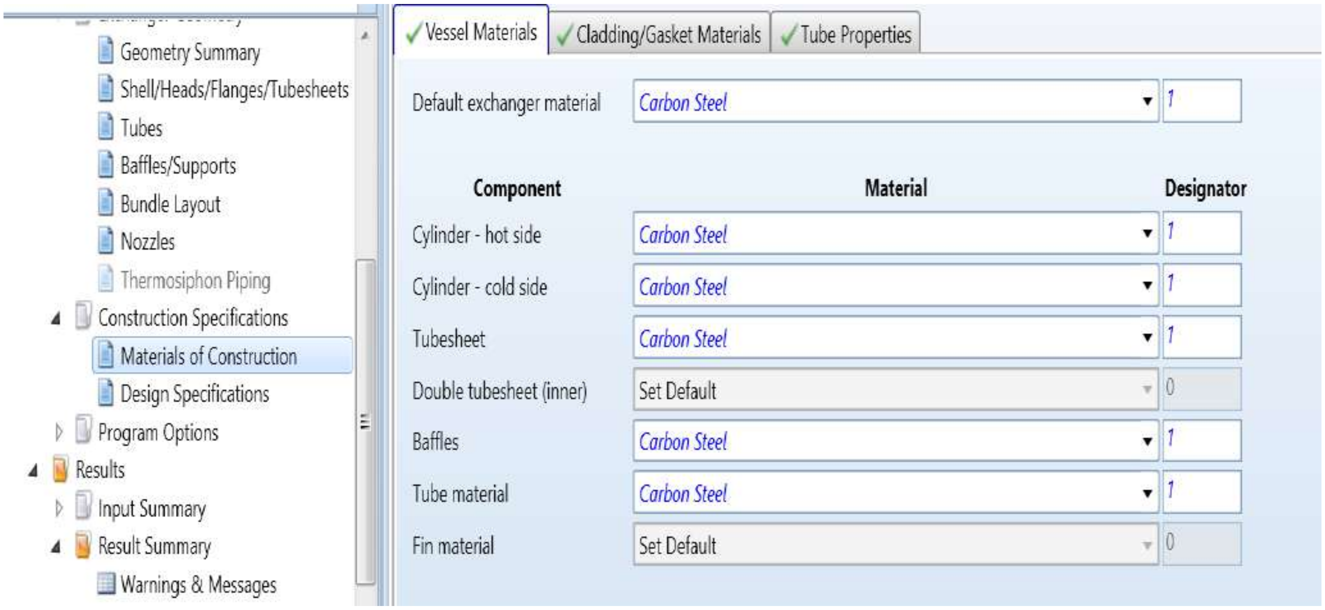

Shell & Tube
Console
Input
Problem Definition
Headings/Remarks
Application Options
Process Data
Property Data
Hot Stream (1) Compositions
Hot Stream (1) Properties
Cold Stream (2) Compositions
Cold Stream (2) Properties
Composition
Property Methods
Interaction Parameters
Physical property package
COMThermo
Cold side composition specification
Weight flowrate or %
ComThermo Components
ComThermo Composition
ComThermo Components ID
1 Methanol 0.98 29
2 H2SO4 0.02 723
3
4

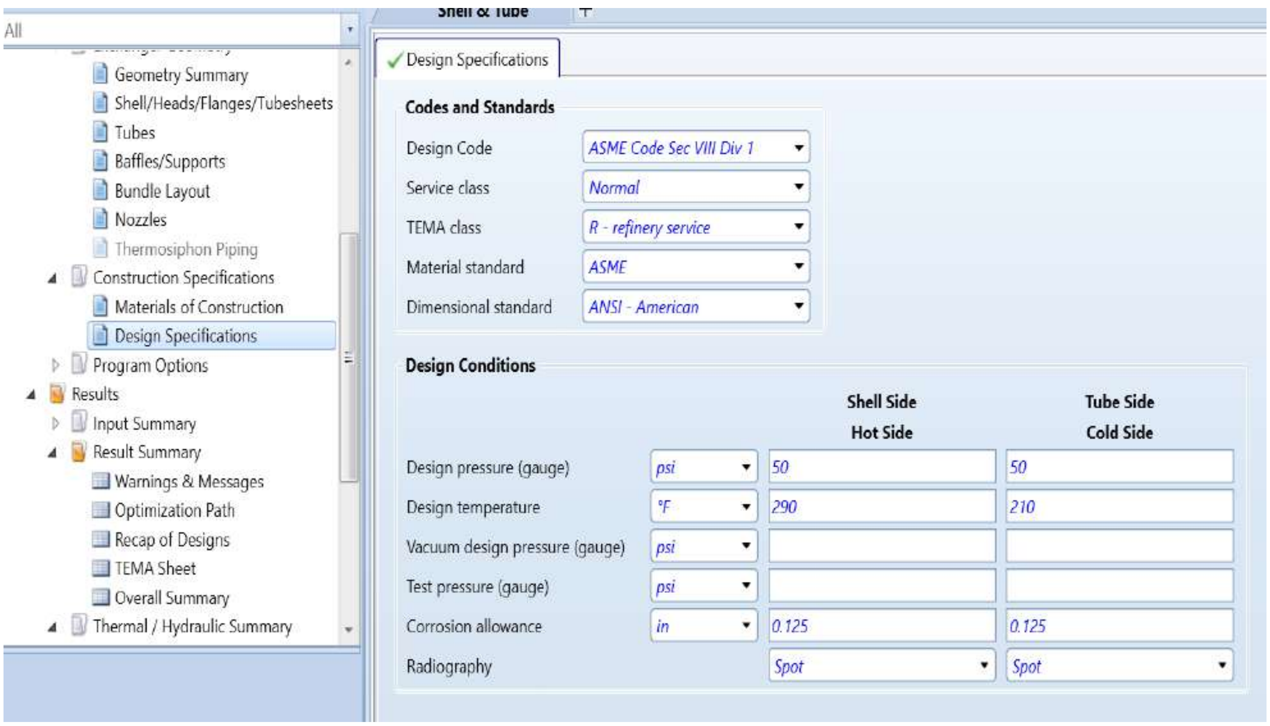

All
Shell & Tube
Console
Input
Problem Definition
Headings/Remarks
Application Options
Process Data
Property Data
Hot Stream (1) Compositions
Hot Stream (1) Properties
Cold Stream (2) Compositions
Cold Stream (2) Properties
Exchanger Geometry
Construction Specifications
Program Options
Results
Input Summary
Result Summary
Warnings & Messages
Properties
Phase Composition
Component Properties
Property Plots
Get Properties
Override Properties
Restore Defaults
Pivot Table
Temperature Points
Number 12
Temperatures Specify range
Range 25 60 °C
Pressure Levels
Number 2
Pressures
1
0.89
bar
Add Set
Delete Set
1 2 3 4 5 6 7 8 9 10 11 12
Temperature °F 77 82.4 88.7 94.1 99.5 105.8 111.2 117.5 122.9 128.3 134.6 140
Liquid density lb/ft³ 49.663 49.467 49.237 49.039 48.839 48.605 48.403 48.166 47.961 47.755 47.512 47.303
Liquid specific heat BTU/(lb-F) 0.85 0.8521 0.8547 0.857 0.8593 0.8622 0.8648 0.8679 0.8706 0.8735 0.877 0.8801
Liquid viscosity cp 0.562 0.5387 0.5132 0.4927 0.4733 0.452 0.4348 0.4159 0.4006 0.386 0.3699 0.3568
Liquid thermal cond. BTU/(ft-h-F) 0.104 0.103 0.102 0.101 0.101 0.1 0.099 0.098 0.098 0.097 0.096 0.095
Liquid surface tension lbf/ft 0.0649 0.06457 0.06419 0.06387 0.06354 0.06316 0.06283 0.06245 0.06213 0.0618 0.06142 0.06109
Liquid molecular weight 32.47927 32.47927 32.47927 32.47927 32.47927 32.47927 32.47927 32.47927 32.47927 32.47927 32.47927 32.47927
Specific enthalpy BTU/lb -3218.4 -3213.8 -3208.4 -3203.8 -3199.2 -3193.8 -3189.1 -3183.6 -3178.9 -3174.2 -3168.7 -3164
Vapor mass fraction 0 0 0 0 0 0 0 0 0 0 0 0
Vapor density lb/ft³
Vapor specific heat BTU/(lb-F)
Vapor viscosity cp
Vapor thermal cond. BTU/(ft-h-F)
Vapor molecular weight
Liquid 2 mass fraction 0 0 0 0 0 0 0 0 0 0 0 0
Liquid 2 density lb/ft³


All
Shell & Tube
Console
Input
Problem Definition
Headings/Remarks
Application Options
Process Data
Property Data
Hot Stream (1) Compositions
Hot Stream (1) Properties
Cold Stream (2) Compositions
Cold Stream (2) Properties
Exchanger Geometry
Geometry Summary
Shell/Heads/Flanges/Tubesheets
Tubes
Baffles/Supports
Bundle Layout
Nozzles
Thermosiphon Piping
Geometry
Tube Layout
Front head type
B - bonnet bolted or integral with tubesheet
Shell type
E - one pass shell
Rear head type
M - bonnet
Exchanger position
Horizontal
Shell(s)
ID
OD
Series
Parallel
in
Tubes
Number
Length
OD 0.75 in
Thickness 0.083 in
Tube Layout
New (optimum) layout
Tubes 396
Tube Passes
Pitch 0.9375 in
Pattern 30-Triangular
Baffles
Spacing (center-center)
Spacing at inlet
Number
Spacing at outlet
Type Single segmental
Tubes in window Yes
Orientation Horizontal
Cut(%d)


Shell & Tube
Console
Input
Problem Definition
Headings/Remarks
Application Options
Process Data
Property Data
Hot Stream (1) Compositions
Hot Stream (1) Properties
Cold Stream (2) Compositions
Cold Stream (2) Properties
Exchanger Geometry
Geometry Summary
Shell/Heads/Flanges/Tubesheets
Tubes
Baffles/Supports
Bundle Layout
Nozzles
Thermosiphon Piping
Shell/Heads
Covers
Tubesheets
Flanges
Front head type
B - bonnet bolted or integral with tubesheet
Shell type
E - one pass shell
Rear head type
M - bonnet
Exchanger position
Horizontal
Location of front head for vertical units
Set default
"E" shell flow direction (inlet nozzle location)
Near rear head
Double pipe or hairpin unit shell pitch
in
Tubeside inlet at front head
Set default
Flow within multi-tube hairpin (M-shell)
Set default
Overall flow for multiple shells
Countercurrent


Shell & Tube
Console
Input
Problem Definition
Headings/Remarks
Application Options
Process Data
Property Data
Hot Stream (1) Compositions
Hot Stream (1) Properties
Cold Stream (2) Compositions
Cold Stream (2) Properties
Exchanger Geometry
Geometry Summary
Shell/Heads/Flanges/Tubesheets
Tubes
Baffles/Supports
Bundle Layout
Nozzles
Thermosiphon Piping
Layout Parameters
Layout Limits/Pass Lanes
Tie Rods/Spacers
Tube Layout
Pass Details
Tube layout option
New (optimum) layout
Number of tubes (total)
Tubes in layout
396
Main input / Tube layout inconsistencies
Set default (use layout)
Full or normal bundle
Normal bundle
Tube pattern
30-Triangular
Tube pitch
0.9375
in
Tube passes
Pass layout
Mixed (H)
Pass layout orientation
Program
Tube layout symmetry
Standard symmetry
Bundle limit symmetry
Limits may be unequal
Number of sealing strip pairs
Sealing strip orientation
Transverse
Orientation of U-bends
Undefined

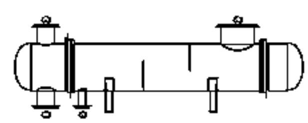

Geometry Summary
Shell/Heads/Flanges/Tubesheets
Tubes
Baffles/Supports
Bundle Layout
Nozzles
Thermosiphon Piping
Construction Specifications
Materials of Construction
Design Specifications
Program Options
Results
Input Summary
Result Summary
Warnings & Messages
Vessel Materials
Cladding/Gasket Materials
Tube Properties
Default exchanger material
Carbon Steel
1
Component
Material
Designator
Cylinder - hot side
Cylinder - cold side
Tubesheet
Double tubesheet (inner)
Set Default
0
Baffles
Tube material
Fin material


All
Design Specifications
Codes and Standards
Design Code
ASME Code Sec VIII Div 1
Service class
Normal
TEMA class
R - refinery service
Material standard
ASME
Dimensional standard
ANSI - American
Design Conditions
Shell Side
Hot Side
Tube Side
Cold Side
Design pressure (gauge)
psi
50
50
Design temperature
°F
290
210
Vacuum design pressure (gauge)
Test pressure (gauge)
Corrosion allowance
in
0.125
0.125
Radiography
Spot
Spot
Optimization Path
Recap of Designs
TEMA Sheet
Overall Summary
Thermal / Hydraulic Summary

Heat Exchanger Specification Sheet

1	Company: Heat exchanger					
2	Location: Wah Engineering College					
3	Service of Unit:	Our Reference:				
4	Item No.: HX-102	Your Reference:				
5	Date: 8-5-2023	Rev No.:	Job No.:			
6	Size : 23 - 96 in	Type: BEM Horizontal	Connected in: 1 parallel 1 series			
7	Surf/unit(eff.) 600.2 ft^2	Shells/unit 1	Surf/shell(eff.) 600.2 ft^2			
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation		Shell Side		Tube Side	
10	Fluid name					
11	Fluid quantity, Total	lb/h	25628		458199	
12	Vapor (In/Out)	lb/h	25628	0	0	0
13	Liquid	lb/h	0	25628	458199	458199
14	Noncondensable	lb/h	0	0	0	0
15						
16	Temperature (In/Out)	°F	221	211.67	77	140
17	Bubble / Dew point	°F	211.67 / 211.67	211.67 / 211.67	/	/
18	Density Vapor/Liquid	lb/ft^3	0.036 /	/ 59.875	/ 49.663	/ 47.302
19	Viscosity	cp	0.0124 /	/ 0.2841	/ 0.562	/ 0.3568
20	Molecular wt, Vap		18.01			
21	Molecular wt, NC					
22	Specific heat	BTU/(lb-F)	0.4912 /	/ 1.002	/ 0.85	/ 0.8801
23	Thermal conductivity	BTU/(ft-h-F)	0.014 /	/ 0.391	/ 0.104	/ 0.095
24	Latent heat	BTU/lb	968.6	968.6		
25	Pressure (abs)	psi	14.5	13.09	14.5	11.67
26	Velocity (Mean/Max)	ft/s	95.5 / 226.32		7.13 / 7.24	
27	Pressure drop, allow./calc.	psi	1.6	1.41	3	2.83
28	Fouling resistance (min)	ft^2-h-F/BTU	0		0	0 Ao based
29	Heat exchanged 24941130 BTU/h				MTD (corrected) 99.92 °F	
30	Transfer rate, Service 415.9		Dirty 440.24		Clean 440.24	BTU/(h-ft^2-F)

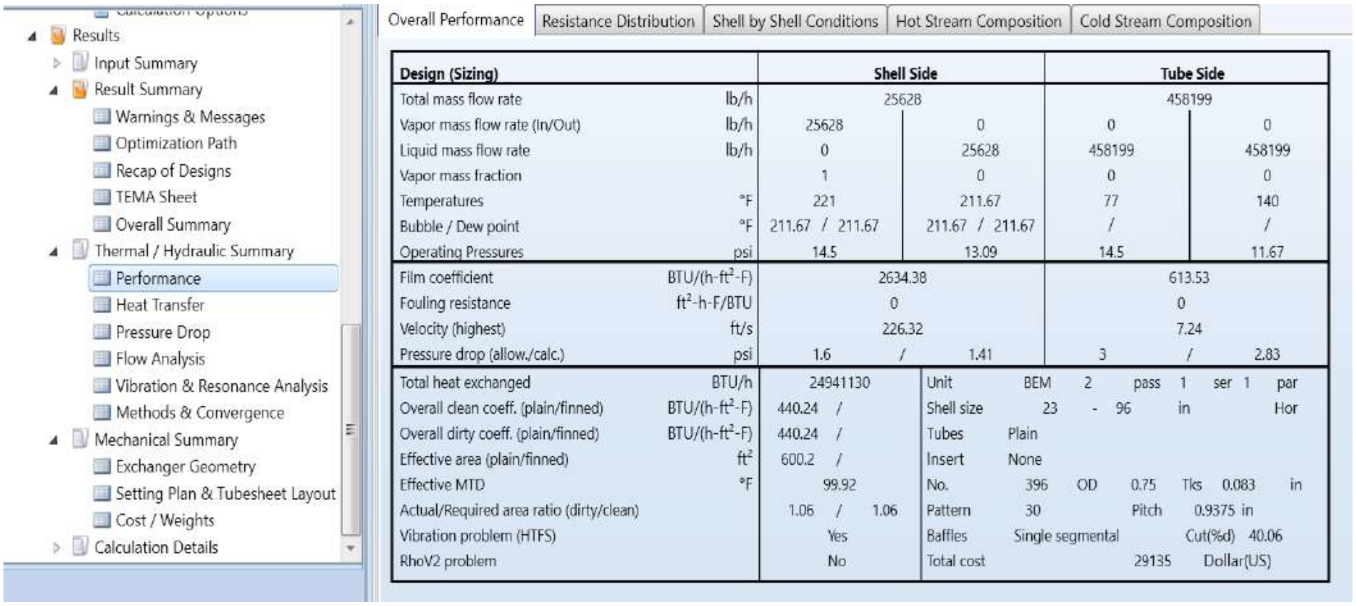
31	**CONSTRUCTION OF ONE SHELL**					**Sketch**
32				Shell Side	Tube Side	
33	Design/Vacuum/test pressure		psi	50 / /	50 / /	
34	Design temperature		°F	290	210	
35	Number passes per shell			1	2	
36	Corrosion allowance		in	0.125	0.125	
37	Connections	In	in	1 16 / -	1 8 / -	
38	Size/Rating	Out		1 3 / -	1 8 / -	
39	Nominal	Intermediate		1 / -	1 / -	

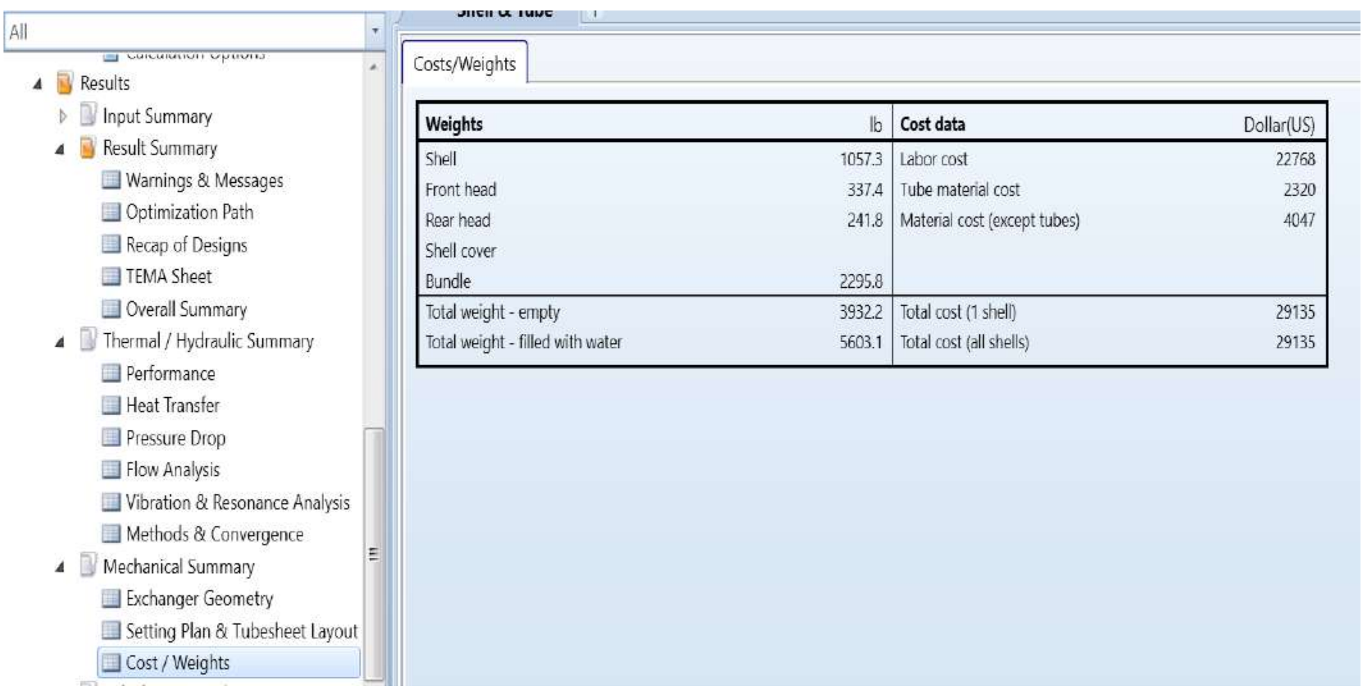


40	Tube #: 396	OD: 0.75	Tks. Average 0.083 in	Length: 96 in	Pitch: 0.9375 in Tube pattern: 30
41	Tube type: Plain	Insert: None	Fin#: #/in	Material: Carbon Steel	
42	Shell Carbon Steel	ID 23.25	OD 24 in	Shell cover -	
43	Channel or bonnet	Carbon Steel		Channel cover -	
44	Tubesheet-stationary	Carbon Steel	-	Tubesheet-floating -	
45	Floating head cover	-		Impingement protection None	
46	Baffle-cross Carbon Steel	Type Single segmental	Cut(%d) 40.06	H Spacing: c/c 23.5 in	
47	Baffle-long -	Seal Type		Inlet 34.5625 in	
48	Supports-tube	U-bend 0		Type	
49	Bypass seal		Tube-tubesheet joint	Expanded only (2 grooves)(App.A 'i')	
50	Expansion joint	-	Type None		
51	RhoV2-Inlet nozzle 881	Bundle entrance 1224	Bundle exit 2	lb/(ft-s^2)	
52	Gaskets - Shell side	-	Tube side	Flat Metal Jacket Fibe	
53	Floating head	-			
54	Code requirements	ASME Code Sec VIII Div 1	TEMA class	R - refinery service	
55	Weight/Shell 3932.2	Filled with water 5603.1	Bundle 2295.8	lb	

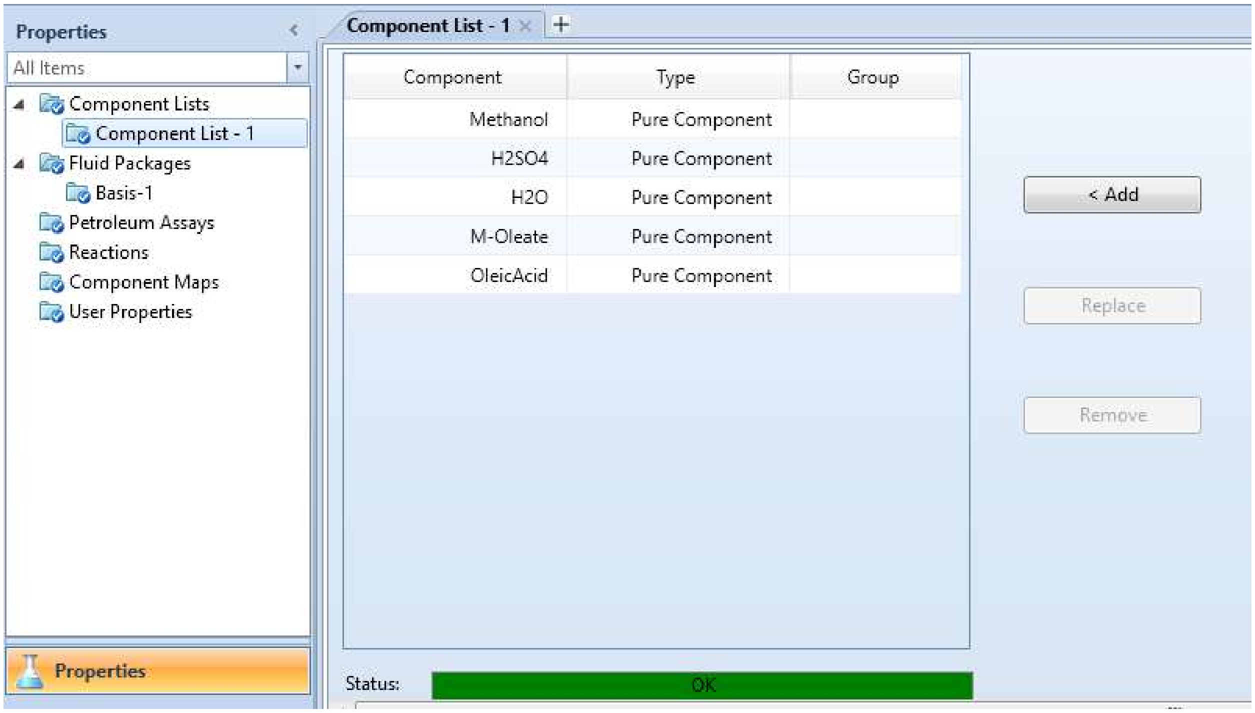
#										
1	Size	23.25 X 96 in		Type BEM Hor			Connected in	1 parallel	1 series	
2	Surf/Unit (gross/eff/finned)		622	/ 600.2	/ ft^2		Shells/unit	1		
3	Surf/Shell (gross/eff/finned)		622	/ 600.2	/ ft^2					
4	Design (Sizing)			**PERFORMANCE OF ONE UNIT**						
5			**Shell Side**		**Tube Side**		**Heat Transfer Parameters**			
6	**Process Data**		**In**	**Out**	**In**	**Out**	Total heat load	BTU/h	24941130	
7	Total flow	lb/h	25628		458199		Eff. MTD/ 1 pass MTD	°F	99.92	/ 99.77
8	Vapor	lb/h	25628	0	0	0	Actual/Reqd area ratio - fouled/clean		1.06	/ 1.06
9	Liquid	lb/h	0	25628	458199	458199				
10	Noncondensable	lb/h	0		0		**Coef./Resist.**	BTU/(h-ft^2-F)	ft^2-h-F/BTU	%
11	Cond./Evap.	lb/h	25628		0		Overall fouled	440.24	0.0023	
12	Temperature	°F	221	211.67	77	140	Overall clean	440.24	0.0023	
13	Bubble Point	°F	211.67	211.67			Tube side film	613.53	0.0016	71.76
14	Dew Point	°F	211.67	211.67			Tube side fouling		0	0
15	Vapor mass fraction		1	0	0	0	Tube wall	3816.94	0.0003	11.53
16	Pressure (abs)	psi	14.5	13.09	14.5	11.67	Outside fouling		0	0
17	DeltaP allow/cal	psi	1.6	1.41	3	2.83	Outside film	2634.38	0.0004	16.71
18	Velocity	ft/s	201.02	0.12	7.07	7.2				
19	**Liquid Properties**						**Shell Side Pressure Drop**		psi	%
20	Density	lb/ft^3		59.875	49.663	47.302	Inlet nozzle		0.15	9.35
21	Viscosity	cp		0.2841	0.562	0.3568	InletspaceXflow		0.72	45.11
22	Specific heat	BTU/(lb-F)		1.002	0.85	0.8801	Baffle Xflow		0.44	27.4
23	Therm. cond.	BTU/(ft-h-F)		0.391	0.104	0.095	Baffle window		0.09	5.76
24	Surface tension	lbf/ft					OutletspaceXflow		0.16	9.76
25	Molecular weight			18.01	32.48	32.48	Outlet nozzle		0.04	2.56
26	**Vapor Properties**						Intermediate nozzles			
27	Density	lb/ft^3	0.036				**Tube Side Pressure Drop**		psi	%
28	Viscosity	cp	0.0124				Inlet nozzle		0.28	9.82
29	Specific heat	BTU/(lb-F)	0.4912				Entering tubes		0.26	9.41
30	Therm. cond.	BTU/(ft-h-F)	0.014				Inside tubes		1.69	60.15
31	Molecular weight		18.01				Exiting tubes		0.42	14.95
32	**Two-Phase Properties**						Outlet nozzle		0.16	5.67
33	Latent heat	BTU/lb	968.6	968.6			Intermediate nozzles			
34	**Heat Transfer Parameters**						**Velocity / Rho*V2**	ft/s		lb/(ft-s^2)
35	Reynolds No. vapor		53211.82				Shell nozzle inlet	157		881
36	Reynolds No. liquid			2328.19	45218.36	69101.26	Shell bundle Xflow	201.02	0.12	
37	Prandtl No. vapor		1.02				Shell baffle window	226.32	0.13	
38	Prandtl No. liquid			1.76	11.14	7.98	Shell nozzle outlet	2.32		321
39	**Heat Load**		BTU/h		BTU/h		Shell nozzle interm			
40	Vapor only		-118004		0			ft/s		lb/(ft-s^2)
41	2-Phase vapor		0		0		Tube nozzle inlet	7.38		2703
42	Latent heat		-24823130		0		Tubes	7.07	7.2	
43	2-Phase liquid		0		0		Tube nozzle outlet	7.75		2838
44	Liquid only		0		24941130		Tube nozzle interm			

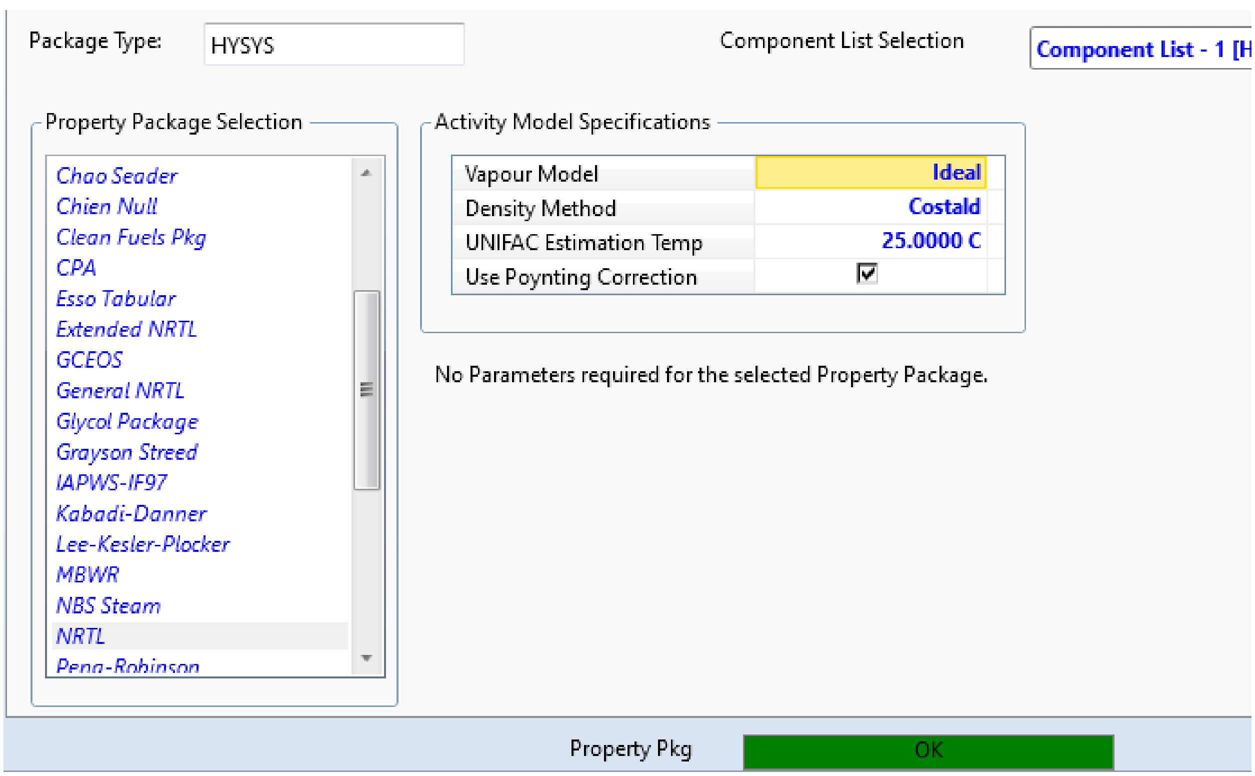
#										
45	**Tubes**			**Baffles**			**Nozzles: (No./OD)**			
46	Type		Plain	Type		Single segmental			**Shell Side**	**Tube Side**
47	ID/OD	in	0.584 / 0.75	Number		2	Inlet	in	1 / 16	1 / 8.625
48	Length act/eff	ft	8 / 7.7188	Cut(%d)		40.06	Outlet		1 / 3.5	1 / 8.625
49	Tube passes		2	Cut orientation		H	Intermediate		/	/
50	Tube No.		396	Spacing: c/c	in	23.5	Impingement protection		None	
51	Tube pattern		30	Spacing at inlet	in	34.5625				
52	Tube pitch	in	0.9375	Spacing at outlet	in	34.5625				
53	Insert		None							
54	Vibration problem (HTFS / TEMA)		Yes /				RhoV2 violation			No

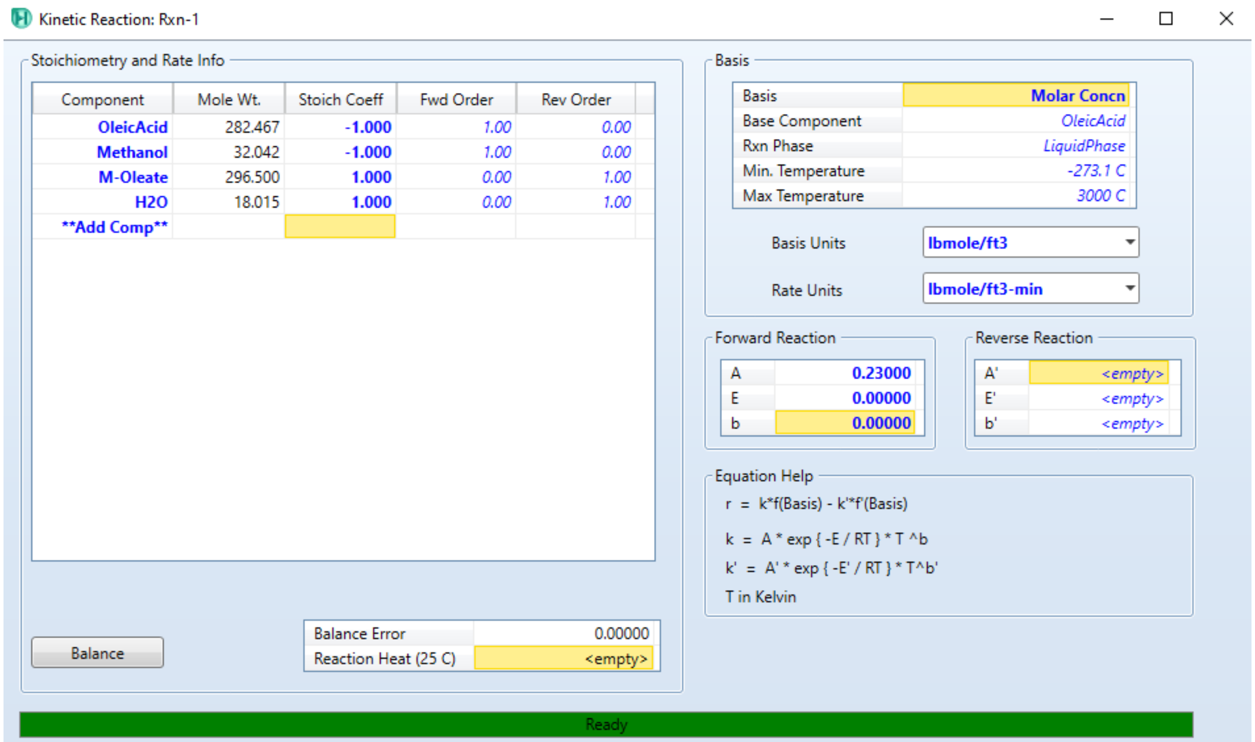

Results
Input Summary
Result Summary
Warnings & Messages
Optimization Path
Recap of Designs
TEMA Sheet
Overall Summary
Thermal / Hydraulic Summary
Performance
Heat Transfer
Pressure Drop
Flow Analysis
Vibration & Resonance Analysis
Methods & Convergence
Mechanical Summary
Exchanger Geometry
Setting Plan & Tubesheet Layout
Cost / Weights
Calculation Details
Overall Performance
Resistance Distribution
Shell by Shell Conditions
Hot Stream Composition
Cold Stream Composition
Design (Sizing) Shell Side Tube Side
Total mass flow rate lb/h 25628 458199
Vapor mass flow rate (In/Out) lb/h 25628 0 0 0
Liquid mass flow rate lb/h 0 25628 458199 458199
Vapor mass fraction 1 0 0 0
Temperatures °F 221 211.67 77 140
Bubble / Dew point °F 211.67 / 211.67 211.67 / 211.67 / /
Operating Pressures psi 14.5 13.09 14.5 11.67
Film coefficient BTU/(h-ft²-F) 2634.38 613.53
Fouling resistance ft²-h-F/BTU 0 0
Velocity (highest) ft/s 226.32 7.24
Pressure drop (allow./calc.) psi 1.6 / 1.41 3 / 2.83
Total heat exchanged BTU/h 24941130
Overall clean coeff. (plain/finned) BTU/(h-ft²-F) 440.24 /
Overall dirty coeff. (plain/finned) BTU/(h-ft²-F) 440.24 /
Effective area (plain/finned) ft² 600.2 /
Effective MTD °F 99.92
Actual/Required area ratio (dirty/clean) 1.06 / 1.06
Vibration problem (HTFS) Yes
RhoV2 problem No
Unit BEM 2 pass 1 ser 1 par
Shell size 23 - 96 in Hor
Tubes Plain
Insert None
No. 396 OD 0.75 Tks 0.083 in
Pattern 30 Pitch 0.9375 in
Baffles Single segmental Cut(%d) 40.06
Total cost 29135 Dollar(US)

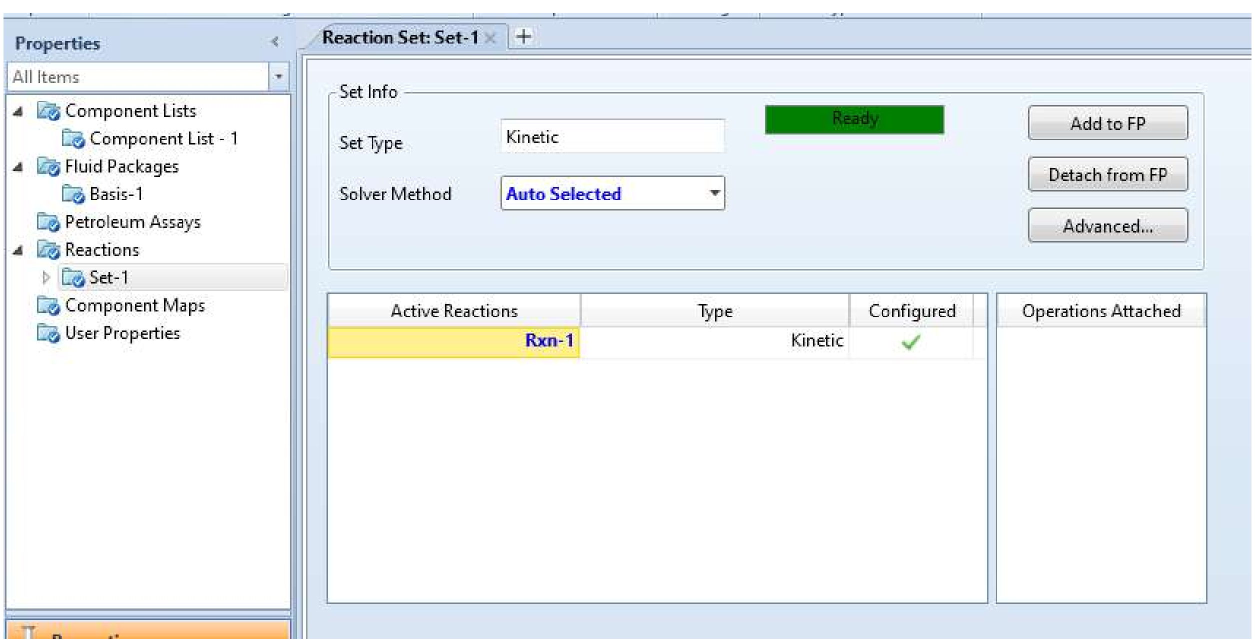

All
Results
Input Summary
Result Summary
Warnings & Messages
Optimization Path
Recap of Designs
TEMA Sheet
Overall Summary
Thermal / Hydraulic Summary
Performance
Heat Transfer
Pressure Drop
Flow Analysis
Vibration & Resonance Analysis
Methods & Convergence
Mechanical Summary
Exchanger Geometry
Setting Plan & Tubesheet Layout
Cost / Weights
Costs/Weights
Weights lb
Shell 1057.3
Front head 337.4
Rear head 241.8
Shell cover
Bundle 2295.8
Total weight - empty 3932.2
Total weight - filled with water 5603.1
Cost data Dollar(US)
Labor cost 22768
Tube material cost 2320
Material cost (except tubes) 4047
Total cost (1 shell) 29135
Total cost (all shells) 29135

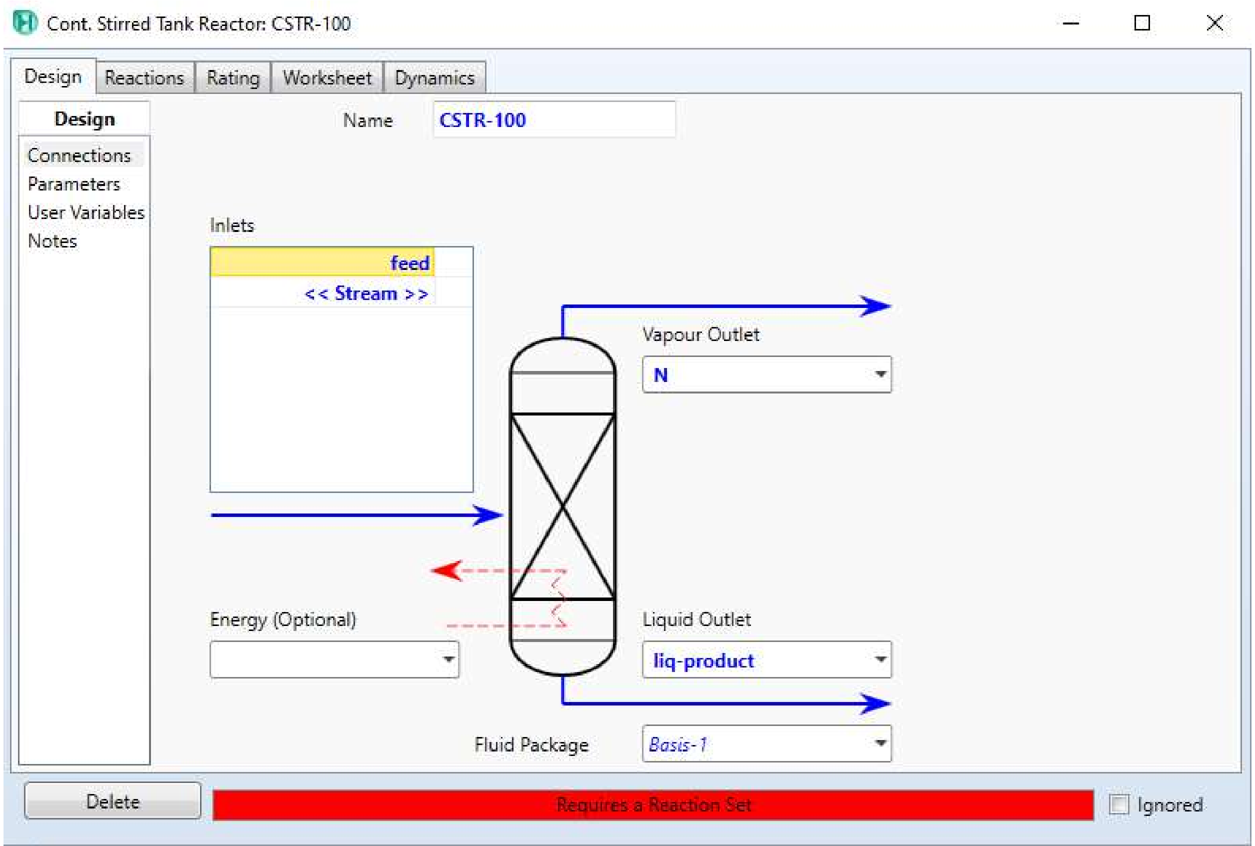
9.3 Simulation of CSTR (R-101)

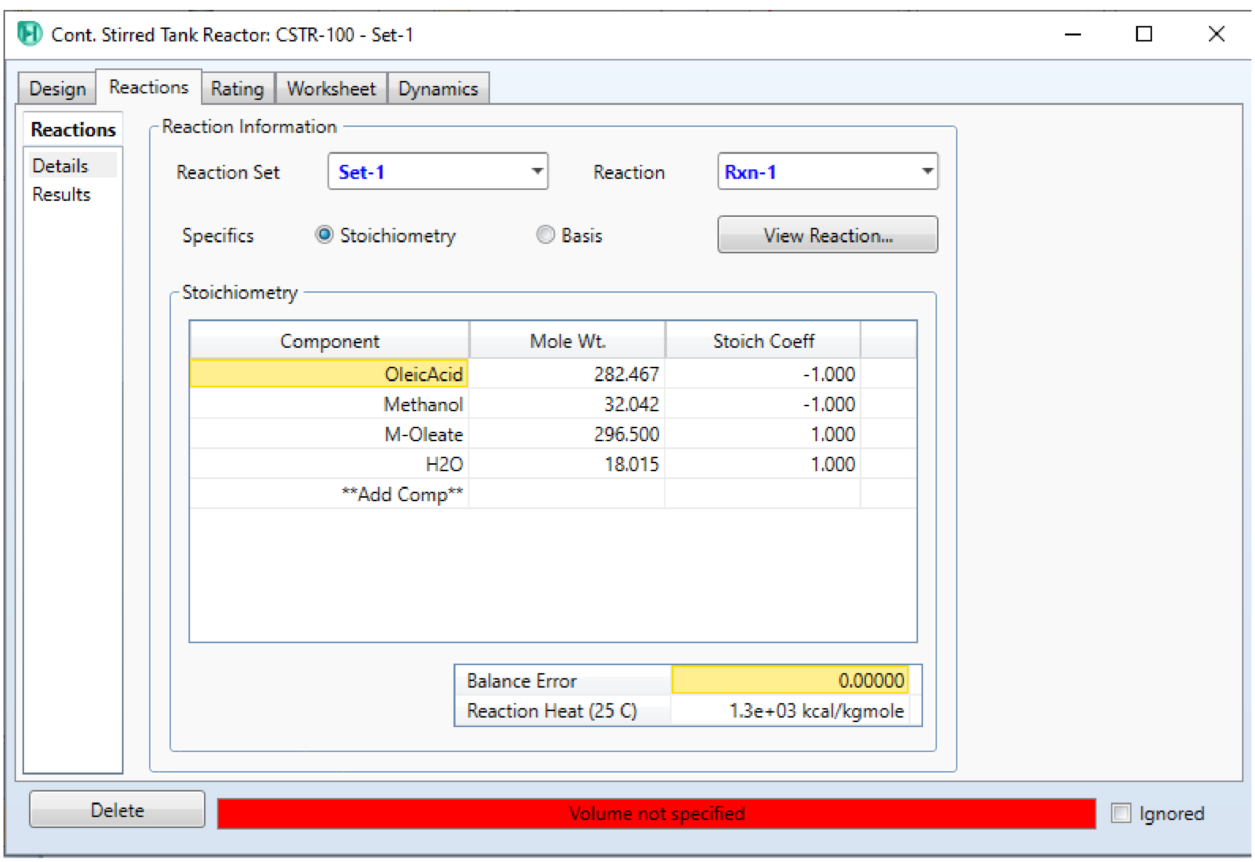


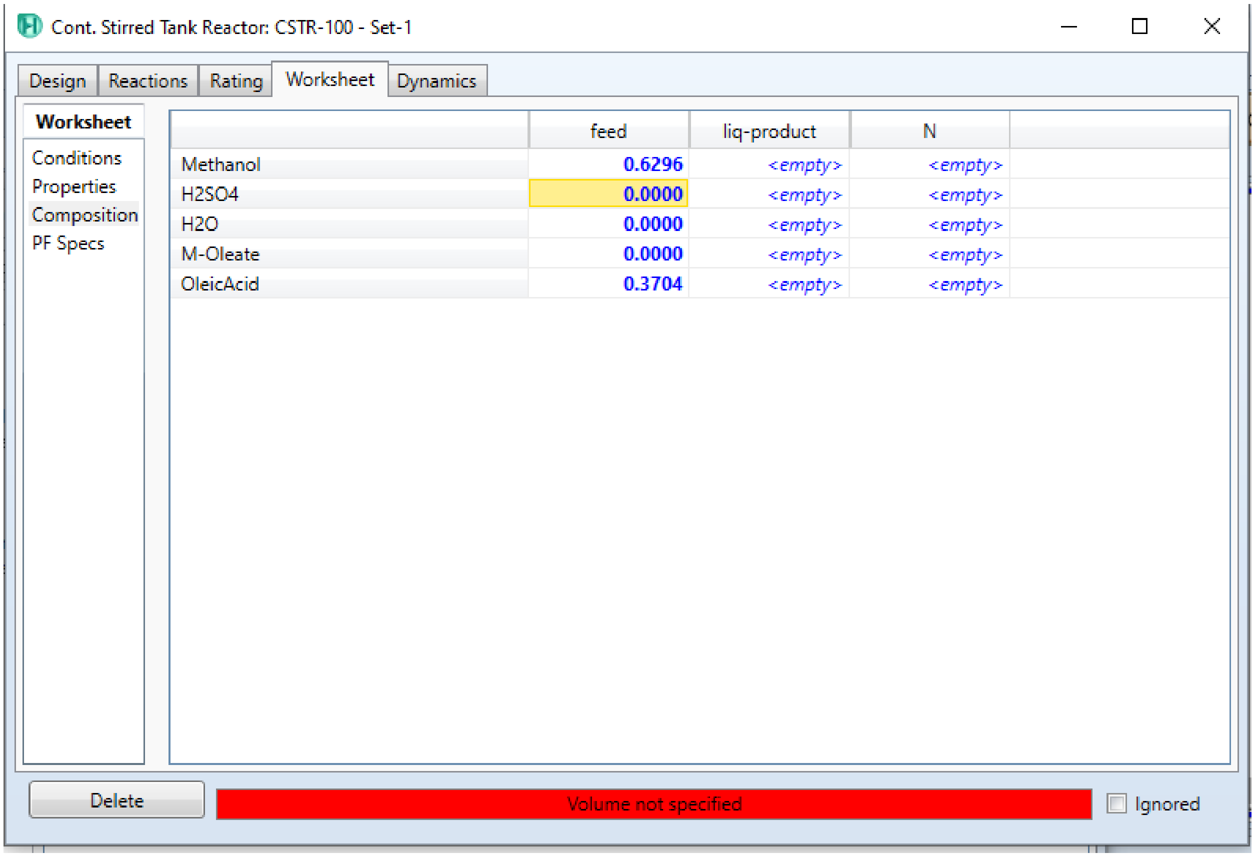


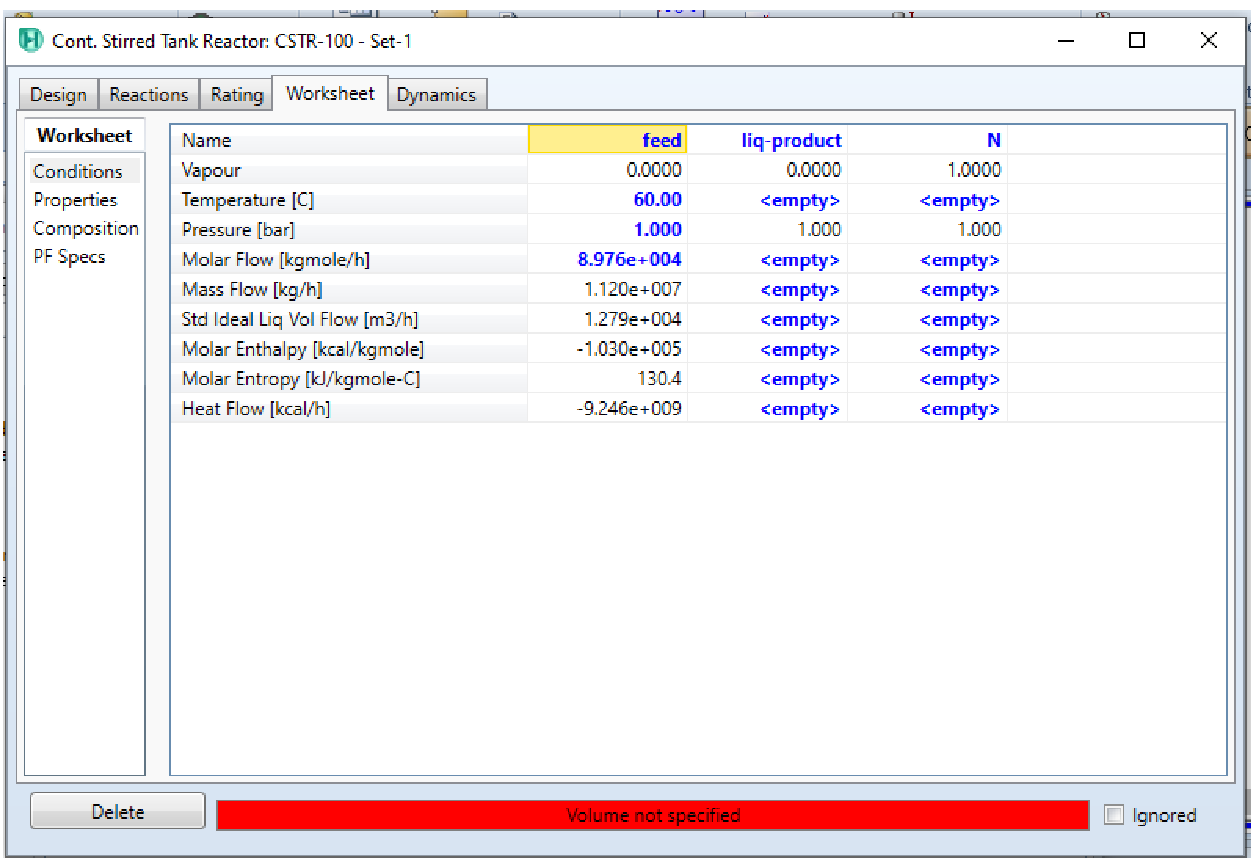

Kinetic Reaction: Rxn-1
Stoichiometry and Rate Info
Component | Mole Wt. | Stoich Coeff | Fwd Order | Rev Order
OleicAcid | 282.467 | -1.000 | 1.00 | 0.00
Methanol | 32.042 | -1.000 | 1.00 | 0.00
M-Oleate | 296.500 | 1.000 | 0.00 | 1.00
H2O | 18.015 | 1.000 | 0.00 | 1.00
Add Comp
Basis
Basis Molar Concn
Base Component OleicAcid
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
Balance
Balance Error 0.00000
Reaction Heat (25 C) <empty>
Ready

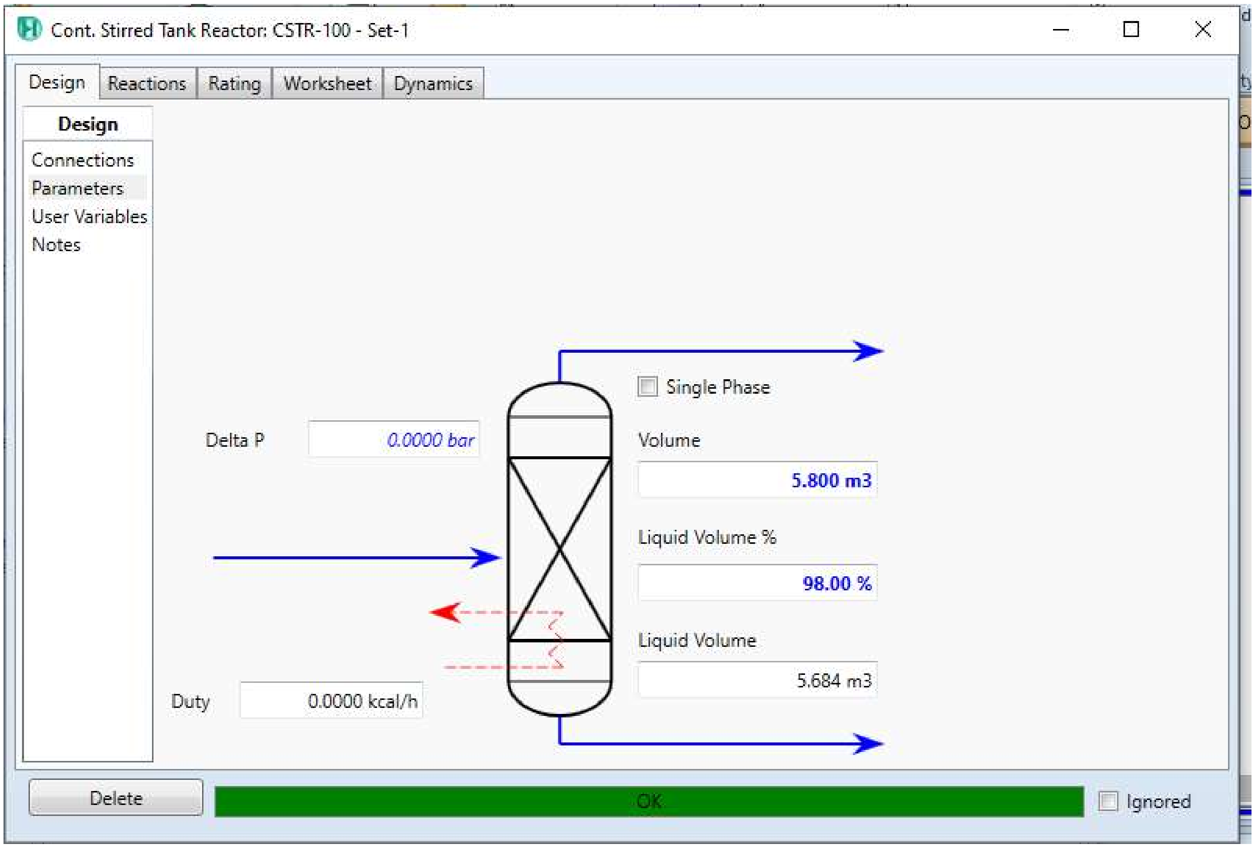

Properties
All Items
Component Lists
Component List - 1
Fluid Packages
Basis-1
Petroleum Assays
Reactions
Set-1
Component Maps
User Properties
Reaction Set: Set-1
Set Info
Set Type Kinetic
Solver Method Auto Selected
Ready
Add to FP
Detach from FP
Advanced...
Active Reactions | Type | Configured
Rxn-1 | Kinetic
Operations Attached

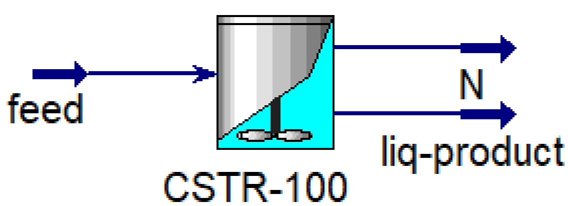

Cont. Stirred Tank Reactor: CSTR-100
Design
Reactions
Rating
Worksheet
Dynamics
Design
Connections
Parameters
User Variables
Notes
Name
CSTR-100
Inlets
feed
<< Stream >>
Vapour Outlet
N
Energy (Optional)
Liquid Outlet
liq-product
Fluid Package
Basis-1
Delete
Requires a Reaction Set
Ignored


Cont. Stirred Tank Reactor: CSTR-100 - Set-1
Design
Reactions
Rating
Worksheet
Dynamics
Reactions
Details
Results
Reaction Information
Reaction Set
Set-1
Reaction
Rxn-1
Specifics
Stoichiometry
Basis
View Reaction...
Stoichiometry
Component
Mole Wt.
Stoich Coeff
OleicAcid
282.467
-1.000
Methanol
32.042
-1.000
M-Oleate
296.500
1.000
H2O
18.015
1.000
Add Comp
Balance Error
0.00000
Reaction Heat (25 C)
1.3e+03 kcal/kgmole
Delete
Volume not specified
Ignored

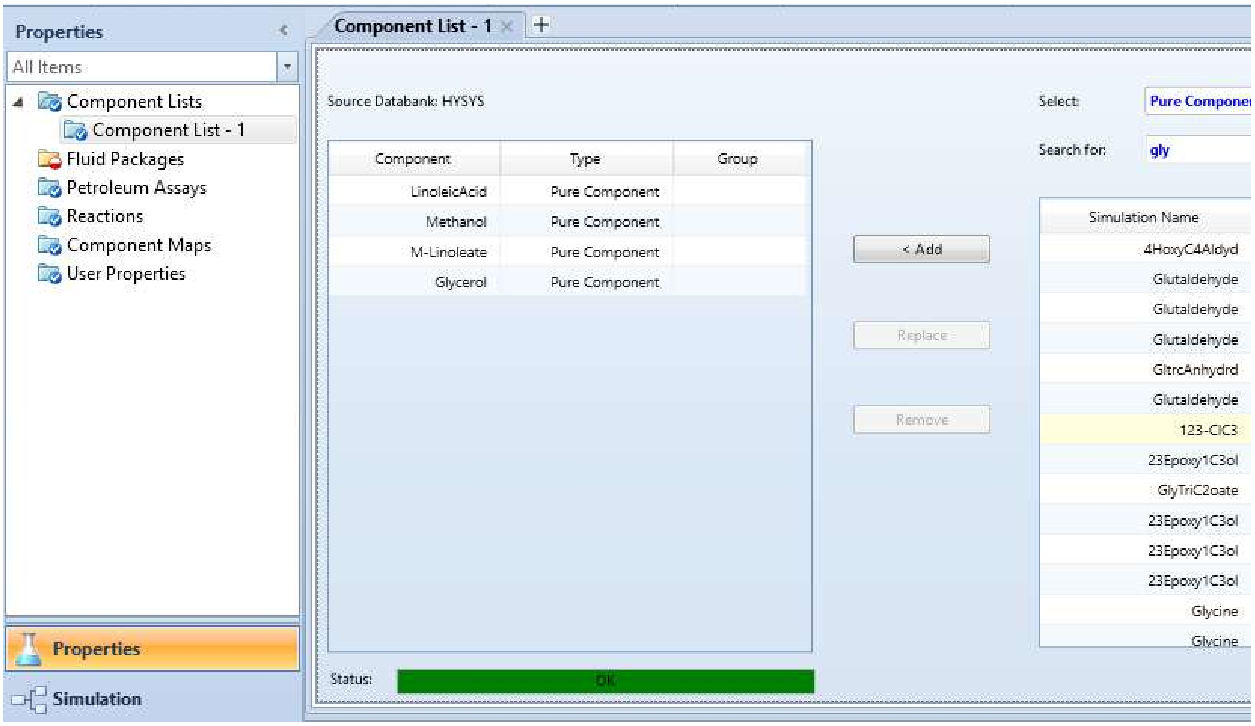

Cont. Stirred Tank Reactor: CSTR-100 - Set-1
Design
Reactions
Rating
Worksheet
Dynamics
Worksheet
Conditions
Properties
Composition
PF Specs
feed
liq-product
N
Methanol 0.6296 <empty> <empty>
H2SO4 0.0000 <empty> <empty>
H2O 0.0000 <empty> <empty>
M-Oleate 0.0000 <empty> <empty>
OleicAcid 0.3704 <empty> <empty>
Delete
Volume not specified
Ignored

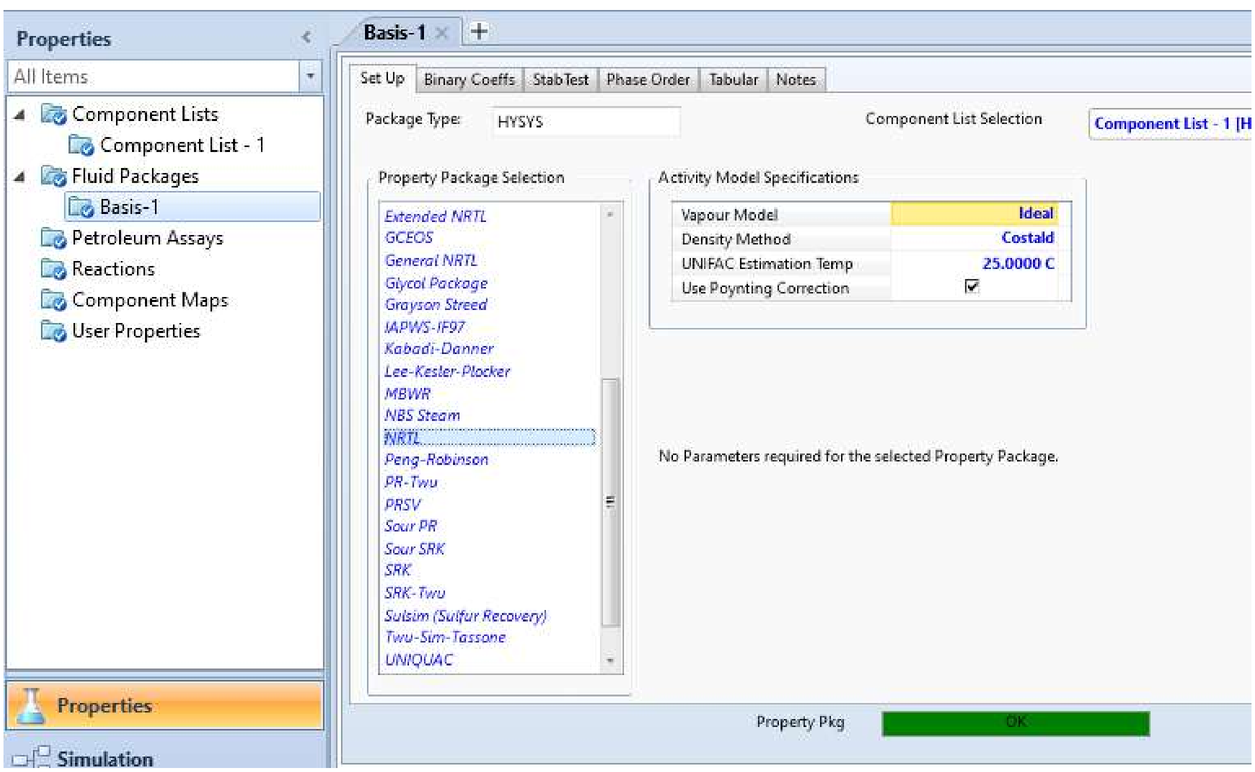

Cont. Stirred Tank Reactor: CSTR-100 - Set-1
Design
Reactions
Rating
Worksheet
Dynamics
Worksheet
Conditions
Properties
Composition
PF Specs
Name feed liq-product N
Vapour 0.0000 0.0000 1.0000
Temperature [C] 60.00 <empty> <empty>
Pressure [bar] 1.000 1.000 1.000
Molar Flow [kgmole/h] 8.976e+004 <empty> <empty>
Mass Flow [kg/h] 1.120e+007 <empty> <empty>
Std Ideal Liq Vol Flow [m3/h] 1.279e+004 <empty> <empty>
Molar Enthalpy [kcal/kgmole] -1.030e+005 <empty> <empty>
Molar Entropy [kJ/kgmole-C] 130.4 <empty> <empty>
Heat Flow [kcal/h] -9.246e+009 <empty> <empty>
Delete
Volume not specified
Ignored

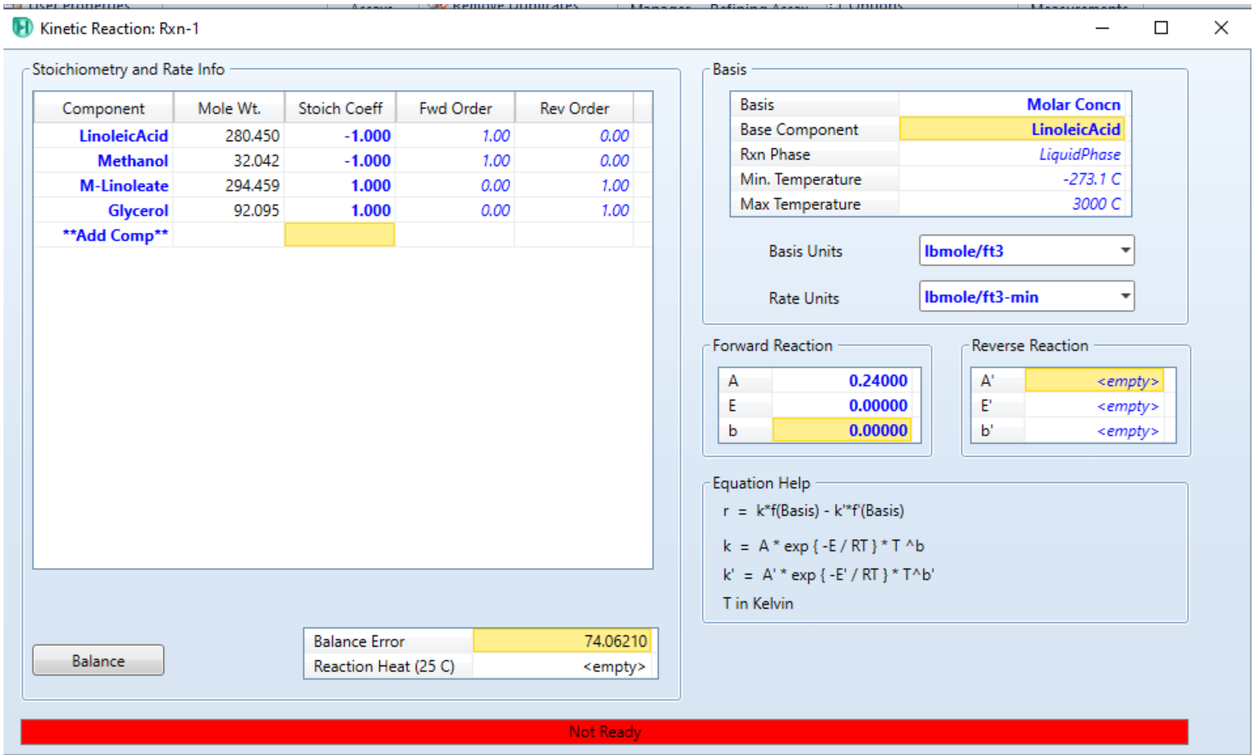

Cont. Stirred Tank Reactor: CSTR-100 - Set-1
Design
Reactions
Rating
Worksheet
Dynamics
Design
Connections
Parameters
User Variables
Notes
Single Phase
Delta P
0.0000 bar
Volume
5.800 m3
Liquid Volume %
98.00 %
Liquid Volume
5.684 m3
Duty
0.0000 kcal/h
Delete
OK
Ignored

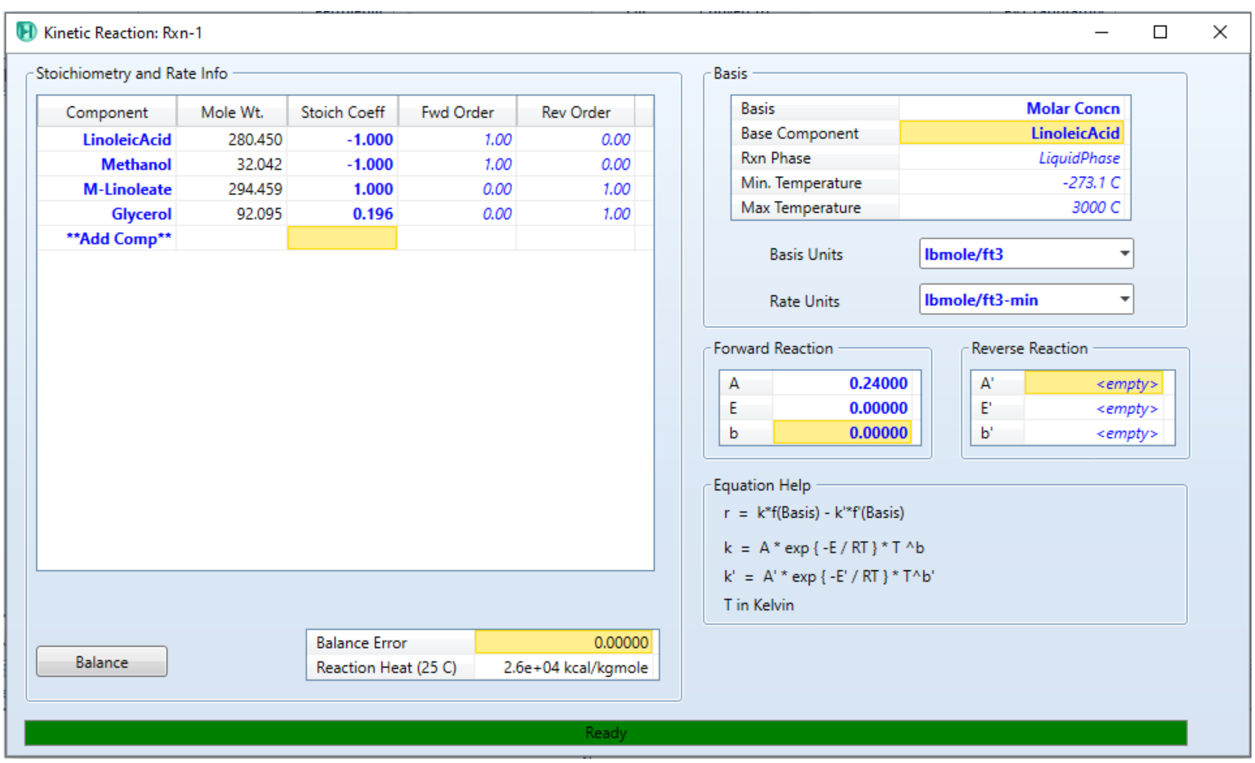

feed
N
liq-product
CSTR-100

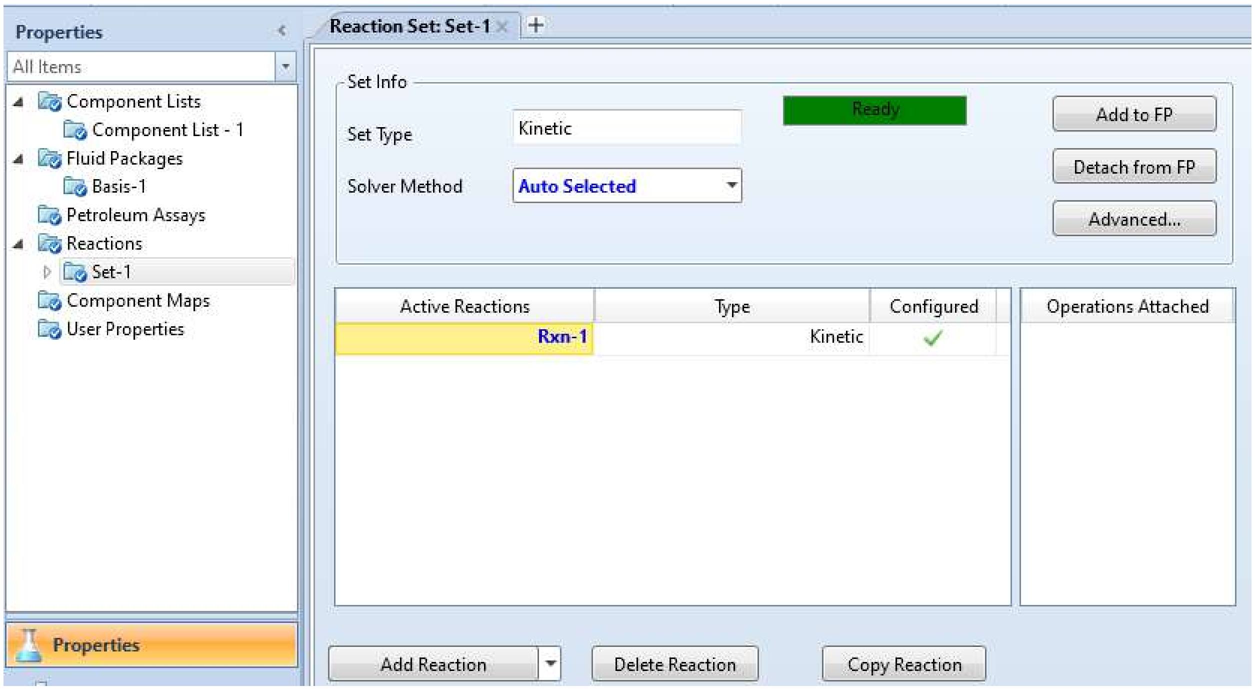
9.4. Simulation of CSTR (R-102)

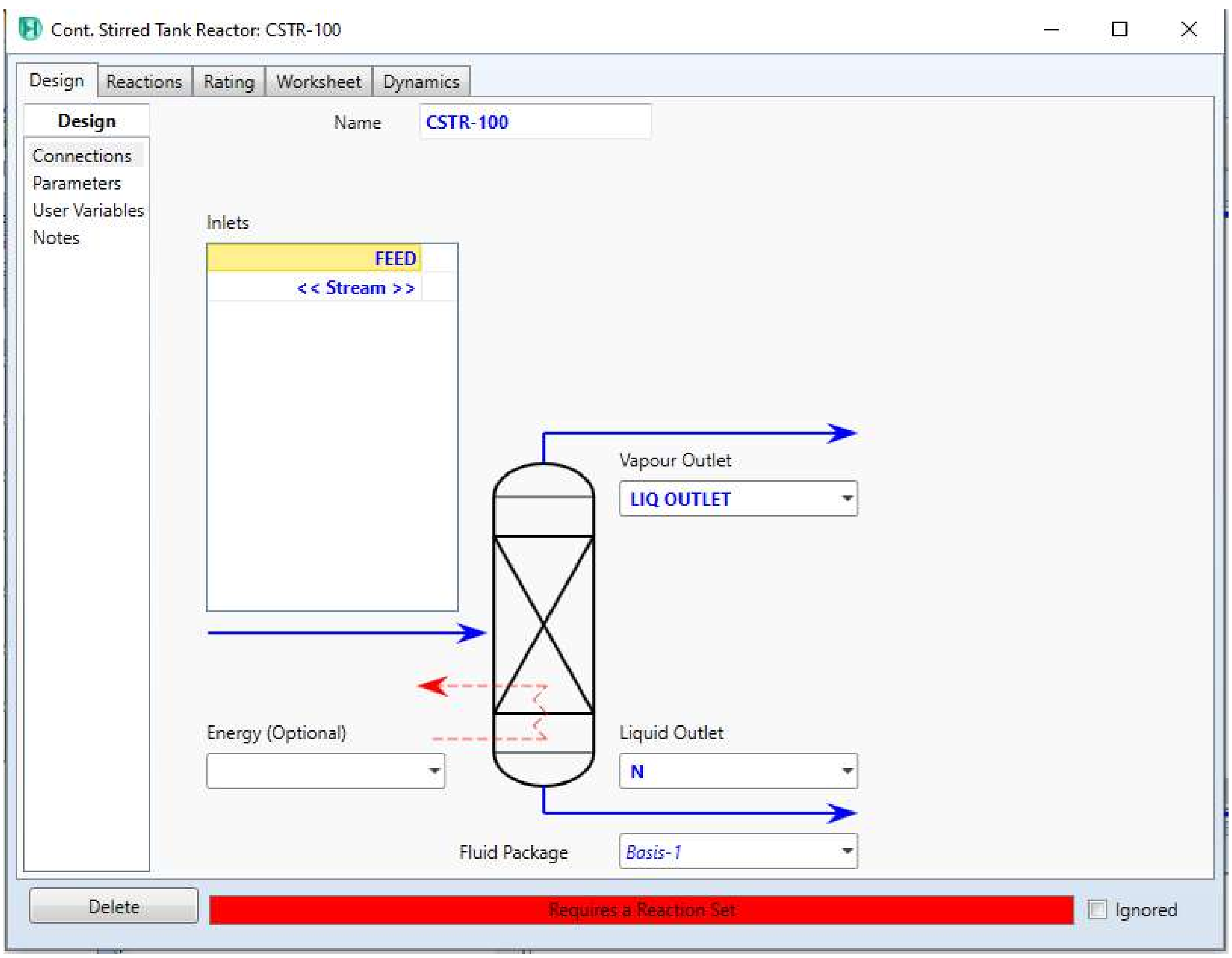


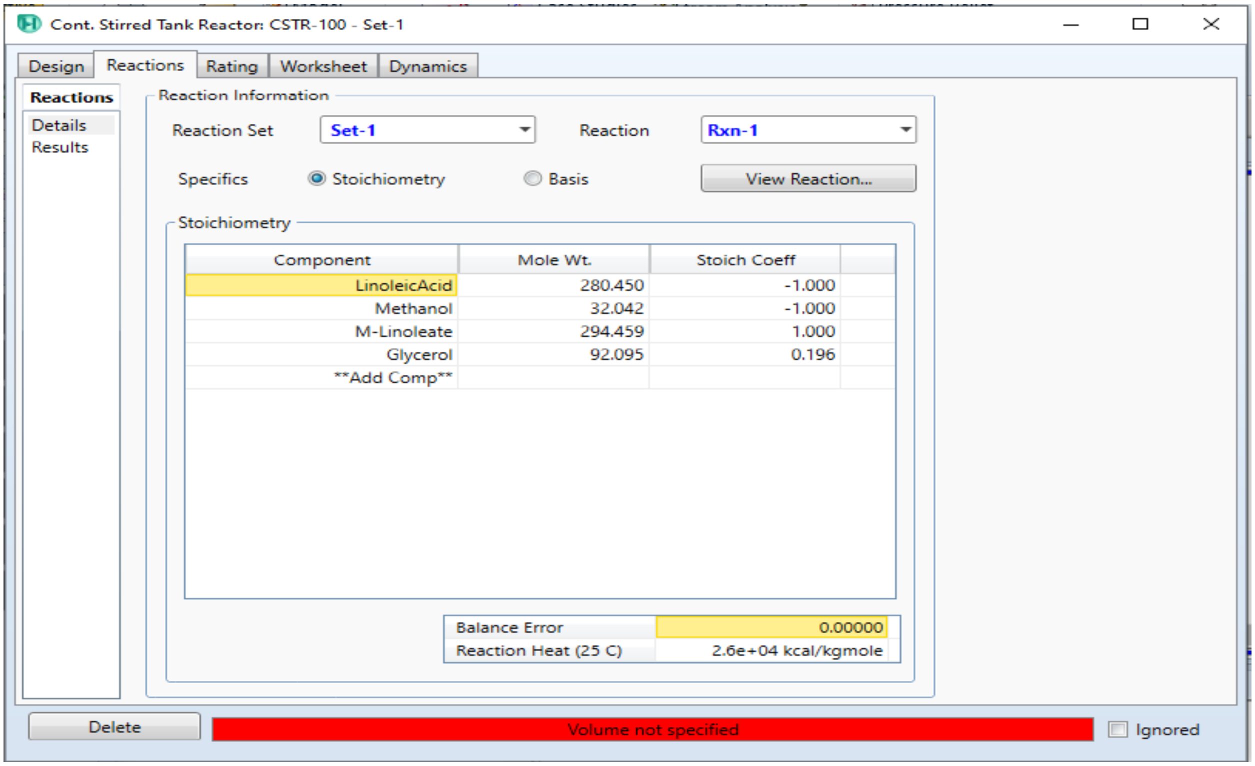


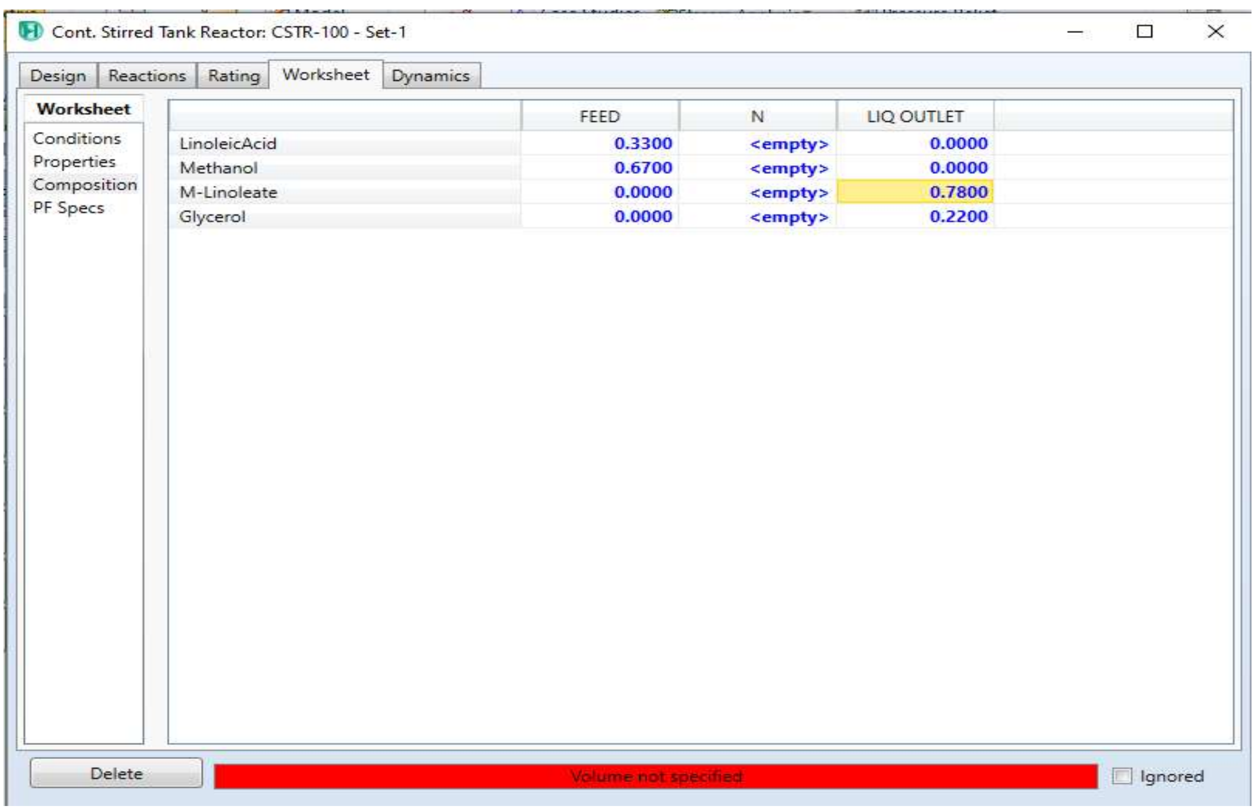

Kinetic Reaction: Rxn-1
Stoichiometry and Rate Info
Component | Mole Wt. | Stoich Coeff | Fwd Order | Rev Order
LinoleicAcid | 280.450 | -1.000 | 1.00 | 0.00
Methanol | 32.042 | -1.000 | 1.00 | 0.00
M-Linoleate | 294.459 | 1.000 | 0.00 | 1.00
Glycerol | 92.095 | 1.000 | 0.00 | 1.00
Add Comp
Basis
Basis | Molar Concn
Base Component | LinoleicAcid
Rxn Phase | LiquidPhase
Min. Temperature | -273.1 C
Max Temperature | 3000 C
Basis Units | lbmole/ft3
Rate Units | lbmole/ft3-min
Forward Reaction
A | 0.24000
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
Balance
Balance Error | 74.06210
Reaction Heat (25 C) | <empty>
Not Ready

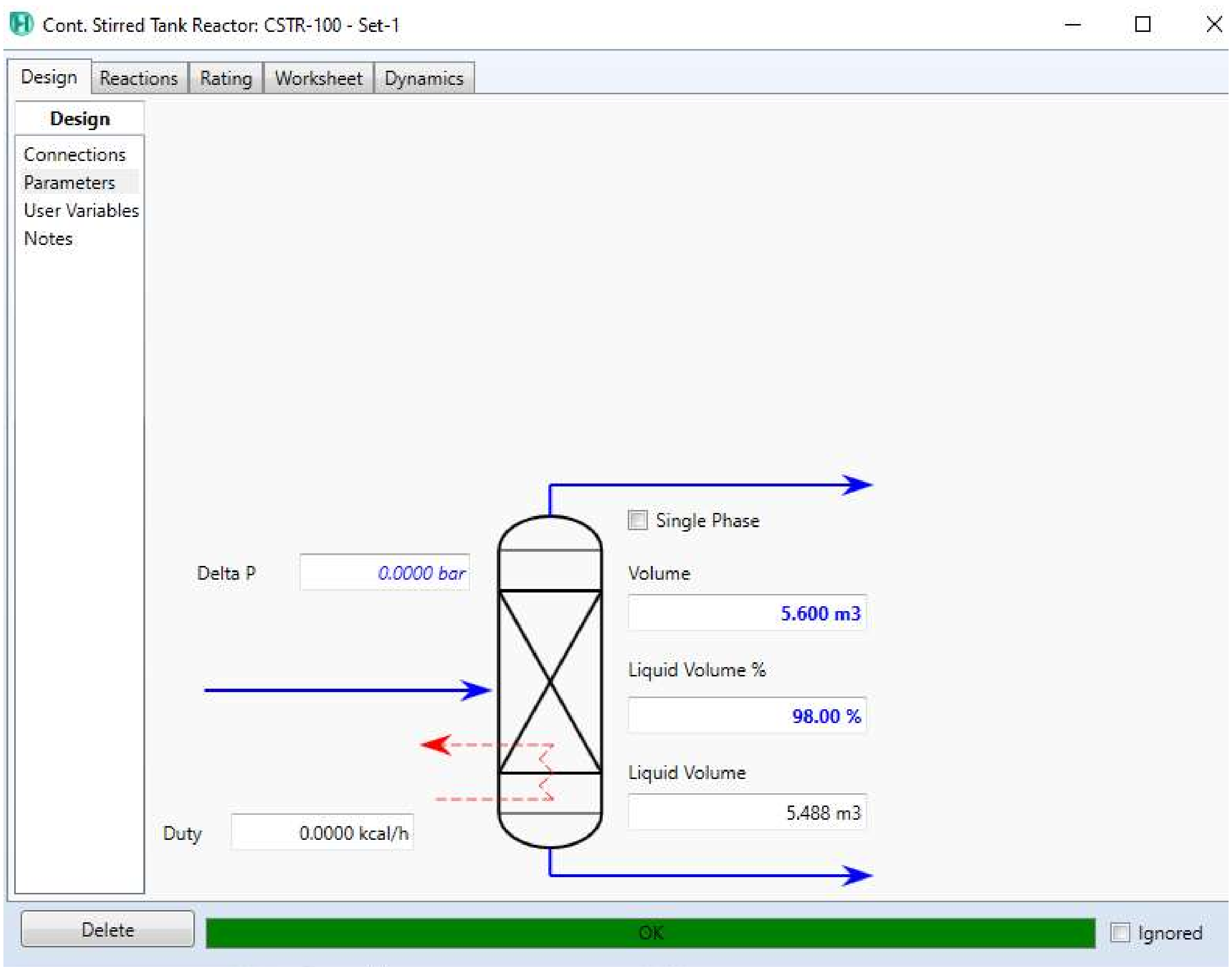

Kinetic Reaction: Rxn-1
Stoichiometry and Rate Info
Component | Mole Wt. | Stoich Coeff | Fwd Order | Rev Order
LinoleicAcid | 280.450 | -1.000 | 1.00 | 0.00
Methanol | 32.042 | -1.000 | 1.00 | 0.00
M-Linoleate | 294.459 | 1.000 | 0.00 | 1.00
Glycerol | 92.095 | 0.196 | 0.00 | 1.00
Add Comp
Basis
Basis | Molar Concn
Base Component | LinoleicAcid
Rxn Phase | LiquidPhase
Min. Temperature | -273.1 C
Max Temperature | 3000 C
Basis Units | lbmole/ft3
Rate Units | lbmole/ft3-min
Forward Reaction
A | 0.24000
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
Balance
Balance Error | 0.00000
Reaction Heat (25 C) | 2.6e+04 kcal/kgmole
Ready

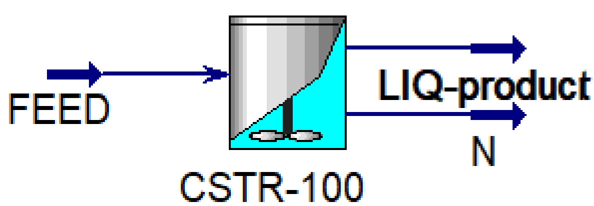

Properties
All Items
Component Lists
Component List - 1
Fluid Packages
Basis-1
Petroleum Assays
Reactions
Set-1
Component Maps
User Properties
Properties
Reaction Set: Set-1
Set Info
Set Type
Kinetic
Ready
Solver Method
Auto Selected
Add to FP
Detach from FP
Advanced...
Active Reactions
Type
Configured
Operations Attached
Rxn-1
Kinetic
Add Reaction
Delete Reaction
Copy Reaction


Cont. Stirred Tank Reactor: CSTR-100
Design
Reactions
Rating
Worksheet
Dynamics
Design
Connections
Parameters
User Variables
Notes
Name
CSTR-100
Inlets
FEED
<< Stream >>
Vapour Outlet
LIQ OUTLET
Energy (Optional)
Liquid Outlet
N
Fluid Package
Basis-1
Delete
Requires a Reaction Set
Ignored

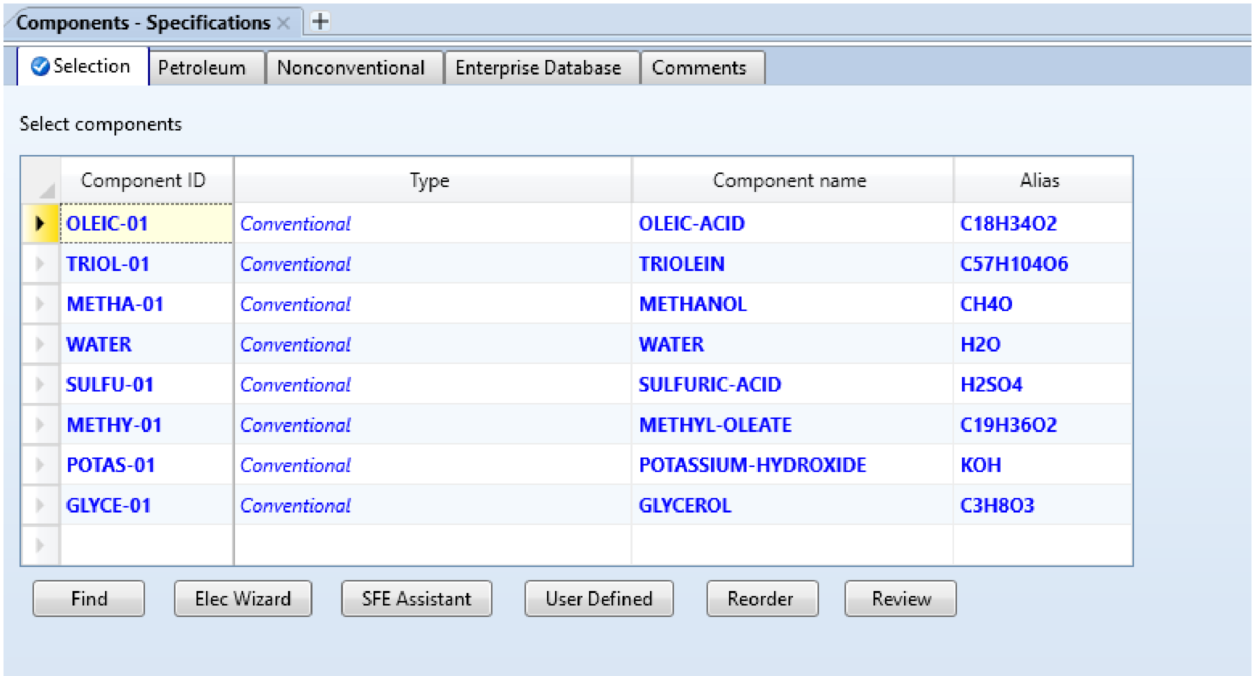

Cont. Stirred Tank Reactor: CSTR-100 - Set-1
Design
Reactions
Rating
Worksheet
Dynamics
Reactions
Details
Results
Reaction Information
Reaction Set
Set-1
Reaction
Rxn-1
Specifics
Stoichiometry
Basis
View Reaction...
Stoichiometry
Component
Mole Wt.
Stoich Coeff
LinoleicAcid 280.450 -1.000
Methanol 32.042 -1.000
M-Linoleate 294.459 1.000
Glycerol 92.095 0.196
Add Comp
Balance Error 0.00000
Reaction Heat (25 C) 2.6e+04 kcal/kgmole
Delete
Volume not specified
Ignored

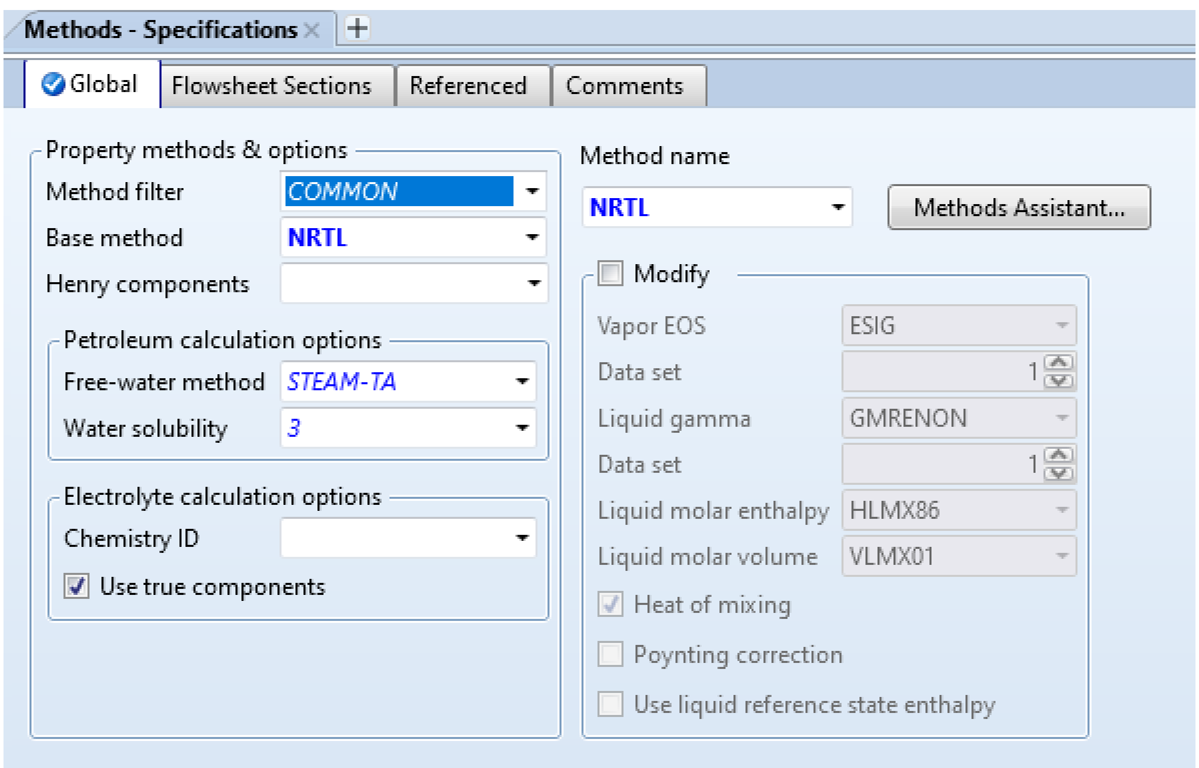

Cont. Stirred Tank Reactor: CSTR-100 - Set-1
Design
Reactions
Rating
Worksheet
Dynamics
Worksheet
Conditions
Properties
Composition
PF Specs
FEED
N
LIQ OUTLET
LinoleicAcid 0.3300 <empty> 0.0000
Methanol 0.6700 <empty> 0.0000
M-Linoleate 0.0000 <empty> 0.7800
Glycerol 0.0000 <empty> 0.2200
Delete
Volume not specified
Ignored

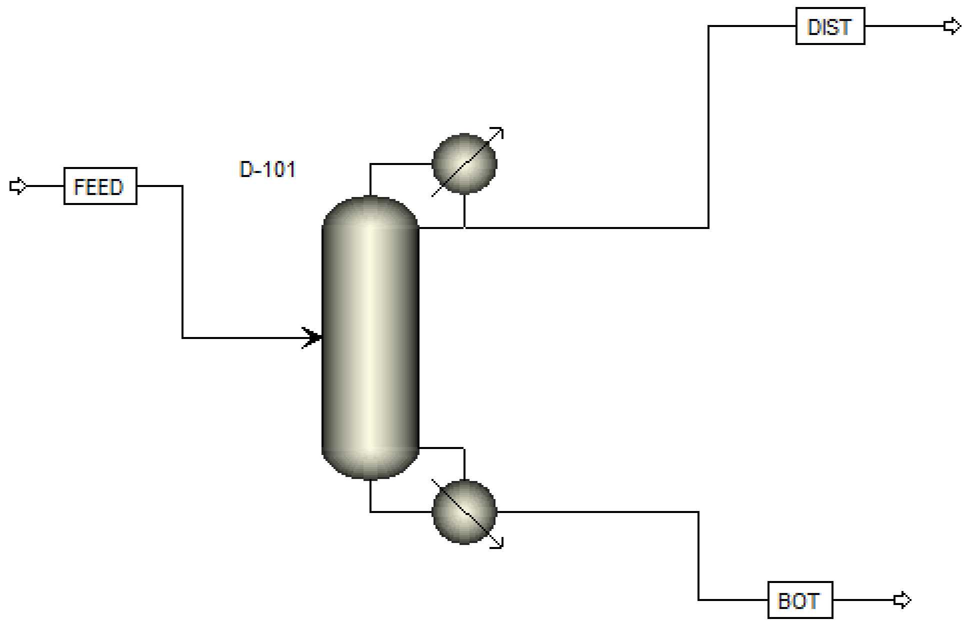

Cont. Stirred Tank Reactor: CSTR-100 - Set-1
Design
Reactions
Rating
Worksheet
Dynamics
Design
Connections
Parameters
User Variables
Notes
Single Phase
Delta P
0.0000 bar
Volume
5.600 m3
Liquid Volume %
98.00 %
Liquid Volume
5.488 m3
Duty
0.0000 kcal/h
Delete
OK
Ignored

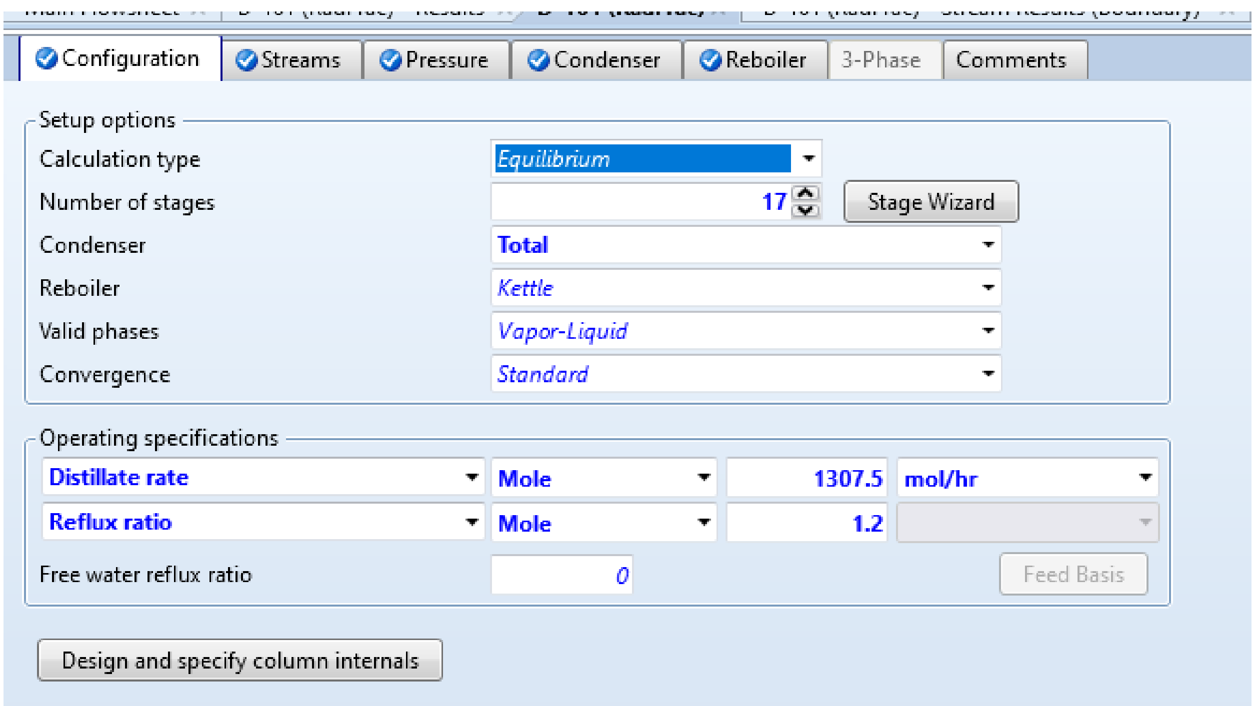

FEED
LIQ-product
N
CSTR-100

9.5. Simulation of Distillation Column






DIST
FEED
D-101
BOT


Configuration
Streams
Pressure
Condenser
Reboiler
3-Phase
Comments
Setup options
Calculation type
Equilibrium
Number of stages
17
Stage Wizard
Condenser
Total
Reboiler
Kettle
Valid phases
Vapor-Liquid
Convergence
Standard
Operating specifications
Distillate rate
Mole
1307.5
mol/hr
Reflux ratio
Mole
1.2
Free water reflux ratio
0
Feed Basis
Design and specify column internals

Basis: Mole

Condenser / Top stage performance

Name	Value	Units
Temperature	64.2038	C
Subcooled temperature		
Heat duty	-101532	kJ/hr
Subcooled duty		
Distillate rate	1.3075	kmol/hr
Reflux rate	1.569	kmol/hr

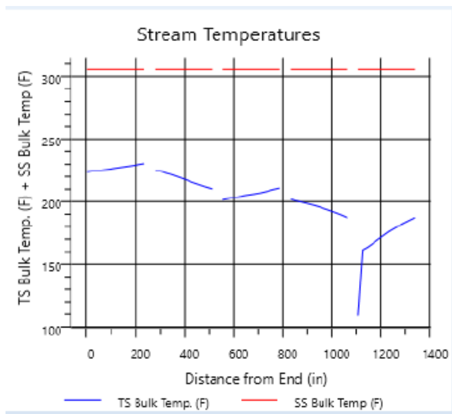
Reboiler / Bottom stage performance

Name	Value	Units
Temperature	113.257	C
Heat duty	177766	kJ/hr
Bottoms rate	3.6275	kmol/hr
Boilup rate	3.28037	kmol/hr
Boilup ratio	0.904307	
Bottoms to feed ratio		

Mass Density	gm/cc	[illegible]	[illegible]	[illegible]
Enthalpy Flow	cal/sec	-165697	-140300	-20339.5
Average MW		159.677	205.683	32.0392
+ Mole Flows	**kmol/hr**	**4.935**	**3.6275**	**1.3075**
− Mole Fractions				
OLEIC-01		0.00603926	0.00821605	7.70019e-29
TRIOL-01		0.00120785	0.00164321	4.23083e-68
METHA-01		0.396578	0.179156	0.999789
WATER		0.00201309	0.00266261	0.000211056
SULFU-01		0.000301963	0.000410803	2.1999e-24
METHY-01		0.442879	0.60251	8.12502e-24
POTAS-01		0.0301963	0.0410803	2.11048e-72
GLYCE-01		0.120785	0.164321	1.04883e-18

9.6. Simulation of Evaporator (V-101)

	Unit	Hotside	ColdSide	Recent Hotside	Recent ColdSide	Previous Hotside	Previous ColdSide
Calculation mode		Design (Sizing)					
Process Conditions							
Mass flow rate	lb/h		1141235	925148	1141235	925148	1141235
Inlet pressure	bar	1	1	1	1	1	1
Outlet pressure	bar	0.89	0.89	0.89	0.91005	0.89	0.89985
Pressure at liquid surface in column	bar						
Inlet Temperature	°C	152	42.5	152	42.5	152	42.5
Outlet Temperature	°C	152	110	151.98	110.11	151.98	109.78
Inlet vapor mass fraction				1	0	1	0
Outlet vapor mass fraction				0	0.8659704	0	0.866083
Heat exchanged	BTU/h			835505104		835505104	
Process Input							
Allowable pressure drop	psi	1.6	3	1.6	3	1.6	3
Fouling resistance	ft²-h-F/BTU	0	0	0	0	0	0
Calculated Results							
Pressure drop	psi			18.29	1.3	22.37	1.45

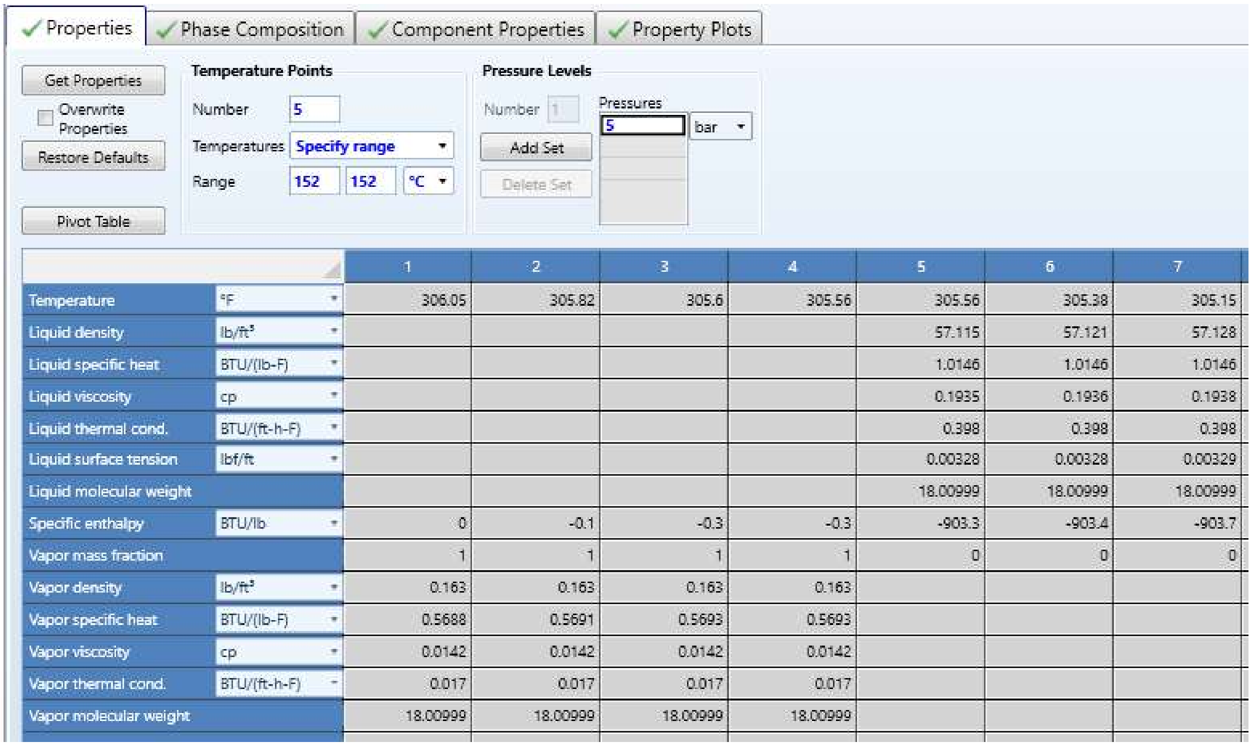


Physical property package: B-JAC

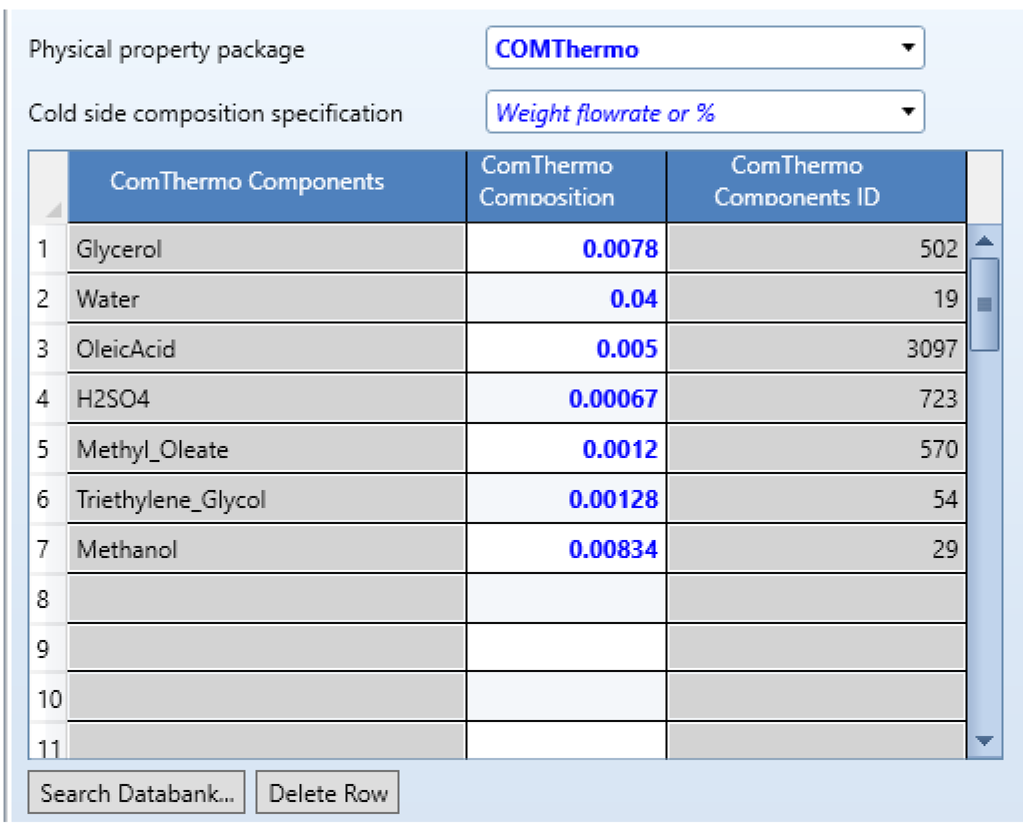
Hot side composition specification: Weight flowrate or %

	BJAC Components	BJAC Composition	Component type
1	Steam	1	Program
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			

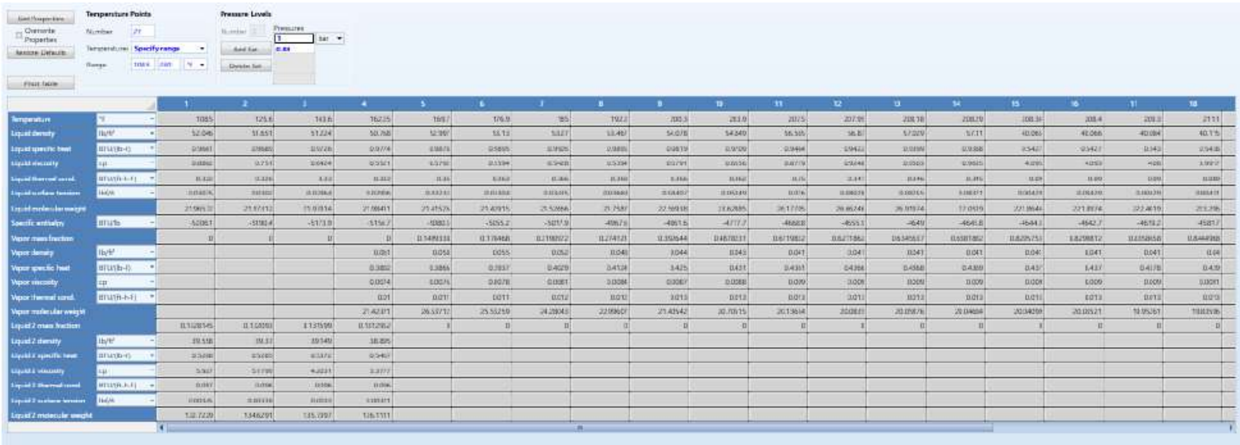
Search Databank... Delete Row

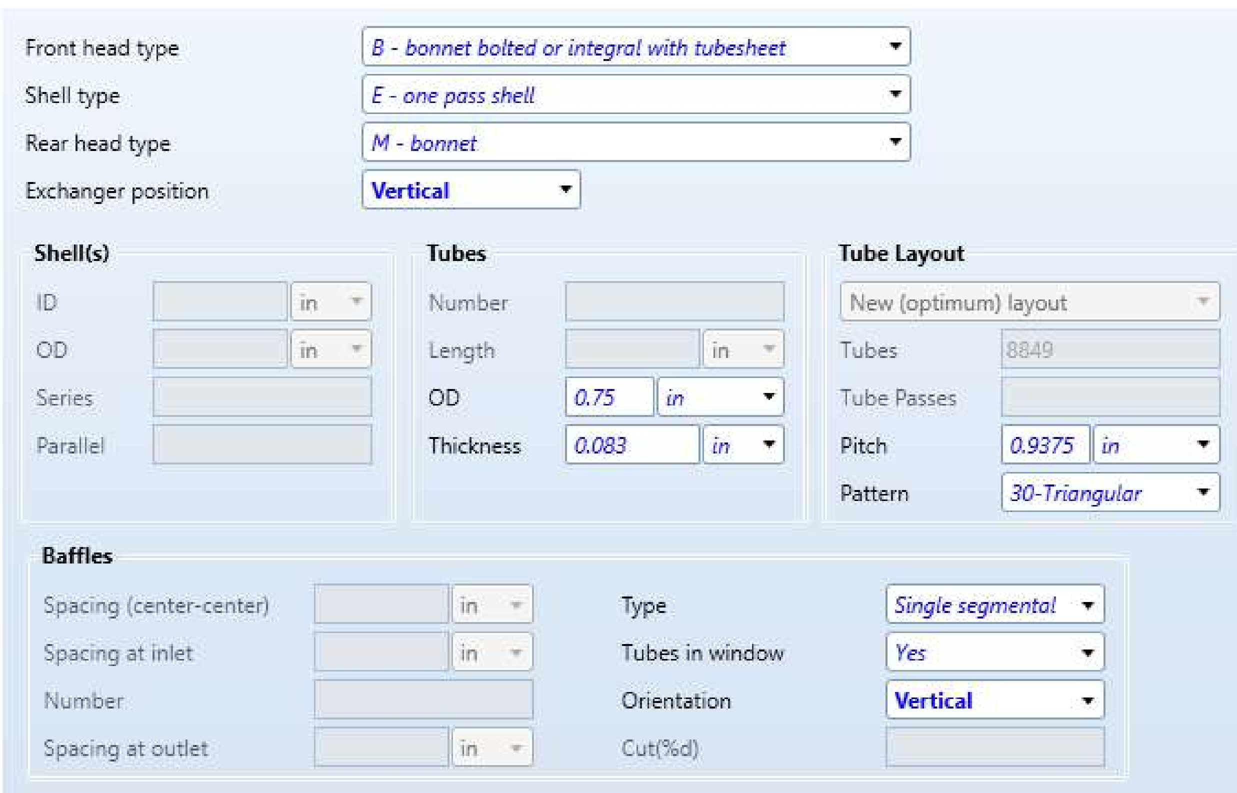


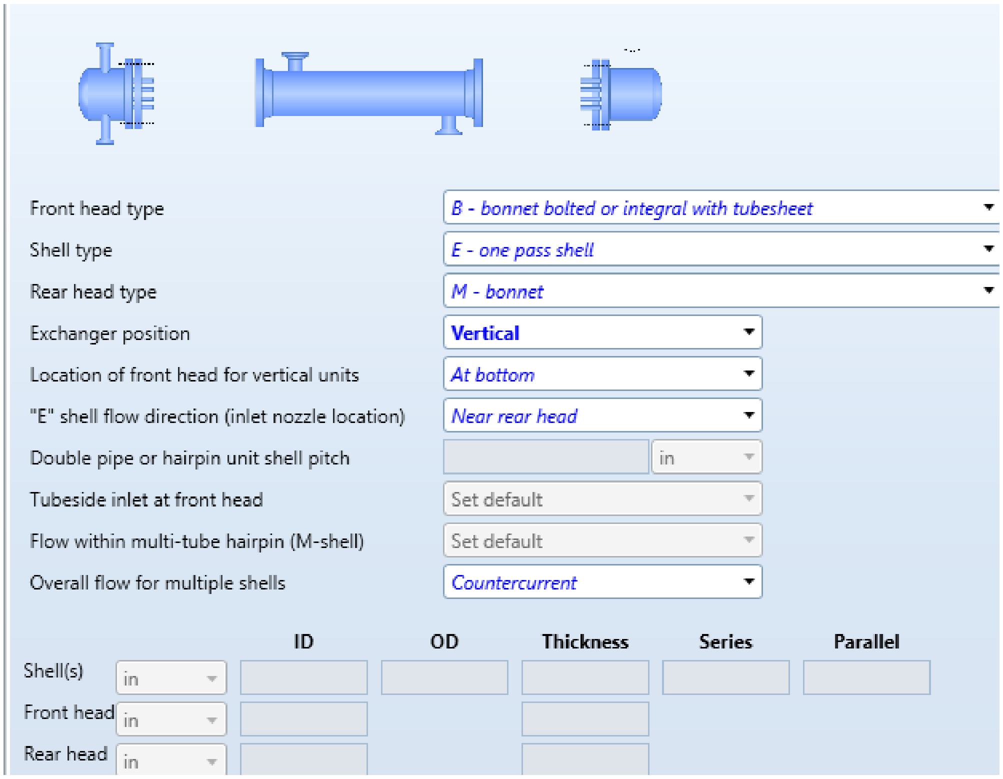
		1	2	3	4	5	6	7
Temperature	°F	306.05	305.82	305.6	305.56	305.56	305.38	305.15
Liquid density	lb/ft³					57.115	57.121	57.128
Liquid specific heat	BTU/(lb-F)					1.0146	1.0146	1.0146
Liquid viscosity	cp					0.1935	0.1936	0.1938
Liquid thermal cond.	BTU/(ft-h-F)					0.398	0.398	0.398
Liquid surface tension	lbf/ft					0.00328	0.00328	0.00329
Liquid molecular weight						18.00999	18.00999	18.00999
Specific enthalpy	BTU/lb	0	-0.1	-0.3	-0.3	-903.3	-903.4	-903.7
Vapor mass fraction		1	1	1	1	0	0	0
Vapor density	lb/ft³	0.163	0.163	0.163	0.163			
Vapor specific heat	BTU/(lb-F)	0.5688	0.5691	0.5693	0.5693			
Vapor viscosity	cp	0.0142	0.0142	0.0142	0.0142			
Vapor thermal cond.	BTU/(ft-h-F)	0.017	0.017	0.017	0.017			
Vapor molecular weight		18.00999	18.00999	18.00999	18.00999			

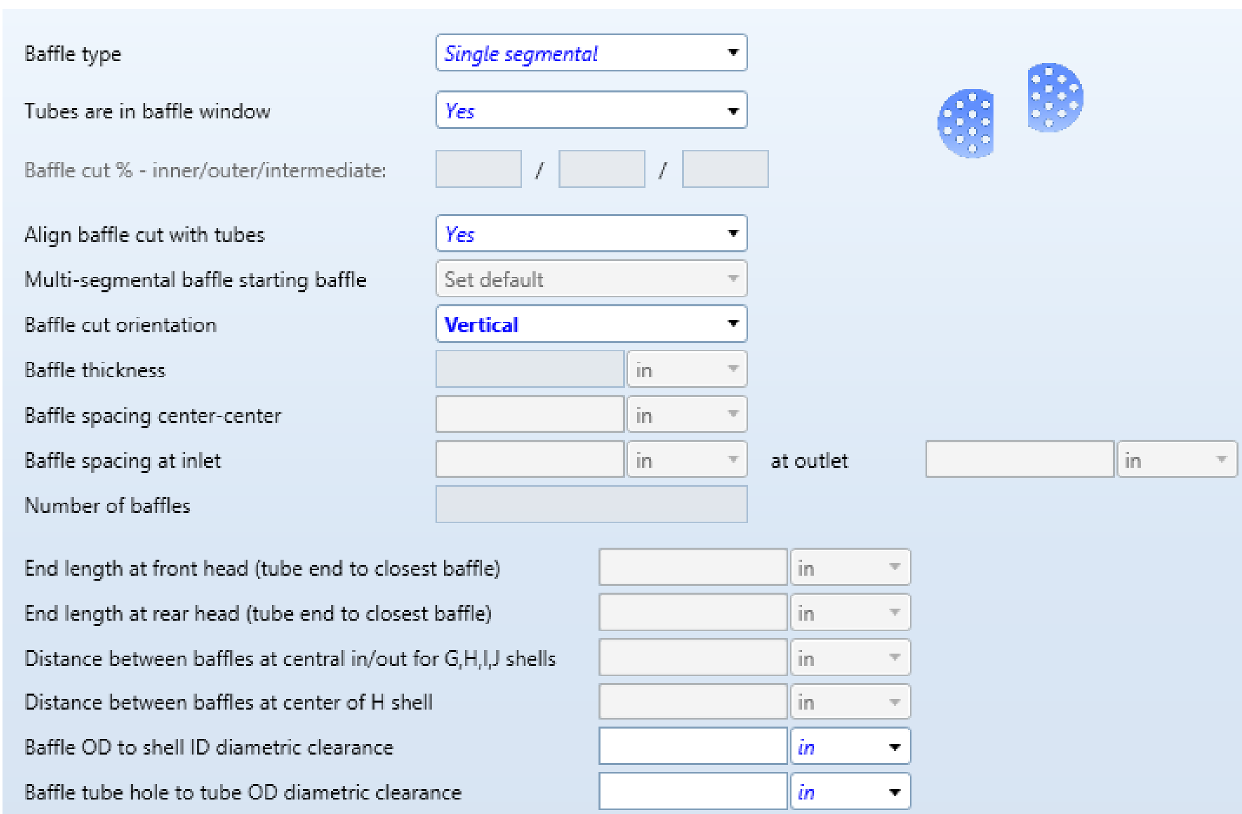


	ComThermo Components	ComThermo Composition	ComThermo Components ID
1	Glycerol	0.0078	502
2	Water	0.04	19
3	OleicAcid	0.005	3097
4	H2SO4	0.00067	723
5	Methyl_Oleate	0.0012	570
6	Triethylene_Glycol	0.00128	54
7	Methanol	0.00834	29
8			
9			
10			
11			

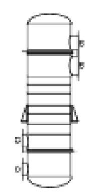



Front head type
B - bonnet bolted or integral with tubesheet
Shell type
E - one pass shell
Rear head type
M - bonnet
Exchanger position
Vertical
Shell(s)
ID
in
OD
in
Series
Parallel
Tubes
Number
Length
in
OD
0.75
in
Thickness
0.083
in
Tube Layout
New (optimum) layout
Tubes
8849
Tube Passes
Pitch
0.9375
in
Pattern
30-Triangular
Baffles
Spacing (center-center)
in
Spacing at inlet
in
Number
Spacing at outlet
in
Type
Single segmental
Tubes in window
Yes
Orientation
Vertical
Cut(%d)


Front head type
B - bonnet bolted or integral with tubesheet
Shell type
E - one pass shell
Rear head type
M - bonnet
Exchanger position
Vertical
Location of front head for vertical units
At bottom
"E" shell flow direction (inlet nozzle location)
Near rear head
Double pipe or hairpin unit shell pitch
in
Tubeside inlet at front head
Set default
Flow within multi-tube hairpin (M-shell)
Set default
Overall flow for multiple shells
Countercurrent
ID
OD
Thickness
Series
Parallel
Shell(s)
in
Front head
in
Rear head
in


Baffle type
Single segmental
Tubes are in baffle window
Yes
Baffle cut % - inner/outer/intermediate:
/
/
Align baffle cut with tubes
Yes
Multi-segmental baffle starting baffle
Set default
Baffle cut orientation
Vertical
Baffle thickness
in
Baffle spacing center-center
in
Baffle spacing at inlet
in
at outlet
in
Number of baffles
End length at front head (tube end to closest baffle)
in
End length at rear head (tube end to closest baffle)
in
Distance between baffles at central in/out for G,H,I,J shells
in
Distance between baffles at center of H shell
in
Baffle OD to shell ID diametric clearance
in
Baffle tube hole to tube OD diametric clearance
in

Heat Exchanger Specification Sheet

1	Company:						
2	Location:						
3	Service of Unit:	Our Reference:					
4	Item No.:	Your Reference:					
5	Date: Rev No.:	Job No.:					
6	Size : 100 - 240 in	Type: BEM Vertical		Connected in: 10 parallel 5 series			
7	Surf/unit(eff.) 1680484 ft^2	Shells/unit 50		Surf/shell(eff.) 33609.7 ft^2			
8	**PERFORMANCE OF ONE UNIT**						
9	Fluid allocation		Shell Side		Tube Side		
10	Fluid name		STEAM		PROCESS FLUID		
11	Fluid quantity, Total	lb/h	925148		1141235		
12	Vapor (In/Out)	lb/h	925148	0	0	988275	
13	Liquid	lb/h	0	925148	1141235	152959	
14	Noncondensable	lb/h	0	0	0	0	
15							
16	Temperature (In/Out)	°F	305.6	305.56	108.5	230.19	
17	Bubble / Dew point	°F	305.56 / 305.56	305.56 / 305.56	162.25 / 708.49	157.71 / 716.77	
18	Density Vapor/Liquid	lb/ft^3	0.033 /	/ 57.115	/ 49.952	0.035 / 40.436	
19	Viscosity	cp	0.0142 /	/ 0.1935	/ 1.3441	0.0094 / 3.3284	
20	Molecular wt, Vap		18.01			19.65	
21	Molecular wt, NC						
22	Specific heat	BTU/(lb-F)	0.5693 /	/ 1.0146	/ 0.9069	0.4428 / 0.5516	
23	Thermal conductivity	BTU/(ft-h-F)	0.017 /	/ 0.398	/ 0.284	0.014 / 0.083	
24	Latent heat	BTU/lb	903	903	462.6	1289.8	
25	Pressure (abs)	psi	14.5	12.91	14.5	13.2	
26	Velocity (Mean/Max)	ft/s	35.33 / 72.87		23.65 / 47.27		
27	Pressure drop, allow./calc.	psi	1.6	18.29	3	1.3	
28	Fouling resistance (min)	ft^2-h-F/BTU	0		0	0	Ao based
29	Heat exchanged 835505100 BTU/h				MTD (corrected) 108.69 °F		
30	Transfer rate, Service 4.57		Dirty 137.69		Clean 137.69 BTU/(h-ft^2-F)		
31	**CONSTRUCTION OF ONE SHELL**						**Sketch**
32				Shell Side	Tube Side		
33	Design/Vacuum/test pressure		psi	50 / /	50 / /		
34	Design temperature		°F	370	300		
35	Number passes per shell			1	1		
36	Corrosion allowance		in	0.125	0.125		
37	Connections	In	in	1 48 / -	1 8 / -		
38	Size/Rating	Out		1 8 / -	1 32 / -		
39	Nominal	Intermediate		1 34 / -	1 28 / -		
40	Tube #: 8849 OD: 0.75 Tks. Average 0.083 in	Length: 240 in	Pitch: 0.9375 in	Tube pattern: 30			
41	Tube type: Plain	Insert: None	Fin#: #/in	Material: Carbon Steel			
42	Shell Carbon Steel ID 100 OD 101 in	Shell cover -					
43	Channel or bonnet Carbon Steel	Channel cover -					
44	Tubesheet-stationary Carbon Steel -	Tubesheet-floating -					
45	Floating head cover -	Impingement protection None					
46	Baffle-cross Carbon Steel Type Single segmental Cut(%d) 29.7	V(Spacing: c/c 23.75 in					
47	Baffle-long - Seal Type	Inlet 51.0394 in					
48	Supports-tube U-bend 0	Type					
49	Bypass seal	Tube-tubesheet joint Expanded only (2 grooves)(App.A 'i')					
50	Expansion joint -	Type None					
51	RhoV2-Inlet nozzle 137	Bundle entrance 376	Bundle exit 1 lb/(ft-s^2)				
52	Gaskets - Shell side -	Tube side	Flat Metal Jacket Fibe				
53	Floating head -						
54	Code requirements ASME Code Sec VIII Div 1	TEMA class R - refinery service					
55	Weight/Shell 141416.5 Filled with water 217130.1	Bundle 119057.1 lb					
56	Remarks						
57							

1	Size	100	X	240	in	Type	BEM	Ver	Connected in	10 parallel	5 series
2	Surf/Unit (gross/eff/finned)		1737495	/	1680484	/	ft²		Shells/unit	50	
3	Surf/Shell (gross/eff/finned)		34749.9	/	33609.7	/	ft²				
4	Design (Sizing)				**PERFORMANCE OF ONE UNIT**						
5			**Shell Side**		**Tube Side**				**Heat Transfer Parameters**		
6	**Process Data**		**In**	**Out**	**In**	**Out**			Total heat load	BTU/h	835505100
7	Total flow	lb/h	925148		1141235				Eff. MTD/ 1 pass MTD	°F 108.69 /	110.26
8	Vapor	lb/h	925148	0	0	988275			Actual/Reqd area ratio - fouled/clean	30.1 /	30.1
9	Liquid	lb/h	0	925148	1141235	152959					
10	Noncondensable	lb/h	0		0				**Coef./Resist.**	BTU/(h-ft²-F) ft²-h-F/BTU	%
11	Cond./Evap.	lb/h	925148		988275				Overall fouled	137.69 0.0073	
12	Temperature	°F	305.6	305.56	108.5	230.19			Overall clean	137.69 0.0073	
13	Bubble Point	°F	305.56	305.56	162.25	157.71			Tube side film	152.55 0.0066	90.26
14	Dew Point	°F	305.56	305.56	708.49	716.77			Tube side fouling	0	0
15	Vapor mass fraction		1	0	0	0.87			Tube wall	3762.55 0.0003	3.66
16	Pressure (abs)	psi	14.5	12.91	14.5	13.2			Outside fouling	0	0
17	DeltaP allow/cal	psi	1.6	18.29	3	1.3			Outside film	2264.42 0.0004	6.08
18	Velocity	ft/s	68.34	0.04	0.04	47.27					
19	**Liquid Properties**								**Shell Side Pressure Drop**	psi	%
20	Density	lb/ft³		57.115	49.952	40.436			Inlet nozzle	0.02	0.13
21	Viscosity	cp		0.1935	1.3441	3.3284			InletspaceXflow	2.84	15.49
22	Specific heat	BTU/(lb-F)		1.0146	0.9069	0.5516			Baffle Xflow	12.19	66.57
23	Therm. cond.	BTU/(ft-h-F)		0.398	0.284	0.083			Baffle window	0.39	2.11
24	Surface tension	lbf/ft				0.00445			OutletspaceXflow	2.39	13.04
25	Molecular weight			18.01	18.96	231.3			Outlet nozzle	0.01	0.04
26	**Vapor Properties**								Intermediate nozzles	0.48	2.6
27	Density	lb/ft³	0.033			0.035			**Tube Side Pressure Drop**	psi	%
28	Viscosity	cp	0.0142			0.0094			Inlet nozzle	0.02	1.53
26	**Vapor Properties**								Intermediate nozzles	0.48	2.6
27	Density	lb/ft³	0.033			0.035			**Tube Side Pressure Drop**	psi	%
28	Viscosity	cp	0.0142			0.0094			Inlet nozzle	0.02	1.53
29	Specific heat	BTU/(lb-F)	0.5693			0.4428			Entering tubes	0.01	0.75
30	Therm. cond.	BTU/(ft-h-F)	0.017			0.014			Inside tubes	0.59	45.49
31	Molecular weight		18.01			19.65			Exiting tubes	0.02	1.7
32	**Two-Phase Properties**								Outlet nozzle	0.05	3.55
33	Latent heat	BTU/lb	903	903	462.6	1289.8			Intermediate nozzles	0.6	46.98
34	**Heat Transfer Parameters**								**Velocity / Rho*V2**	ft/s	lb/(ft-s²)
35	Reynolds No. vapor		14604.35			12876.19			Shell nozzle inlet	64.7	137
36	Reynolds No. liquid			1071.65	103.78	5.62			Shell bundle Xflow	68.34 0.04	
37	Prandtl No. vapor		1.13			0.72			Shell baffle window	54.03 0.03	
38	Prandtl No. liquid			1.19	10.39	53.39			Shell nozzle outlet	1.3	96
39	**Heat Load**		BTU/h		BTU/h				Shell nozzle interm	130.5	556
40	Vapor only		-104660		0					ft/s	lb/(ft-s²)
41	2-Phase vapor		0		14067600				Tube nozzle inlet	1.83	167
42	Latent heat		-835400300		731908000				Tubes	0.04 47.27	
43	2-Phase liquid		0		33474360				Tube nozzle outlet	146.01	869
44	Liquid only		0		56055030				Tube nozzle interm	183.56	1437
45	**Tubes**				**Baffles**				**Nozzles: (No./OD)**		
46	Type			Plain	Type	Single segmental				**Shell Side**	**Tube Side**
47	ID/OD	in	0.584 /	0.75	Number		7		Inlet in	1 / 48	1 / 8.625
48	Length act/eff	ft	20 /	19.3438	Cut(%d)	29.7			Outlet	1 / 8.625	1 / 32
49	Tube passes		1		Cut orientation		V		Intermediate	1 / 34	1 / 28
50	Tube No.		8849		Spacing: c/c	in	23.75		Impingement protection	None	
51	Tube pattern		30		Spacing at inlet	in	51.0394				
52	Tube pitch	in	0.9375		Spacing at outlet	in	38.5856				
53	Insert			None							
54	Vibration problem (HTFS / TEMA)		Yes	/					RhoV2 violation		No

Basic Geometry | Tubes | Baffles | Supports-Misc. Baffles | Bundle | Enhancements | Thermosiphon Piping

Tubes

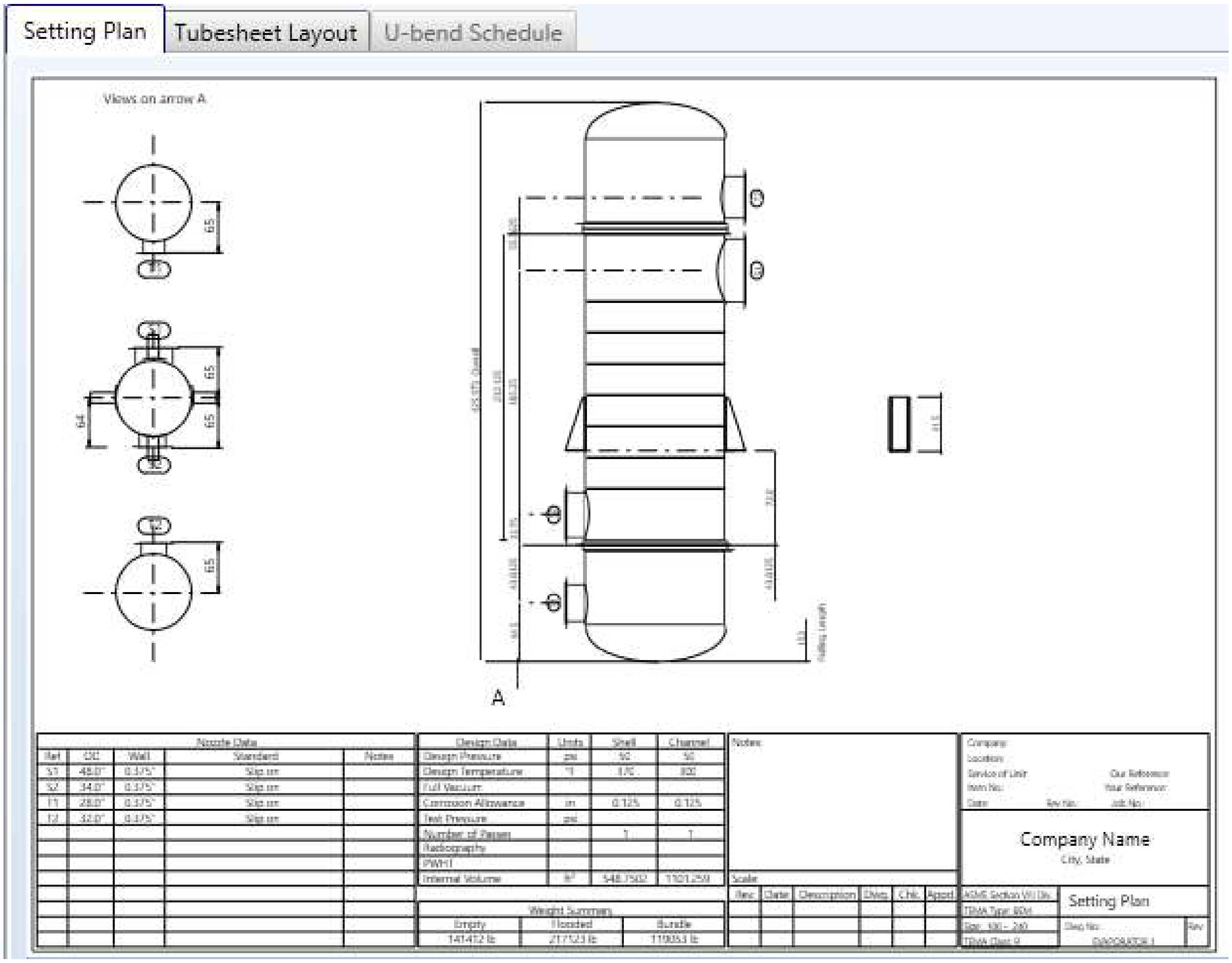
Type		Plain	Total number of tubes		8849
Outside diameter	in	0.75	Number of tubes plugged		0
Inside diameter	in	0.584	Tube length actual	ft	20
Wall thickness	in	0.083	Tube length effective	ft	19.3438
Area Ratio Ao/Ai		1.284247	Front tubesheet thickness	in	3.875
Pitch	in	0.9375	Rear tubesheet thickness	in	3.875
Pattern		30	Material		Carbon Steel
External enhancement			Thermal conductivity	BTU/(ft-h-F)	29.415
Internal enhancement					
Low fins			**Longitudinal fins**		
Fin density	#/in		Fin number		0
Fin height	in		Fin thickness	in	
Fin thickness	in		Fin height	in	
Tube root diameter	in		Fin spacing	in	
Tube wall thickness under fin	in		Cut and twist length	in	
Tube inside diameter under fins	in				
Other (high) fins					
High Fin Type		Default	High Fin Thick	in	
High Fin Tip Diameter	in		High Fin Frequency	#/in	

Baffles

Type		Single segmental	Baffle cut: inner/outer/interm					
Tubes in window		Yes	Actual (% diameter)		/	29.7	/	
Number		7	Nominal (% diameter)		/	30	/	
Spacing (center-center)	in	23.75	Actual (% area)		/	24.89	/	
Spacing at inlet	in	51.0394	Cut orientation					V
Spacing at outlet	in	38.5856	Thickness	in				0.625
Spacing at center in/out for G,H,I,J	in		Tube rows in baffle overlap					50
Spacing at center for H shell	in		Tube rows in baffle window					35.5
End length of the front head	in	42.5856	Baffle hole - tube od diam clearance	in				0.0156
End length of the rear head	in	54.9144	Shell id - tube od diam clearance	in				0.4375

Variable Baffle Spacings

Baffle spacing	in	
Baffle cut percent, outer		
Baffle cut percent, inner		
Number of baffle spaces		
Baffle region length	in	
Baffle cut area percent, outer		
Baffle cut area percent, inner		


Setting Plan
Tubesheet Layout
U-bend Schedule
Views on arrow A
A
Nozzle Data
Ref
OD
Wall
Standard
Notes
Design Data
Units
Shell
Channel
Design Pressure
Design Temperature
Full Vacuum
Corrosion Allowance
Test Pressure
Number of Passes
Radiography
PWHT
Internal Volume
Weight Summary
Empty
Flooded
Bundle
Notes
Company Name
City, State
Setting Plan

CHAPTER 10

INSTUMENTATION AND PROCESS CONTROL

10.1 Introduction

Instrumentation is the study of automated measurement and control. Numerous applications of this science can be found in modern research, industry, and daily life. Everything around us is automated, including home thermostats, aero plane autopilots, vehicle engine control systems, and pharmaceutical drug production. Selecting the best measuring technique is essential for first step in the design and formulation of many process control systems. While using manual control, an operator may read the process variable and adjust the input up or down until the temperature reaches the optimum value. In non-critical applications, manual control is used when the operator's attention needs to be maintained to a minimum and any process condition changes gradually and modestly. When under automated management, measurement and changes are made automatically on a regular basis. The following benefits have led to the widespread usage of automated control in industry today.

- Product quality enhancement
- Increase in the manufacturing rate's process yield
- Boost employee and equipment safety.
- Economic savings in materials and time
- Enhancement of working conditions
- Manual control does not allow for the completion of the procedure.

10.2 Objectives

The following are the goals of the Instrumentation and Control System:

- Suppressing and eliminating external disruptions
- Maintain the process's stability.
- Optimize the functioning of the process

10.3 Components of control system

Components of Control System are follows

- Process
- Measuring Element
- Process Variable

- Controller

10.4 Process

A process is any activity or combination of operations that results in the intended end result.

10.5 Measuring Element

As with other components of a control system, the measuring element is likely the most critical. 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.

10.6 Process Variable

The control of process variables is critical to the smooth running of a process. These are described as changing conditions in process materials or apparatus. The principal variables include temperature, pressure, flow, and liquid level, followed by a dozen or so less often encountered variables such as chemical composition, viscosity, density, humidity, moisture content, and so on. Measurement is a key need for process control, whether it is automatic, semi-automatic, or human. An automated control is used to measure, rectify, and alter the four major categories of process variations.

- Measuring temperature
- Measuring pressure
- Measuring flow rate
- Measuring level

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

10.6.1 Temperature Measurement and Control

Temperature readings are utilized to control the intake and output temperatures. flows in reactors, heat exchangers, and other devices. To make it easier to bring the measurement to a centralized place, thermocouples are used for the majority of temperature measurements in the industry. Bimetallic or filled system thermometers are utilized for local measurements at the equipment to a lesser extent. Resistance thermometers with high measurement accuracy are utilized.

All of these meters are covered by thermo-walls when being used locally. This offers defense against the elements of the weather as well as other natural hazards.

10.6.2 Pressure Measurement and Control

Pressure, like temperature, is a variable that indicates the condition and composition of a substance. In fact, when taken together, these two metrics are the fundamental evaluation devices for 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 measurement instruments attached to them. As a result, measures of pressure are used to determine whether or not energy has increased. The majority of pressure measurements in industry are made using elastic element devices that are either relayed to a centralized location or directly linked for local use. A bourdon tube or a bellows with a diaphragm is the most typical industrial pressure component.

10.6.3 Flow Measurement and Control

Flow measurement is an important aspect of practically every industrial process, and numerous ways have been developed to do so. Similar to pressure measurement, flow measurement frequently makes use of a sensing device coupled to a DP cell. For 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 control 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. In industrial, variable head devices are used to measure flow. Variables are employed to a lesser extent, as are the various accessible kinds when particular measurement scenarios arise.

Table 10.1: Measuring Devices

Measured Process Variable	Measuring Devices	Comments
Temperature	Thermocouples, Thermometer, Thermistor, Bimetallic Thermometers, Radiation Pyrometers	Most frequently used for Radiation pyrometers with low temperatures High-Temperature applications
Pressure	Manometers Bourdon tube Elements Bellow Elements Strain Gauges Capsule gauges Thermal conductivity Gauge McLeod gauge	Based on the elastic deformation of materials, floats or displacers are used. Pressure is converted to an electrical signal using this device. For the purpose of measuring vacuum
Flowrate	Orifice plate Venture flow nozzle Pitot tube Turbine flow meter Hot wire anemometry Positive displacement Mass flowmeter	Pressure decrease over a flow restriction is measured. Positive displacement and mass flowmeters for Quantity Flowmeters with High Precision
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. Utilizing Indirect Hydrostatic Pressure

10.7 Type of Controls

In industry, several sorts of controls are utilized depending on the requirements and individual demands. They span from very simple controls to highly complicated systems, and may be divided into two primary categories:

- Feed forward control
- Feed Backward control

10.7.1 Feed Forward Control

A feedback control, as the name indicates, operates on the same principle. Any change to an input to a system results in "disturbances," which are modifications to the system. These interruptions are noted, and subsequent adjustments are made to the input to undo the impact of the change.

Advantages

- It is not necessary to identify and measure the disruption.
- Insensitive to modelling flaws.
- Changes in parameters have no effect

Disadvantages

- After irregularities have been detected, control action is done.
- Unsatisfactory due of a lengthy and considerable dead time procedure.
- It might result in instability in the closed-loop reaction.

10.7.2 Feed Backward Control

Adjusts the value of manipulated variables based on direct measurement of disturbances.

Advantages

- It takes action before the system feels the effects of the disturbance.
- It works well with sluggish systems or ones that have a lot of downtime.
- It doesn't cause the control system to become unstable.

Disadvantages

- It necessitates the identification of all potential disruptions as well as their immediate measurement.
- Cannot handle unmeasured disturbances.
- Sensitive to changes in process parameters.
- It is not possible to eliminate steady-state offset.
- It necessitates a thorough understanding of the process model.

10.8 Control on Distillation Column

Control Objective

- Temperature of distillation column
- Flowrate of coolant in condenser
- Flowrate of steam in reboiler

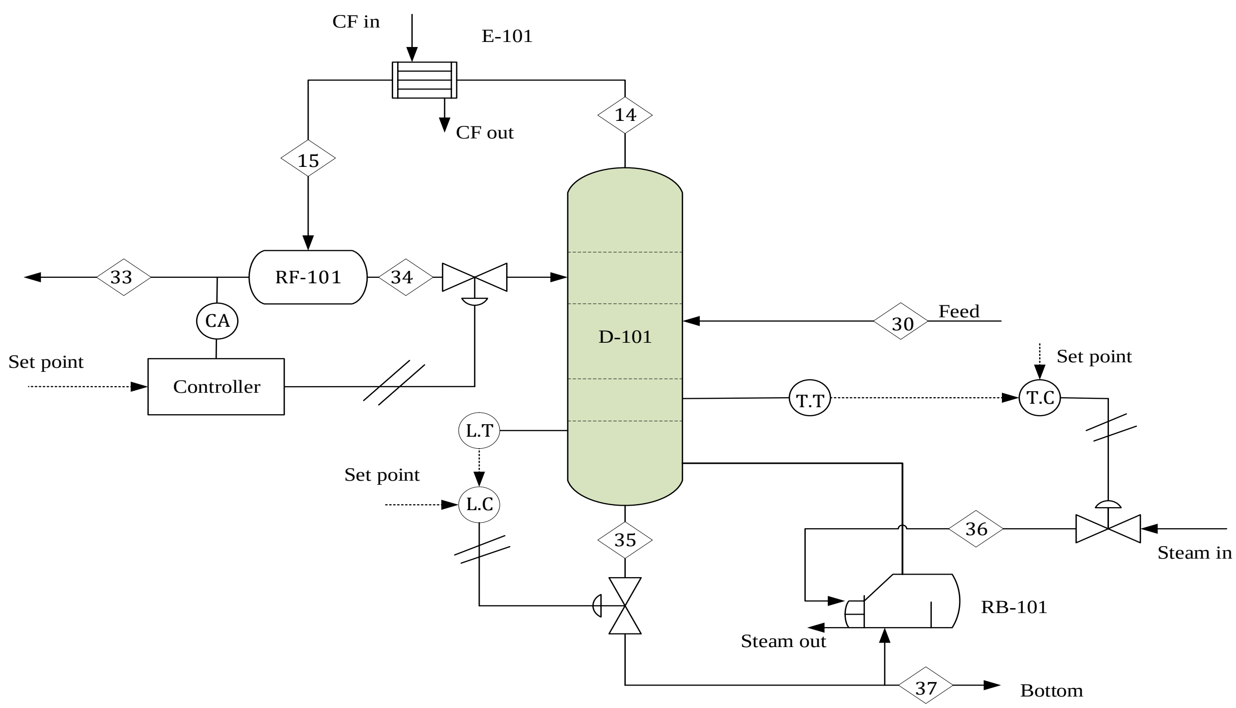


Figure 10-1: Control on Distillation Column

Manipulated Variables

- Steam flowrate
- Coolant flowrate

Disturbances

- Temperature of feed
- Temperature of steam
- Temperature of coolant
- Flowrate of feed
- Flowrate of steam
- Flowrate of coolant

10.9 Control on CSTR

Control Objective

- Temperature inside the reactor
- Temperature of coolant

Manipulated Variable

- Flowrate of feed and water

Disturbances

- Temperature of feed
- Temperature of coolant
- Flowrate of feed
- Flowrate of coolant

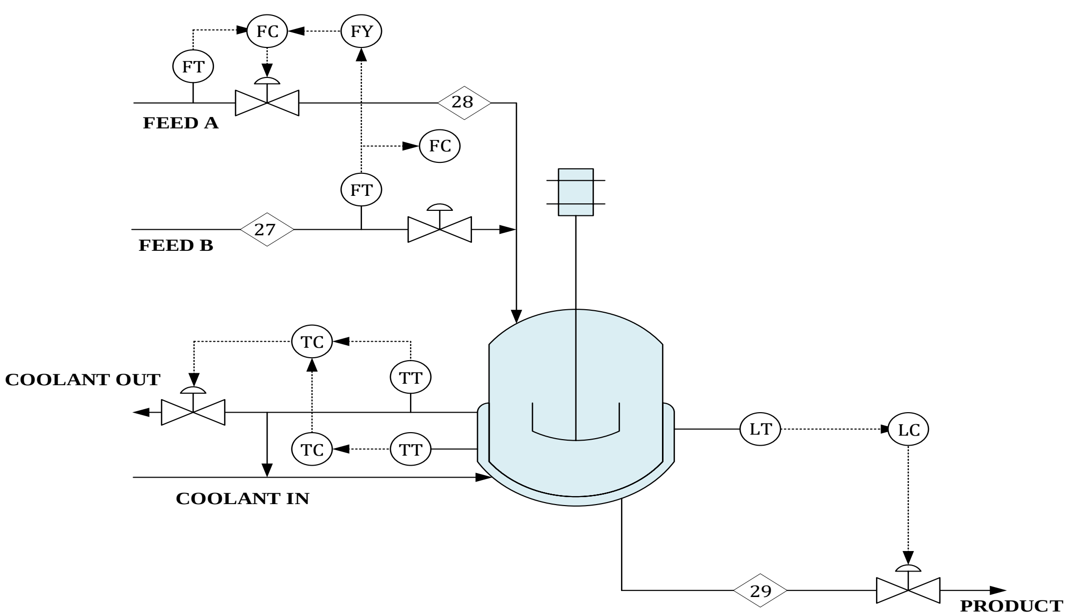


Figure 10-2: Control on Reactor

CHAPTER 11

HAZOP STUDY

11.1 HAZOP Study

The HAZOP study, also known as a hazard and operability study, is a methodical approach for identifying all plant or equipment dangers and operability issues. Each component (pipeline, piece of machinery, instrument, etc.) is thoroughly evaluated and any potential deviations from the identified usual operating conditions.

11.2 Objectives of HAZOP

The contractor frequently had to take the following into account, as is evident from the lessons learned from the practical application of HAZOP in the process industry.

- The potential for material degradation or breakdown,
- The potential for human factors to fail,
- the potential for an exothermic reaction runaway, the danger of raw materials, the reaction mixture, intermediate products, and finished goods decomposing,
- the potential for negative side effects,
- the potential for a utility outage.

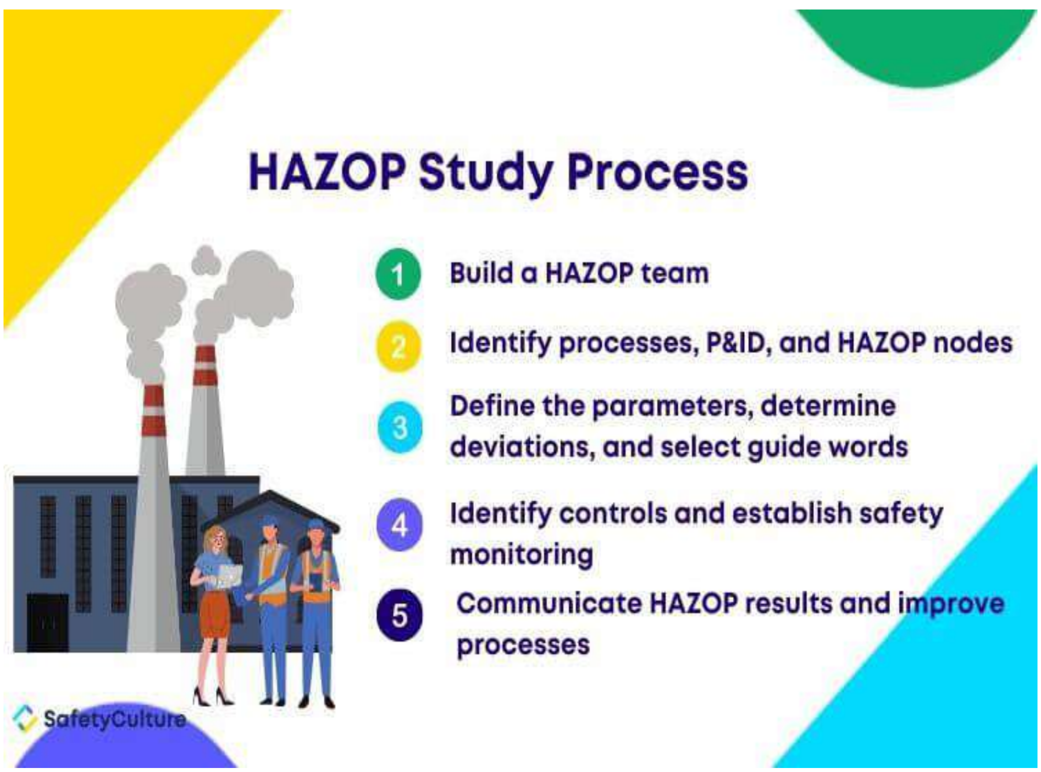


Figure 111: HAZOP Study Process

11.3 Guide Words

Table 11.1: Guided Words

Guide words	Meaning	Example
NO	Total negation of opposite function	No flow
MORE	Quantitative increase	Higher flow
LESS	Quantitative decrease	Lower flow
AS WELL AS	Qualitative increase	Penetration of water in reactor
PART OF	Qualitative decrease	Compound is missing
REVERSE	Opposite function	Reverse flow of fluid
OTHER THAN	Total substitution	Presence of other substances

11.4 Advantages and Disadvantages

HAZOP has following advantages

- A thorough and methodical analysis of the examined equipment to find potentially dangerous situations,
- The capacity to evaluate the results of a personnel failure and recognize situations where a personnel error could have detrimental impacts,
- Discovery of new harmful circumstances, a methodical approach that enables the discovery of new dangerous circumstances that may arise,
- Making operational regulations more stringent, enhancing the efficiency of the operational equipment, and detecting situations that could interfere with the operation, result in unplanned breaks, harm the equipment, or result in the loss of raw materials still being processed.

HAZOP has following disadvantages:

- Long period of time necessary (based on the scale of the technology).
- Without a clear description of objectives (such as the identification of emergency situations), studies might be endless and produce results that are unclear. This is why a set of HAZOP studies that account for the impacts at the beginning of the study are necessary.
- High expectations are placed on research participants' knowledge and abilities, and effective HAZOP studies cannot be carried out without a strong HAZOP team.

11.5 HAZOP Study on Distillation Column (D-101)

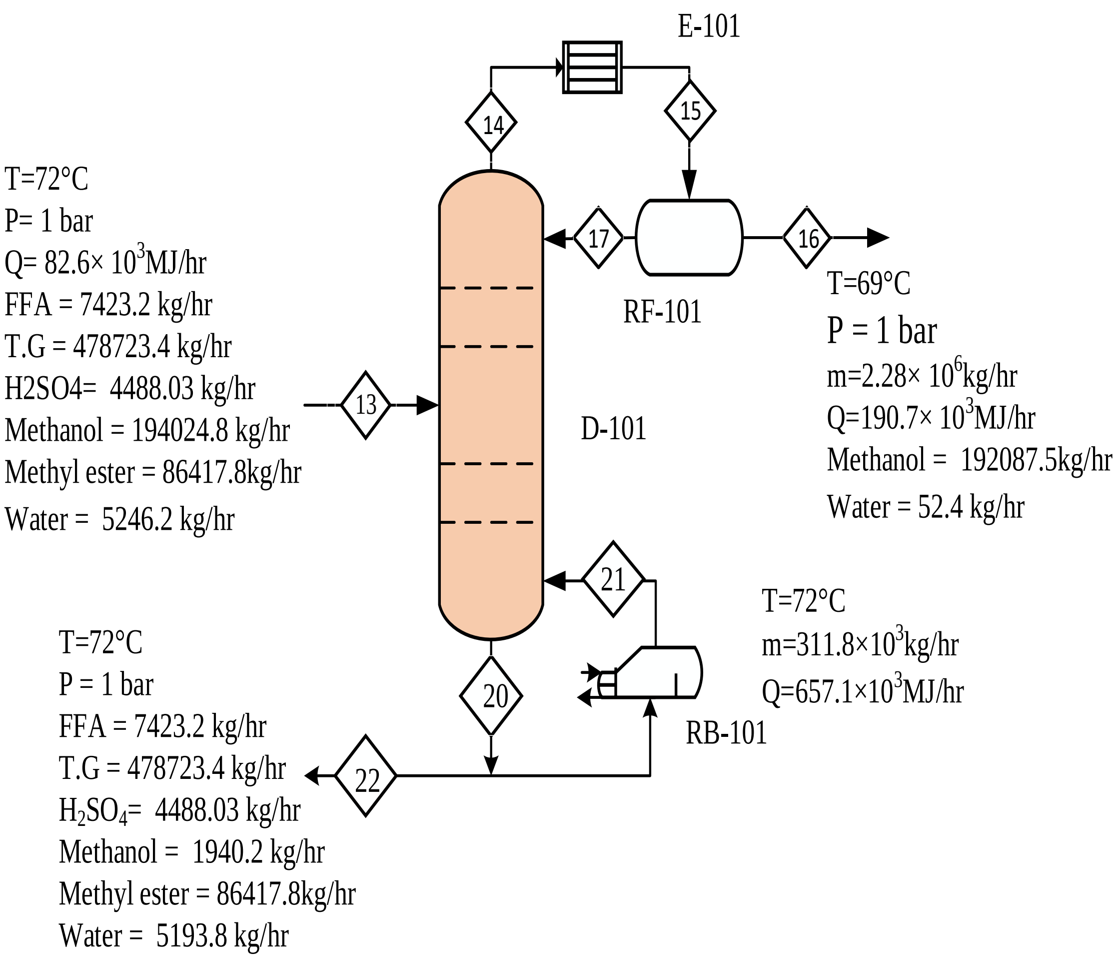


Figure 11.2: HAZOP Study on Distillation Column

Table 11.2: Guide Words for Distillation Column

Process parameter	Guide word	Possible causes	Possible consequences	Action required
Flow	No	Pipe is broken or plugging	Loss of feed in column/ desired output not achieved	Schedule inspection
Flow	Low	Pipe is partial plugged/leakage	Decrease of level in column	Install check valves
Flow	High	High pressure	Flooding in column	-
Flow	Low	Pipe partial clogged/ leakage	Level decrease in column	Schedule inspection + install valves
Temperature	Low	High flowrate from condenser	Low level inside reboiler	Schedule inspection
Temperature	More	Failure of cooling media in condenser	Low level of reflux	Install temperature indicator
Pressure	More	Valve close	Line over pressure	Failure of compressor
Flow	Less	Leakage in upstream system	Low level in condenser	Level controller (LC)

11.6 HAZOP Study of Heat Exchanger (HX-104)

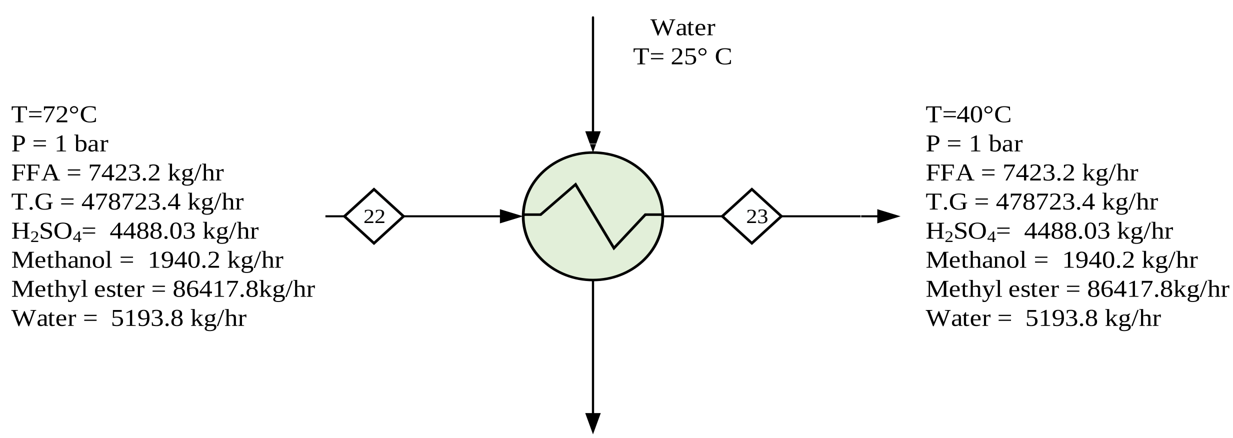


Figure 11.3: HAZOP Study on Distillation Column

Table 11.3: Guide Words for Heat Exchanger

Process parameter	**Guide word**	**Possible causes**	**Possible consequences**	**Action required**
Flow	Low	Pipe is partial plugged/leakage	Decrease of level in exchanger	Install check valve
Flow	Reverse	Failure of inlet valve	Fluid flow is reversed.	Install check valve.
Temperature	Less	Blockage in pipe	Temperature of process fluid remains constant	High temperature alarm
Temperature	More	Failure of valve	Process fluid temperature decreases	Low temperature alarm
Temperature	None	Failure of inlet valve to open	Temperature of process fluid remains constant	Install temperature indicator
Pressure	More of	Failure of process fluid valve	Bursting of tubes of exchanger	Install high pressure alarm

CHAPTER 12

ENVIRONMENTAL IMPACT ASSESSMENT

12.1 Environmental Impact Assessment

The evaluation of the impacts that are likely to result from a big project (or other action) that has a significant environmental impact is known as an environmental impact assessment (EIA). In reality, it is a tool for assessing how commercial activity, profitable planning, or action that affects the bio-geophysical environment and human health and well-being will be interpreted and communicated to the general public. All environmental factors are taken into account during the EIA process, starting with the project's initial planning and decision-making stages.

In EIA the negative and positive aspects of a certain project is inspected meticulously. And during the design stages of the product it also take into account these aspects. Environmental effects that the project can will also be pointed out by EIA. It also prognosticates the negative impact on environment and also suggest different techniques that will help lessen them. This technique has many advantages such as it protects the environment, utilization of resources is maximized and the outlay of project is reduced by applying different techniques to control environmental problems during the planning of project [6]

12.2 Biodiesel

The transesterification of oils or fats from plants or animals with short-chain alcohols like methanol and ethanol produces, an alkyl ester of fatty acids called biodiesel. A very good alternative fuel for diesel engines is biodiesel and it is nontoxic, biodegradable fuel. Instead of releasing carbon dioxide that has been stored in the atmosphere, we are cycling carbon with the aid of biodiesel.

It burns cleanly and has a lot of lubricity. Although it functions similarly to petroleum diesel, biodiesel made from renewable sources emits substantially less air pollution. [6]

12.3 Composition of Biodiesel Exhaust Emissions

Combustion emissions, fugitive emissions, and spills are only a few of the risks and hazards connected with biodiesel facilities. These risks and hazards can be reduced by technological and behavioral mitigation techniques.

It has been demonstrated that biodiesel emissions have lower levels of particulate matter, carbon monoxide, and polycyclic aromatic hydrocarbons (PAHs) than emissions from petroleum-based diesel. Sulfur-containing molecules also don't seem to be present. However, the combustion of biodiesel in a diesel engine often results in an increase in the generation of nitrogen oxides, which have been recognized as an ozone precursor in addition to potentially having negative health impacts. [6]

12.4 Respiratory Issues

The proportion of ultrafine (100-nm diameter) particles in the PM typically increases as the proportion of biodiesel in the fuel mix does as well. This is crucial because epidemiological connections between inhaled PM and respiratory health are most often caused by ultrafine (as opposed to larger) particles. Because they have a larger specific surface area, smaller particles can more efficiently adsorb harmful chemicals such polyromantic hydrocarbons (PAH), volatile organics, aldehydes, and ketones. Many of them, which are present in biodiesel exhaust, are dangerous, can cause cancer, or can cause mutations in both humans and animals. [6]

Because ultrafine particles have a greater inflammatory effect, particle size and respiratory health may be connected. Airway restriction appears to hasten the accumulation of ultrafine particles in the lungs of people with obstructive or restrictive lung disease (such as asthma). Because of their smaller size, biodiesel exhaust particles float in the air for longer, are easier to breathe in, can enter the lungs more deeply, and may even go straight to the pulmonary circulation. [6]

These issues can be solved by using filters in diesel engines.

12.5 Storage

Biodiesel may be stored and handled largely in the same ways as conventional petroleum diesel. The fuel needs to be kept in a tidy, dry, and dark location. Aluminum, steel, polyethylene, polypropylene, and Teflon are suggested materials for storage tanks, while concrete-lined storage tanks are not. If at all feasible, the storage tank should not include any copper, brass, lead, tin, zinc, or rubber fittings (in actuality, many people use brass ball valves with little to no harm).

A fungicide or algaecide should always be used while storing biodiesel during warm weather because it is an organic liquid. For optimal performance, biodiesel and conventional diesel should only be stored for a maximum of six months.

12.6 Byproduct Handling

Approximately 25% of the volume of crude glycerol by-product is methanol-contaminated, making it potentially hazardous waste. At room temperature, methanol will not adequately evaporate from stored glycerol to deem the glycerol uncontaminated.

Handle raw methanol-glycerol byproduct as though it were methanol. This entails donning gloves and safety glasses, as well as avoiding intense vapors. This glycerol can be sold to other industries in which it can be used as a raw material. [6]

12.7 Wash Water

Getting rid of and treating wash water waste from the production of biodiesel is quite difficult. Methanol, soap, too much catalyst, glycerol, fat oil, free fatty acids, and biodiesel are all possible contaminants of wash water. Typically, wash water has a high, alkaline pH. Before dumping the water in a sanitary sewer, the pH of the water should be measured. Local laws may differ, however because of its corrosive nature, any liquid with a pH of 9.5 or higher is of concern. [6]

Wash water's alkalinity can be reduced in small batches using muriatic acid or vinegar that has been diluted. However, neutralizing waste through "pretreatment" or before disposal is governed. Water treatment plants can be installed to treat the water so that it can be reused again and again.

12.8 Handling of Chemicals Used in Biodiesel Production

12.8.1 Methanol Handling

Methanol must be handled and utilized in a well-ventilated location since it is hazardous. At greater amounts, methanol can be fatal or can cause blindness when ingested or inhaled. Safety goggles, chemical-resistant clothes, and gloves must be worn whenever handling the substance because it is particularly harmful to the eyes. It is necessary to wear air-supplied respirators, preferably with a full-face mask, if airborne concentrations are higher than 200 ppm. [6]

12.8.2 KOH Handling

Potassium hydroxide (KOH) is caustic and potentially deadly if consumed. Affected skin should be properly washed with water or a weak vinegar solution to prevent serious burns. It is feasible to inhale solid KOH if the substance is broken down into dust-sized particles. Any of these circumstances calls for emergency medical care because they are all critical. [6]

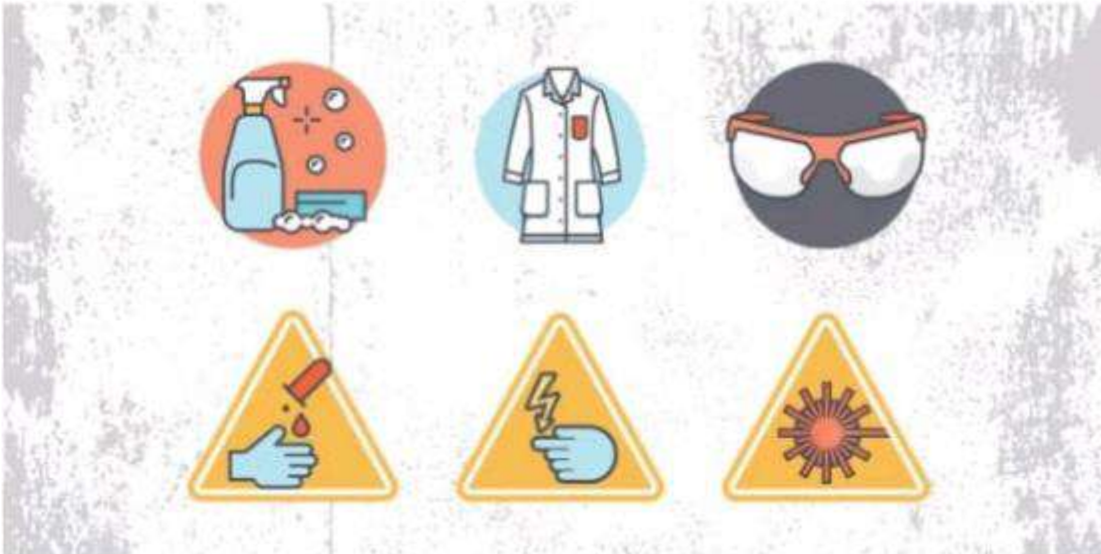


Figure 12.1: Handling of Chemicals

REFERENCES

References

1. Alexandre C. Dim, C. B. (2008). Chemical Process Design .
2. Ali Farokhnia, S. M. (2022). A novel design for biodiesel production from methanol+mutton bone fat mixture.
3. Anietie Okon Etim, C. F. (2022). Production of Biodiesel from Non-Edible Sources.
4. Azhaham Perumal Saravanan, A. P. (2020). A comprehensive assessment of biofuel policies in the BRICS nations: Implementation, blending target and gaps.
5. Daming Huang, H. Z. (2012). Biodiesel: an Alternative to Conventional Fuel.
6. Diana-Carolina Cruz-Forero, O.-A. G.-R. (2012). Calculation of thermophysical properties of oils and triacylglycerols using an Extended Constituent Fragments approach.
7. Fahed Javed a, Z. S. (2021). Conversion of poultry-fat waste to a sustainable feedstock for biodiesel production .
8. Gerhard Knothe, J. K. (2010). *the biodiesel handbook.*
9. H. Noureddini, D. Z. (2008). Kinetics of Transesterification of SoyBean Oil.
10. Hajar Rastegari, H. J. (2020). Biodiesel Guide – Sources, Production, Uses, & Regulations.
11. J.M. Encinar, S. N.-D. (2021). Pre-esterification of high acidity animal fats to produce biodiesel: A kinetic study.
12. John Abraham, V. R. (2013). Yield and Quality Characteristics of Rendered Chicken Oil for Biodiesel Production.
13. K. Sandesh Suresh, T. G. (2019). Prospective ecofuel feedstocks for sustainable production.
14. Kaniz Ferdous, M. R. (2013). Preparation of Biodiesel Using Sulfuric Acid as a Catalyst.
15. Kesieme, U. K. (2019). Biofuel as alternative shipping fuel: technology, environmental and economic assessment.
16. Lalit M. Bal, S. S. (2010). Solar dryer with thermal energy storage systems for drying agricultural food products: A review.
17. Marchetti, J. M. (2012). A summary of the available technologies for biodiesel production based on a comparison of different feedstock's properties.
18. Marcos V.D. Silva, R. C. (2015). Determination of Enthalpies of Formation of Fatty Acids and Esters by Density Functional Theory Calculations with an Empirical Correction.

19. Renata N. Vilas Bôas, M. F. (2022). A REVIEW OF BIODIESEL PRODUCTION FROM NON-EDIBLE RAW MATERIALS USING THE TRANSESTERIFICATION PROCESS WITH A FOCUS ON INFLUENCE OF FEEDSTOCK COMPOSITION AND FREE FATTY ACIDS.
20. Rungnapa Kaewmeesri, A. S. (2014). Deoxygenation of Waste Chicken Fats to Green Diesel over Ni/Al2O3: Effect of Water and Free Fatty Acid Content.
21. S. Tamalampudi, H. F. (2011). Industrial Biotechnology and Commodity Products.
22. Saifuddin Nomanbhay, R. H. (2018). Sustainability of biodiesel production in Malaysia by production of bio-oil from crude glycerol using microwave pyrolysis: a review.
23. Steiman, M. (2008). Biodiesel Safety and Best Management Practices for Small-Scale Noncommercial Use and Production.
24. Sujan Shee, B. P. (2022). Pincer-Metal Complexes Applications in Catalytic Dehydrogenation Chemistry.
25. Zaitsau, D. H., & Verevkin, S. P. (2013). Thermodynamics of biodiesel: combustion experiments in the standard conditions and adjusting of calorific values for the practically relevant range (273 to 373) K and (1 to 200) bar.

APPENDICES

Appendix-A

Tables

Table A.1: Maximum Allowable Stress

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

Table A.2: Degree of Radiography

Type of joint	Degree of radiography		
	100 per cent	spot	none
Double-welded butt or equivalent	1.0	0.85	0.7
Single-weld butt joint with bonding strips	0.9	0.80	0.65

Table A.3: Minimum Practical Thickness

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.4: 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.5: Typical Percentages of Fixed Capital Investment

Component	Range of FCI, %
Direct costs	
Purchased equipment	15–40
Purchased-equipment installation	6–14
Instrumentation and controls (installed)	2–12
Piping (installed)	4–17
Electrical systems (installed)	2–10
Buildings (including services)	2–18
Yard improvements	2–5
Service facilities (installed)	8–30
Land	1–2
Indirect costs	
Engineering and supervision	4–20
Construction expenses	4–17
Legal expenses	1–3
Contractor's fee	2–6
Contingency	5–15

Table A.6: Purchased Prices of Equipment's 2003

1. Agitators
[Meyers and Kime, *Chem. Eng.*, 109–112 (27 Sep. 1976)]

$$C = \exp[a + b \ln HP + c(\ln HP)^2] \quad \$, \quad 1 < HP < 400$$

		Single Impeller			Dual Impeller		
		Speed 1	2	3	1	2	3
Carbon steel	a	8.57	8.43	8.31	8.80	8.50	8.43
	b	0.1195	−0.0880	−0.1368	0.1603	0.0257	−0.1981
	c	0.0819	0.1123	0.1015	0.0659	0.0878	0.1239
Type 316	a	8.82	8.55	8.52	9.25	8.82	8.72
	b	0.2474	0.0308	−0.1802	0.2801	0.1235	−0.1225
	c	0.0654	0.0943	0.1158	0.0542	0.0818	0.1075

Speeds 1: 30, 37, and 45 rpm
2: 56, 68, 84, and 100 rpm
3: 125, 155, 190, and 230 rpm

2. Compressors, turbines, and fans (K$)

Centrifugal compressors, without drivers (IFP, 1981):

$$C = 6.49(HP)^{0.62} \quad K\$, \quad 200 < HP < 30{,}000$$

Reciprocating compressors without drivers (IFP):

$$C = 5.96(HP)^{0.61} \quad K\$, \quad 100 < HP < 20{,}000$$

Screw compressors with drivers (IFP):

$$C = 1.49(HP)^{0.71} \quad K\$, \quad 10 < HP < 800$$

Turbines (IFP):

Pressure discharge, $C = 0.31(HP)^{0.81}$ K$, $20 < HP < 5000$
vacuum discharge, $C = 0.69(HP)^{0.81}$ K$, $200 < HP < 8000$

Fans with motors (Ulrich)

$$C = f_m f_p \exp[a + b \ln Q + c(\ln Q)^2] \text{ installed cost, K\$}, \quad Q \text{ in KSCFM}$$

	a	*b*	*c*	*Q*
Radial blades	0.4692	0.1203	0.0931	2–500
Backward curved	0.0400	0.1821	0.0786	2–900
Propeller	−0.4456	0.2211	0.0820	2–300
Propeller, with guide vanes	−1.0181	0.3332	0.0647	2–500

materials factor, f_m

Carbon steel	2.2
Fiberglass	4.0
Stainless steel	5.5
Nickel alloy	11.0

Pressure Factors, F_p

	Centrifugal		Axial	
Pressure (kPa[gage])	Radial	Backward Curved	Prop.	Vane
1	1.0	1.0	1.0	1.00
2	1.15	1.15	—	1.15
4	1.30	1.30	—	1.30
8	1.45	1.45	—	—
16	1.60	—	—	—

3. Conveyors (IFP) K$

Troughed belt: $C = 1.40L^{0.66}$, $10 < L < 1300$ ft
Flat belt: $C = 0.90L^{0.66}$, $10 < L < 1300$ ft
Screw (steel): $C = 0.40L^{0.78}$, $7 < L < 100$ ft
Screw (stainless steel): $C = 0.70L^{0.78}$, $7 < L < 100$ ft
Bucket elevator: $C = 4.22L^{0.63}$, $10 < L < 100$ ft
Pneumatic conveyor (*Chemical Engineers' Handbook*, McGraw-Hill, New York, 1984), 600 ft length

$$C = \exp[3.5612 - 0.0048 \ln W + 0.0913(\ln W)^2], \quad 10 < W < 100 \text{ klb/hr}$$

4. Cooling towers, installed K$

Concrete (IFP) $C = 135fQ^{0.61}$, $1 < Q < 60$ K gal/min:

Δt (°C)	10	12	15
f	1.0	1.5	2.0

Redwood, without basin (Hall): $C = 33.9Q^{0.66}$, $1.5 < Q < 20$ K gal/min

5. Crushers and grinders (IFP) K$

Cone crusher: $C = 1.55W^{1.05}$, $20 < W < 300$ tons/hr
Gyratory crusher: $C = 8.0W^{0.60}$, $25 < W < 200$ tons/hr
Jaw crusher: $C = 6.3W^{0.57}$, $10 < W < 200$ tons/hr
Hammer mill: $C = 2.44W^{0.78}$, $2 < W < 200$ tons/hr
Ball mill: $C = 50.0W^{0.69}$, $1 < W < 30$ tons/hr
Pulverizer: $C = 22.6W^{0.39}$, $1 < W < 5$ tons/hr

6. Crystallizers (IFP, *Chemical Engineers' Handbook*, p. 19.40)

External forced circulation:

$$C = f \exp[4.868 + 0.3092 \ln W + 0.0548(\ln W)^2],$$
$$10 < W < 100 \text{ klb/hr of crystals}$$

Internal draft tube: $C = 176fW^{0.58}$, $15 < W < 100$ klb/hr of crystals
Batch vacuum: $C = 8.16fV^{0.47}$, $50 < V < 1000$ cuft of vessel

Type	Material	*f*
Forced circulation	Mild steel	1.0
	Stainless type 304	2.5
Vacuum batch	Mild steel	1.0
	Rubber-lined	1.3
	Stainless type 304	2.0

7. Distillation and absorption towers, tray and packed (Evans et al., 1984) prices in $

Tray towers:

$$C_T = f_1 C_b + N f_2 f_3 f_4 C_t + C_{pl},$$

Distillation:

$$C_b = \exp[7.123 + 0.1478(\ln W) + 0.02488(\ln W)^2 + 0.01580(L/D)\ln(T_b/T_p)],$$

$9020 < W < 2{,}470{,}000$ lbs of shell exclusive of nozzles and skirt

$C_t = 375.8 \exp(0.1739D)$, $2 < D < 16$ ft tray diameter

N = number of trays

$C_{pl} = 204.9D^{0.6332}L^{0.8016}$, $2 < D < 24$,
$57 < L < 170$ ft (platforms and ladders)

Material	f_1	f_2
Stainless steel, 304	1.7	1.189 + 0.0577*D*
Stainless steel, 316	2.1	1.401 + 0.0724*D*
Carpenter 20CB-3	3.2	1.525 + 0.0788*D*
Nickel-200	5.4	
Monel-400	3.6	2.306 + 0.1120*D*
Inconel-600	3.9	
Incoloy-825	3.7	
Titanium	7.7	

(continued)

Tray Types	f_t
Valve	1.00
Grid	0.80
Bubble cap	1.59
Sieve (with downcomer)	0.85

$f_{t} = 2.25/(1.0414)^{N}$, when the number of trays N is less than 20

T_b is the thickness of the shell at the bottom, T_p is thickness required for the operating pressure, D is the diameter of the shell and tray, L is tangent-to-tangent length of the shell

Absorption:

$C_b = \exp[6.629 + 0.1826(\ln W) + 0.02297(\ln W)^2]$,
4250 < W < 980,000 lb shell

$C_{pl} = 246.4D^{0.7396}L^{0.7068}$, $3 < D < 21$,
$27 < L < 40$ ft (platforms and ladders),

f_i, f_p, f_t, and f_s as for distillation

Packed towers:

$C = f_1 C_b + V_p C_p + C_{pl}$

V_p is volume of packing, C_p is cost of packing \$/cuft

Packing Type	C_p (\$/cuft)
Ceramic Raschig rings, 1 in.	19.6
Metal Raschig rings, 1 in.	32.3
Intalox saddles, 1 in.	19.6
Ceramic Raschig rings, 2 in.	13.6
Metal Raschig rings, 2 in.	23.0
Metal Pall rings, 1 in.	32.3
Intalox saddles, 2 in.	13.6
Metal Pall rings, 2 in.	23.0

8. Dryers (IFP)

Rotary combustion gas heated: $C = (1 + f_g + f_m)\exp[4.9504 - 0.5827(\ln A) + 0.0925(\ln A)^2]$, $200 < A < 30{,}000$ sqft lateral surface

Rotary hot air heated: $C = 2.38(1 + f_g + f_m)A^{0.63}$, $200 < A < 4000$ sqft lateral surface

Rotary steam tube: $C = 1.83FA_t^{0.60}$, $500 < A_t < 18{,}000$ sqft tube surface, $F = 1$ for carbon steel, $F = 1.75$ for 304 stainless

Cabinet dryer: $C = 1.15f_p A^{0.77}$, $10 < A < 50$ sqft tray surface

Pressure	f_p
Atmospheric pressure	1.0
Vacuum	2.0

Material	f_m
Mild steel	1.0
Stainless type 304	1.4

Drying Gas	f_g
Hot air	0.00
Combustion gas (direct contact)	0.12
Combustion gas (indirect contact)	0.35

Materials	f_m
Mild steel	0.00
Lined with stainless 304–20%	0.25
Lined with stainless 316–20%	0.50

Spray dryers:

$C = F\exp[0.8403 + 0.8526(\ln x) - 0.0229(\ln x)^2]$,
$30 < x < 3000$ lb/hr evaporation

Material	F
Carbon steel	0.33
304, 321	1.00
316	1.13
Monel	3.0
Inconel	3.67

Multiple hearth furnaces (Hall et al., 1984)

$C = \exp(a + 0.88N)$, $4 < N < 14$ number of hearths

Diameter (ft)	6.0	10.0	14.25	16.75	18.75	22.25	26.75
Sqft/hearth, approx	12	36	68	119	172	244	342
a	5.071	5.295	5.521	5.719	5.853	6.014	6.094

9. Evaporators (IFP; also Chemical Engineers Handbook, p. 11.42)

Forced circulation: $C = f_m\exp[5.9785 - 0.6056(\ln A) + 0.08514(\ln A)^2]$, $150 < A < 8000$ sqft heat transfer surface

Long tube: $C = 0.36f_m A^{0.85}$, $300 < A < 20{,}000$ sqft

Falling film (316 internals, carbon steel shell)

$C = \exp[3.2362 - 0.0126(\ln A) + 0.0244(\ln A)^2]$, $150 < A < 4000$ sqft

Forced-Circulation Evaporators

Construction Material: Shell/Tube	f_m
Steel/copper	1.00
Monel/cupronickel	1.35
Nickel/nickel	1.80

Long-Tube Evaporators

Construction Material: Shell/Tube	f_m
Steel/copper	1.0
Steel/steel	0.6
Steel/aluminum	0.7
Nickel/nickel	3.3

10. Fired heaters, installed (Hall) K\$

Box type: $C = k(1 + f_d + f_p)Q^{0.86}$, $20 < Q < 200$ M Btu/hr

Tube Material	k
Carbon steel	25.5
CrMo steel	33.8
Stainless	45.0

Design Type	f_d
Process heater	0
Pyrolysis	0.10
Reformer (without catalyst)	0.35

Design Pressure, (psi)	f_p
Up to 500	0
1,000	0.10
1,500	0.15
2,000	0.25
2,500	0.40
3,000	0.60

Cylindrical type: $C = k(1 + f_d + f_p)Q^{0.82}$, $2 < Q < 30$ M Btu/hr

Tube Material	k
Carbon steel	27.3
CrMo steel	40.2
Stainless	42.0

(continued)

Design Type	f_d
Cylindrical	0
Dowtherm	0.33

Design Pressure (psi)	f_p
Up to 500	0
1,000	0.15
1,500	0.20

11. Heat exchangers

Shell-and-tube (Evans): $C = f_d f_m f_p C_b$, price in $

$$C_b = \exp[8.821 - 0.30863(\ln A) + 0.0681(\ln A)^2], \quad 150 < A < 12{,}000 \text{ sqft}$$

Type	f_d
Fixed-head	$\exp[-1.1156 + 0.0906(\ln A)]$
Kettle reboiler	1.35
U-tube	$\exp[-0.9816 + 0.0830(\ln A)]$

Pressure Range (psig)	f_p
100–300	$0.7771 + 0.04981(\ln A)$
300–600	$1.0305 + 0.07140(\ln A)$
600–900	$1.1400 + 0.12088(\ln A)$

Material	$f_m = g_1 + g_2(\ln A)$	
	g_1	g_2
Stainless steel 316	0.8603	0.23296
Stainless steel 304	0.8193	0.15984
Stainless steel 347	0.6116	0.22186
Nickel 200	1.5092	0.60859
Monel 400	1.2989	0.43377
Inconel 600	1.2040	0.50764
Incoloy 825	1.1854	0.49706
Titanium	1.5420	0.42913
Hastelloy	0.1549	0.51774

Double pipe (IFP): $C = 900 f_m f_p A^{0.18}$, $2 < A < 60$ sqft, price in $

Material: Shell/Tube	f_m
cs/cs	1.0
cs/304L stainless	1.9
cs/316 stainless	2.2

Pressure (bar)	f_p
<4	1.00
4–6	1.10
6–7	1.25

Air coolers (Hall): $C = 24.6A^{0.40}$, $0.05 < A < 200$ K sqft, price in K$

12. Mechanical separators

Centrifuges: solid bowl, screen bowl or pusher types

$C = a + bW$, K$

	Inorganic Process		Organic Process	
Material	a	b	a	b
Carbon steel	42	1.63	—	—
316	65	3.50	98	5.06
Monel	70	5.50	114	7.14
Nickel	84.4	5.56	143	9.43
Hastelloy	—	—	300	10.0
	$10 < W < 90$		$5 < W < 40$ tons/hr	

Disk separators, 316 stainless (IFP):

$C = 8.0Q^{0.52}$, $15 < Q < 150$ gpm, K$

Cyclone separators (IFP): K$

heavy duty: $C = 1.39Q^{0.98}$, $2 < Q < 40$ K SCFM

standard duty: $C = 0.65Q^{0.91}$, $2 < Q < 40$ K SCFM

multiclone: $C = 1.56Q^{0.98}$, $9 < Q < 180$ K SCFM

Filters (Hall), prices in $/sqft:

rotary vacuum belt discharge: $C = \exp[11.20 - 1.2252(\ln A) + 0.0587(\ln A)^2]$, $10 < A < 800$ sqft

rotary vacuum drum scraper discharge: $C = \exp[11.27 - 1.3408(\ln A) + 0.0709(\ln A)^2]$ $/sqft, $10 < A < 1500$ sqft

rotary vacuum disk: $C = \exp[10.50 - 1.008(\ln A) + 0.0344(\ln A)^2]$ $/sqft, $100 < A < 4000$ sqft

horizontal vacuum belt: $C = 28300/A^{0.5}$ $/sqft, $10 < A < 1200$ sqft

pressure leaf: $C = 695/A^{0.29}$ $/sqft, $30 < A < 2500$ sqft

plate-and-frame: (*Chemical Engineers' Handbook*):

$C = 460/A^{0.45}$ $/sqft, $10 < A < 1000$ sqft

vibrating screen (IFP): $C = 3.1A^{0.68}$ K$, $0.5 < A < 35$ sqft

13. Motors and couplings, prices in $

Motors: $C = 1.2\exp[a_1 + a_2(\ln HP) + a_3(\ln HP)^2]$

Belt drive coupling: $C = 1.2\exp[3.689 + 0.8917(\ln HP)]$

Chain drive coupling: $C = 1.2\exp[5.329 + 0.5048(\ln HP)]$

Variable speed drive coupling:

$C = 12{,}000/(1.562 + 7.877/HP)$, $HP < 75$

Type	Coefficients a_1	a_2	a_3	HP limit
Open, drip-proof				
3600 rpm	4.8314	0.09666	0.10960	1–7.5
	4.1514	0.53470	0.05252	7.5–250
	4.2432	1.03251	−0.03595	250–700
1800 rpm	4.7075	−0.01511	0.22888	1–7.5
	4.5212	0.47242	0.04820	7.5–250
	7.4044	−0.06464	0.05448	250–600
1200 rpm	4.9298	0.30118	0.12630	1–7.5
	5.0999	0.35861	0.06052	7.5–250
	4.6163	0.88531	−0.02188	250–500
Totally enclosed, fan-cooled				
3600 rpm	5.1058	0.03316	0.15374	1–7.5
	3.8544	0.83311	0.02399	7.5–250
	5.3182	1.08470	−0.05695	250–400
1800 rpm	4.9687	−0.00930	0.22616	7.5–250
	4.5347	0.57065	0.04609	250–400
1200 rpm	5.1532	0.28931	0.14357	1–7.5
	5.3858	0.31004	0.07406	7.5–350
Explosion-proof				
3600 rpm	5.3934	−0.00333	0.15475	1–7.5
	4.4442	0.60820	0.05202	7.5–200
1800 rpm	5.2851	0.00048	0.19949	1–7.5
	4.8178	0.51086	0.05293	7.5–250
1200 rpm	5.4166	0.31216	0.10573	1–7.5
	5.5655	0.31284	0.07212	7.5–200

14. Pumps

Centrifugal (Evans) prices in $: $C = F_M F_T C_b$, base cast-iron, 3560 rpm VSC

$$C_b = 1.55\exp[8.833 - 0.6019(\ln Q\sqrt{H}) + 0.0519(\ln Q\sqrt{H})^2], \quad Q \text{ in gpm}, \quad H \text{ in ft head}$$

Material	Cost Factor F_M
Cast steel	1.35
304 or 316 fittings	1.15
Stainless steel, 304 or 316	2.00
Cast Gould's alloy no. 20	2.00
Nickel	3.50
Monel	3.30
ISO B	4.95
ISO C	4.60
Titanium	9.70
Hastelloy C	2.95
Ductile iron	1.15
Bronze	1.90

$$F_T = \exp[b_1 + b_2(\ln Q\sqrt{H}) + b_3(\ln Q\sqrt{H})^2]$$

(continued)

Equipment	Multiplier	Equipment	Multiplier
Cyclones	1.4	Pumps, centrifugal, carbon steel	2.8
Dryers, spray and air	1.6	centrifugal, stainless steel	2.0
other	1.4	centrifugal, Hastelloy trim	1.4
Ejectors	1.7	centrifugal, nickel trim	1.7
Evaporators, calandria	1.5	centrifugal, Monel trim	1.7
thin film, carbon steel	2.5	centrifugal, titanium trim	1.4
thin film, stainless steel	1.9	all others, stainless steel	1.4
Extruders, compounding	1.5	all others, carbon steel	1.6
Fans	1.4	Reactor kettles, carbon steel	1.9
Filters, all types	1.4	kettles, glass lined	2.1
Furnaces, direct fired	1.3	kettles, carbon steel	1.9
Gas holders	1.3	Reactors, multitubular, stainless steel	1.6
Granulators for plastic	1.5	multitubular, copper	1.8
Heat exchangers, air cooled, carbon steel	2.5	multitubular, carbon steel	2.2
coil in shell, stainless steel	1.7	Refrigeration plant	1.5
glass	2.2	Steam drums	2.0
graphite	2.0	Sum of equipment costs, stainless steel	1.8
plate, stainless steel	1.5	Sum of equipment costs, carbon steel	2.0
plate, carbon steel	1.7	Tanks, process, stainless steel	1.8
shell and tube, stainless/stainless steel	1.9	Tanks, process, copper	1.9
shell and tube, carbon/stainless steel	2.1	process, aluminum	2.0
Heat exchangers, shell and tube, carbon steel/aluminum	2.2	storage, stainless steel	1.5
shell and tube, carbon steel/copper	2.0	storage, aluminum	1.7
shell and tube, carbon steel /Monel	1.8	storage, carbon steel	2.3
shell and tube, Monel/Monel	1.6	field erected, stainless steel	1.2
shell and tube, carbon steel/Hastelloy	1.4	field erected, carbon steel	1.4
Instruments, all types	2.5	Turbines	1.5
Miscellaneous, carbon steel	2.0	Vessels, pressure, stainless steel	1.7
stainless steel	1.5	pressure, carbon steel	2.8

Table A.7: Typical overall Coefficients

Shell and tube exchangers		
Hot fluid	Cold fluid	U (W/m^2°C)
Heat exchangers		
Water	Water	800–1500
Organic solvents	Organic solvents	100–300
Light oils	Light oils	100–400
Heavy oils	Heavy oils	50–300
Gases	Gases	10–50
Coolers		
Organic solvents	Water	250–750
Light oils	Water	350–900
Heavy oils	Water	60–300
Gases	Water	20–300
Organic solvents	Brine	150–500
Water	Brine	600–1200
Gases	Brine	15–250
Heaters		
Steam	Water	1500–4000
Steam	Organic solvents	500–1000
Steam	Light oils	300–900
Steam	Heavy oils	60–450
Steam	Gases	30–300
Dowtherm	Heavy oils	50–300
Dowtherm	Gases	20–200
Flue gases	Steam	30–100
Flue	Hydrocarbon vapours	30–100
Condensers		
Aqueous vapours	Water	1000–1500
Organic vapours	Water	700–1000
Organics (some non-condensables)	Water	500–700
Vacuum condensers	Water	200–500
Vaporisers		
Steam	Aqueous solutions	1000–1500
Steam	Light organics	900–1200
Steam	Heavy organics	600–900

Table A.8: Fouling Factors

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.9: Constants to Use in Equation

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.10: Typical Baffle Clearances

Shell diameter, D_s	Baffle diameter	Tolerance
Pipe shells		
6 to 25 in. (152 to 635 mm)	$D_s - \frac{1}{16}$ in. (1.6 mm)	$+\frac{1}{32}$ in. (0.8 mm)
Plate shells		
6 to 25 in. (152 to 635 mm)	$D_s - \frac{1}{8}$ in. (3.2 mm)	$+0, -\frac{1}{32}$ in. (0.8 mm)
27 to 42 in. (686 to 1067 mm)	$D_s - \frac{3}{16}$ in. (4.8 mm)	$+0, -\frac{1}{16}$ in. (1.6 mm)

Table A.11: 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

Appendix-B

Figures

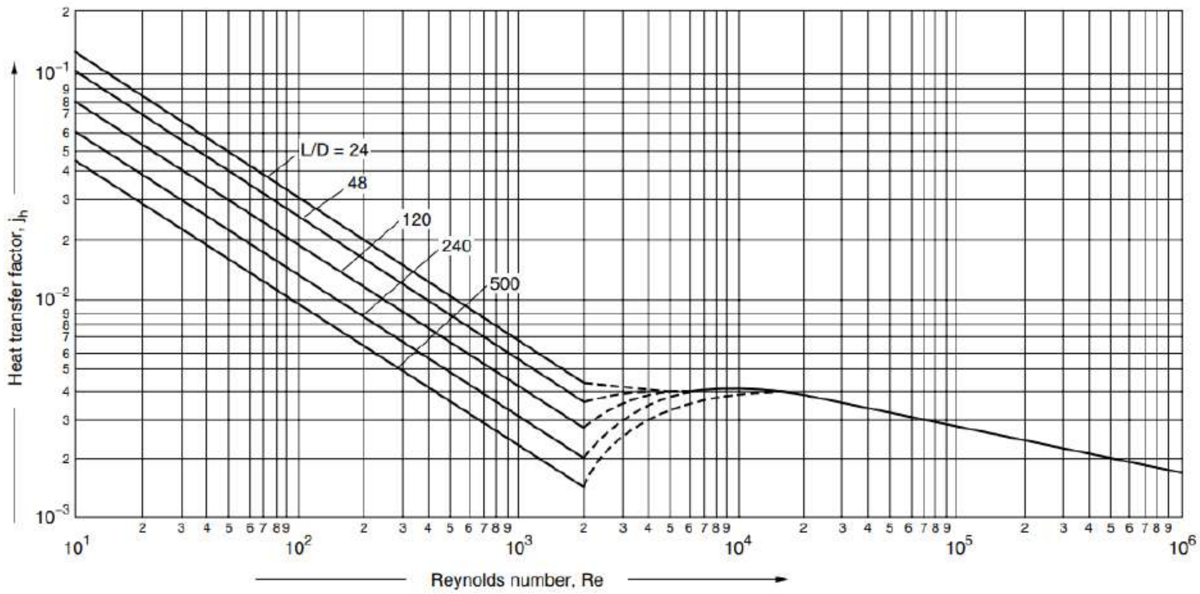


Figure B.1: Tube Side Heat Transfer Factor

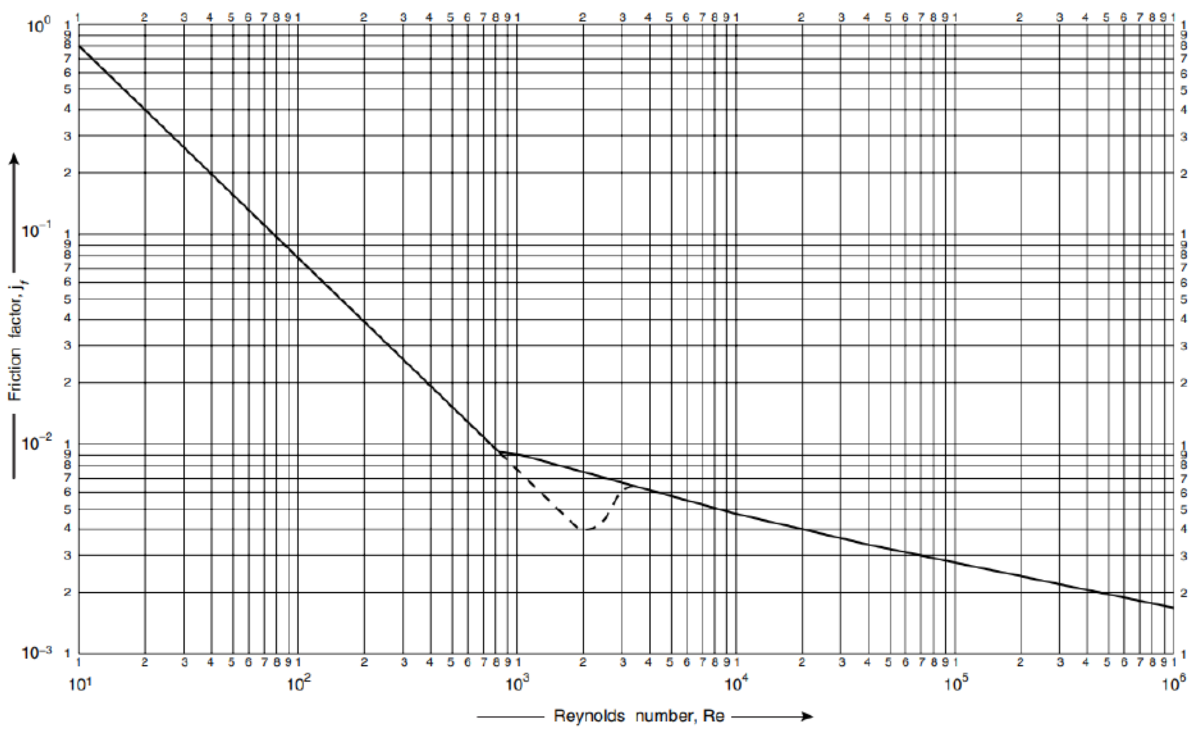


Figure B.2: Tube side Friction Factor

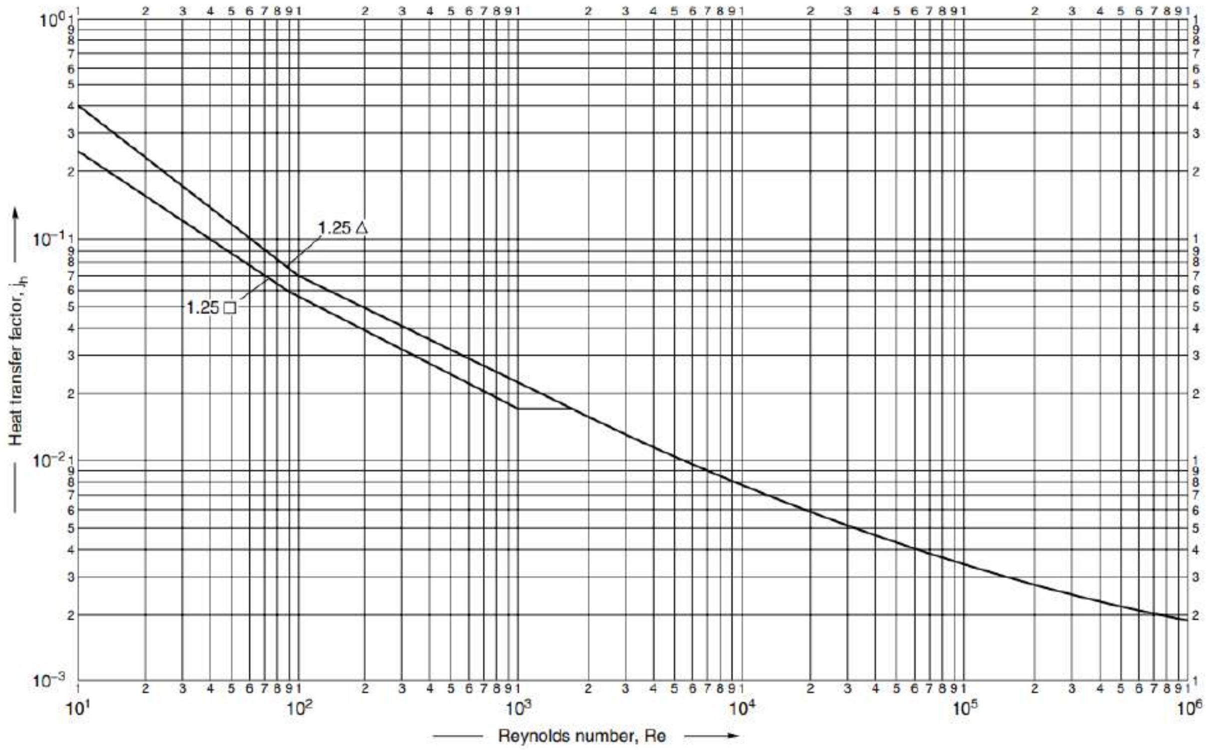


Figure B.3: Heat Transfer Factor for Crossflow Tube Banks

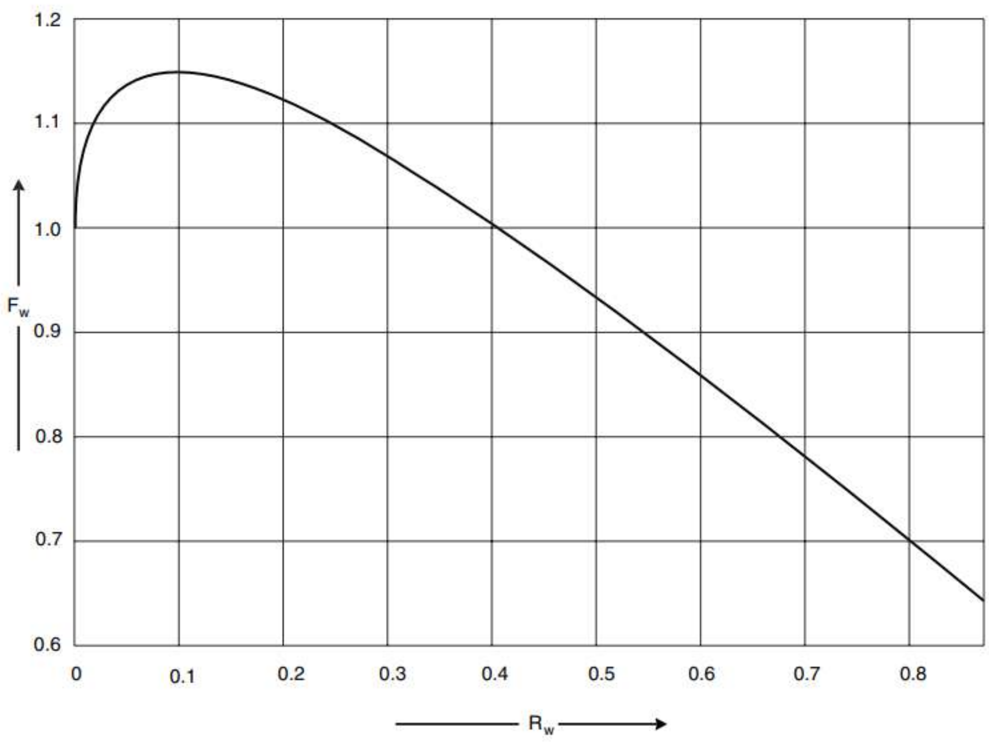


Figure B.4: Window Correction Factor

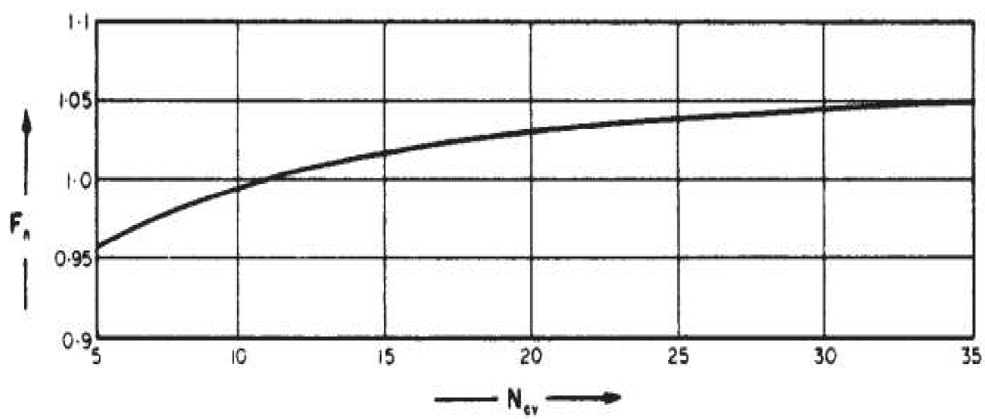


Figure B.5: Tube Row Correction Factor

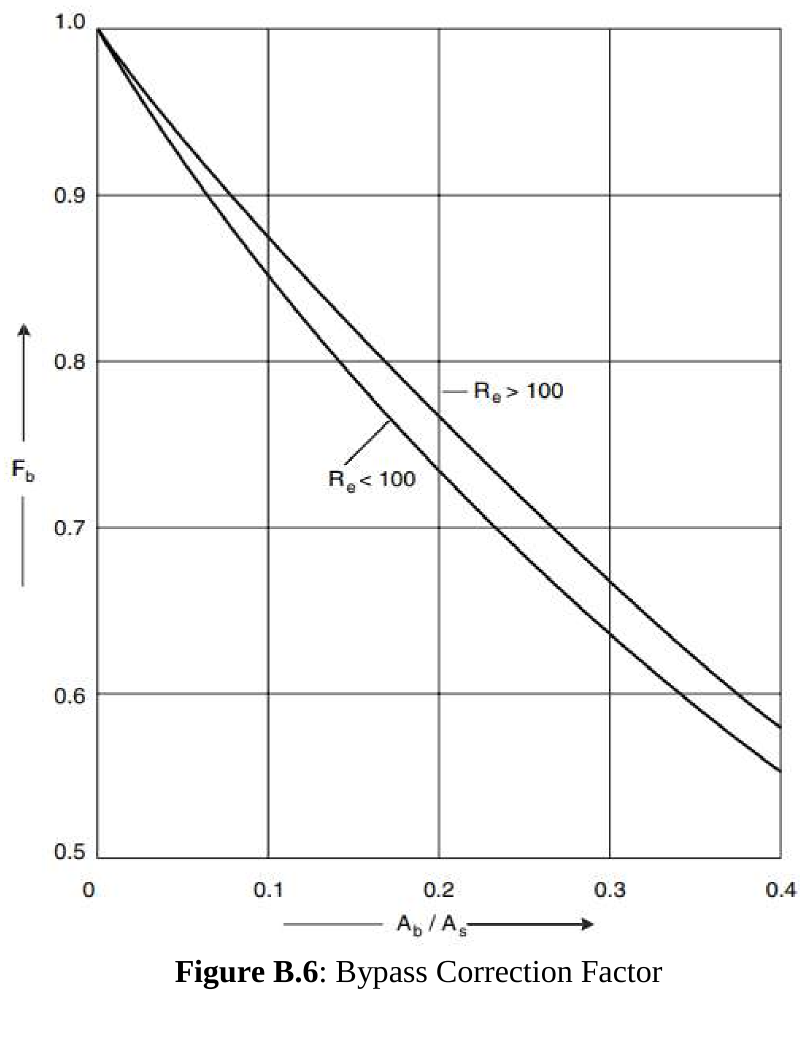


Figure B.6: Bypass Correction Factor

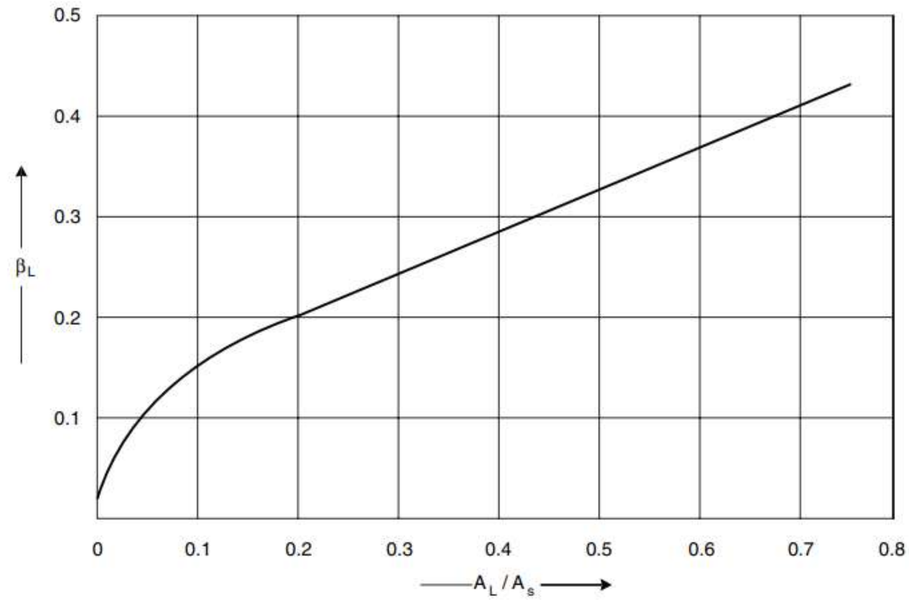


Figure B.7: Coefficient of F_L

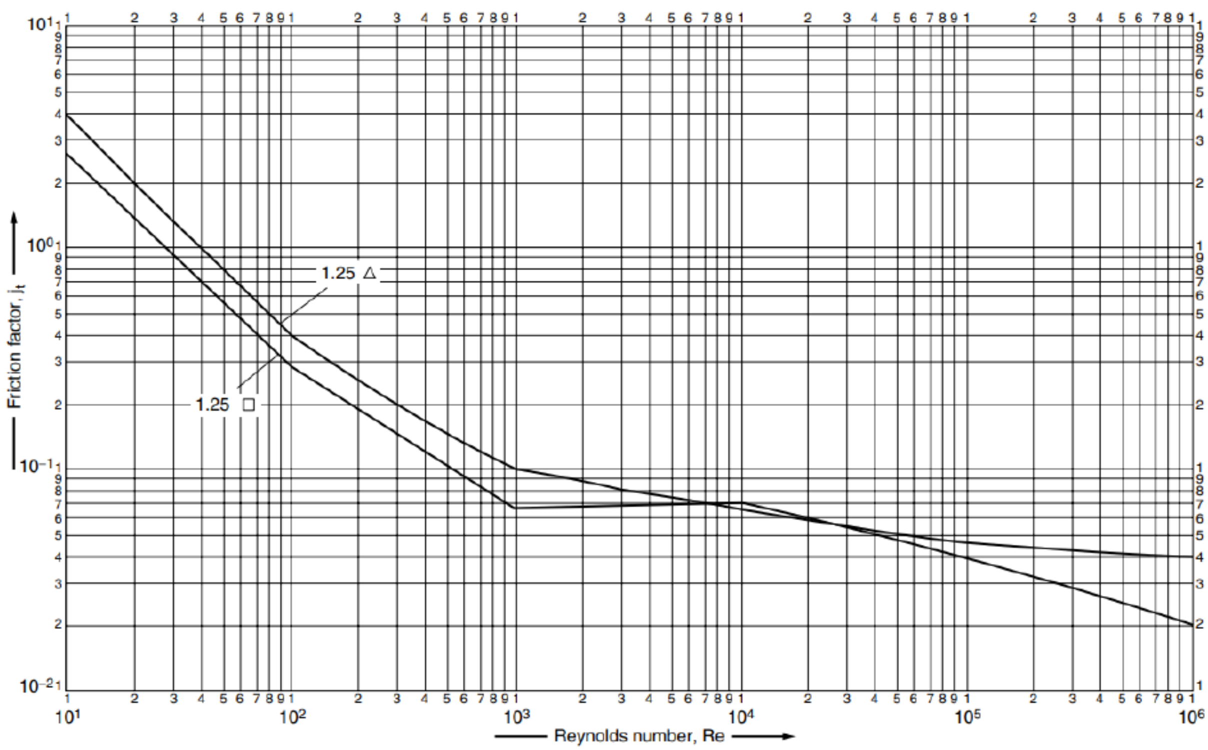


Figure B.8: Friction Factor for Crossflow Tube Banks

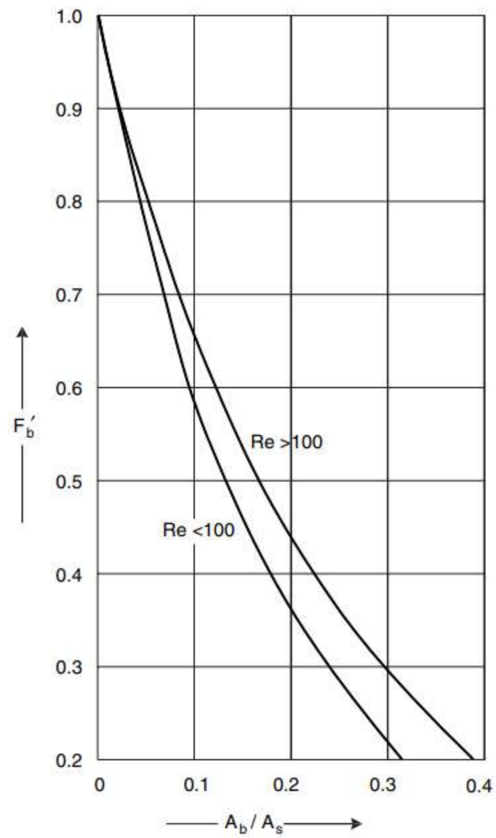


Figure B.9: Bypass Factor for Pressure Drop

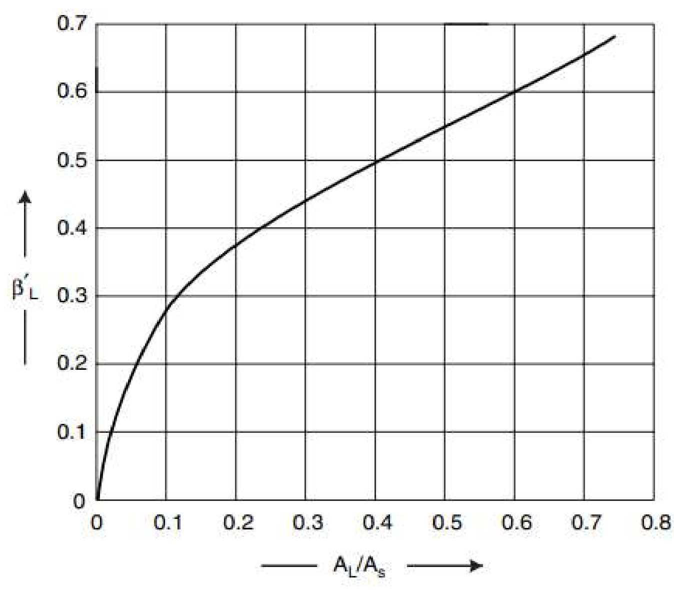


Figure B.10: Correction F_L' for Pressure Drop

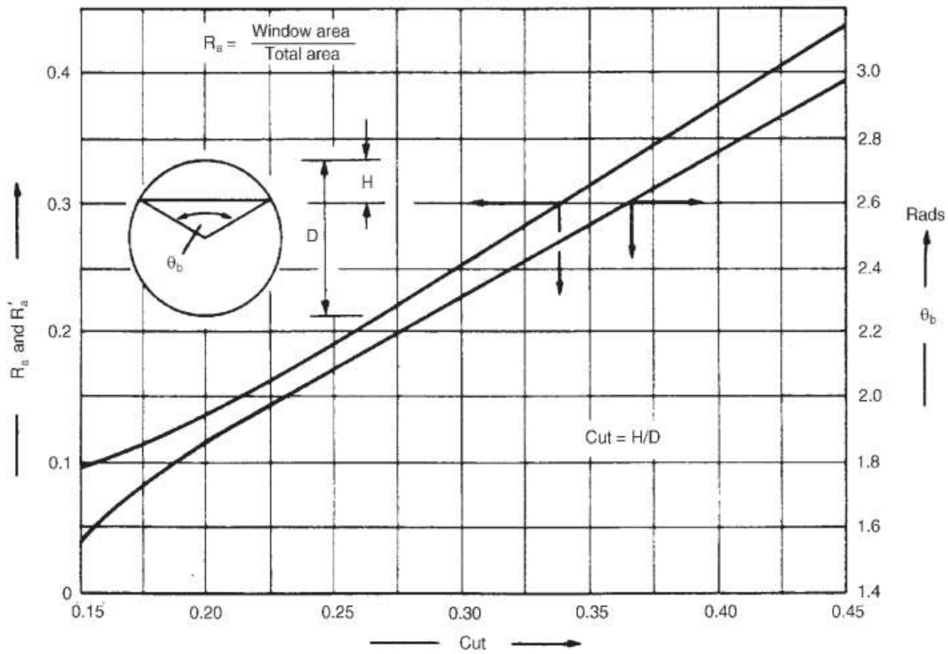


Figure B.11: Baffle Geometrical Factors

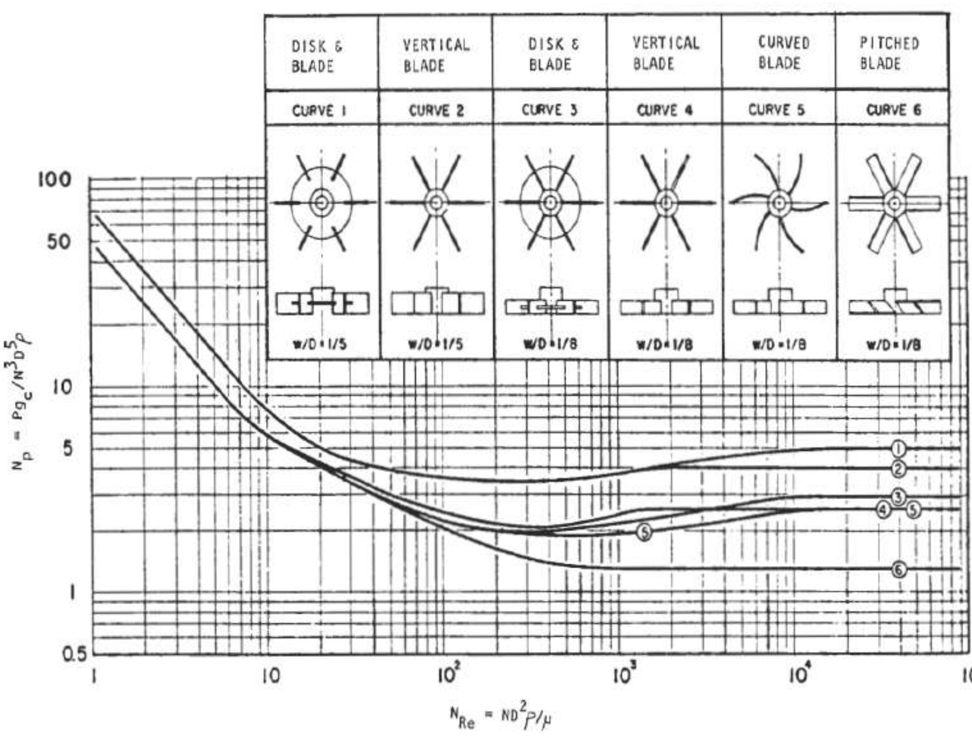


Figure **B.12:** Power Number vs Reynolds Number Graph

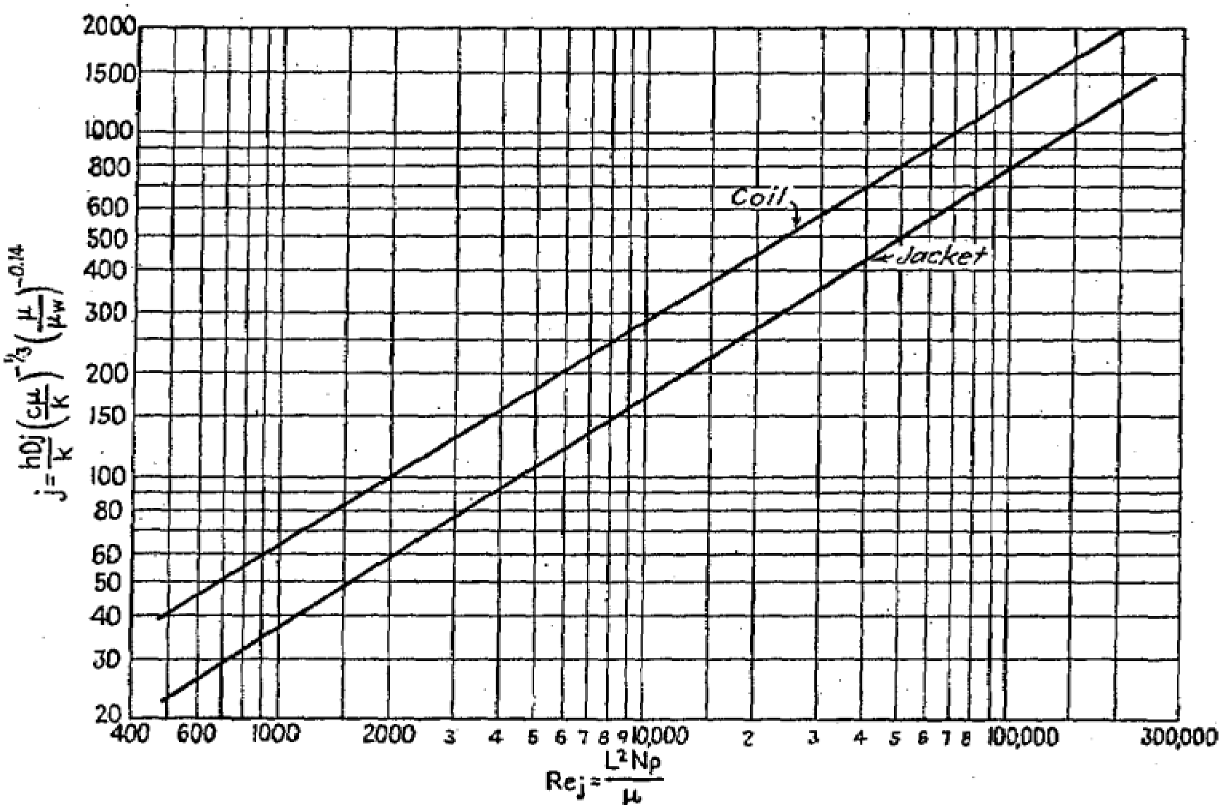


Figure B.13: J_H factor for Jackets

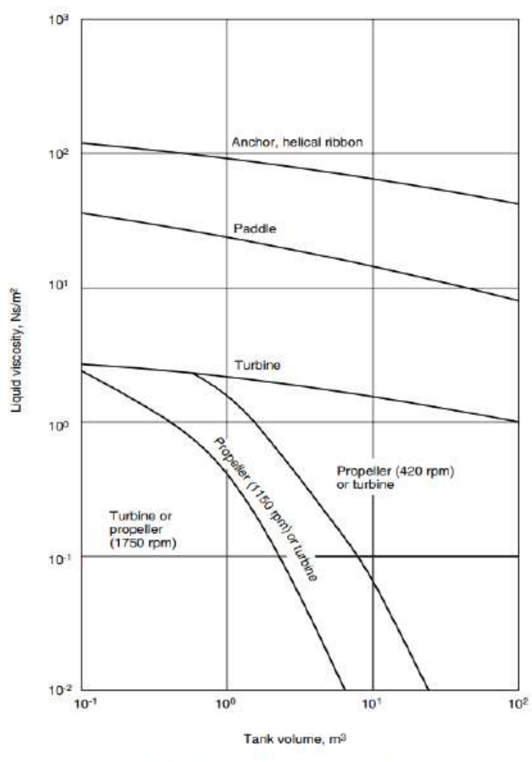


Figure B.14: Agitator Selection

	Feed conditions							Suitable for heat-sensitive materials
	Viscosity, mN s/m^2							
Evaporator type	Very viscous > 1000	Medium viscosity < 1000 max	Low viscosity < 100	Foaming	Scaling or fouling	Crystals produced	Solids in suspension	
Recirculating Calandria (short vertical tube)		↔	↔	↔	↔	↔	↔	No
Forced circulation		↔	↔	↔	↔	↔		Yes
Falling film			↔					No
Natural circulation			↔	↔				No
Single pass wiped film	↔	↔	↔	↔	↔	↔	↔	Yes
Tubular (long tube) Falling film			↔					Yes
Rising film			↔	↔				Yes

Figure B.15: Evaporator Selection

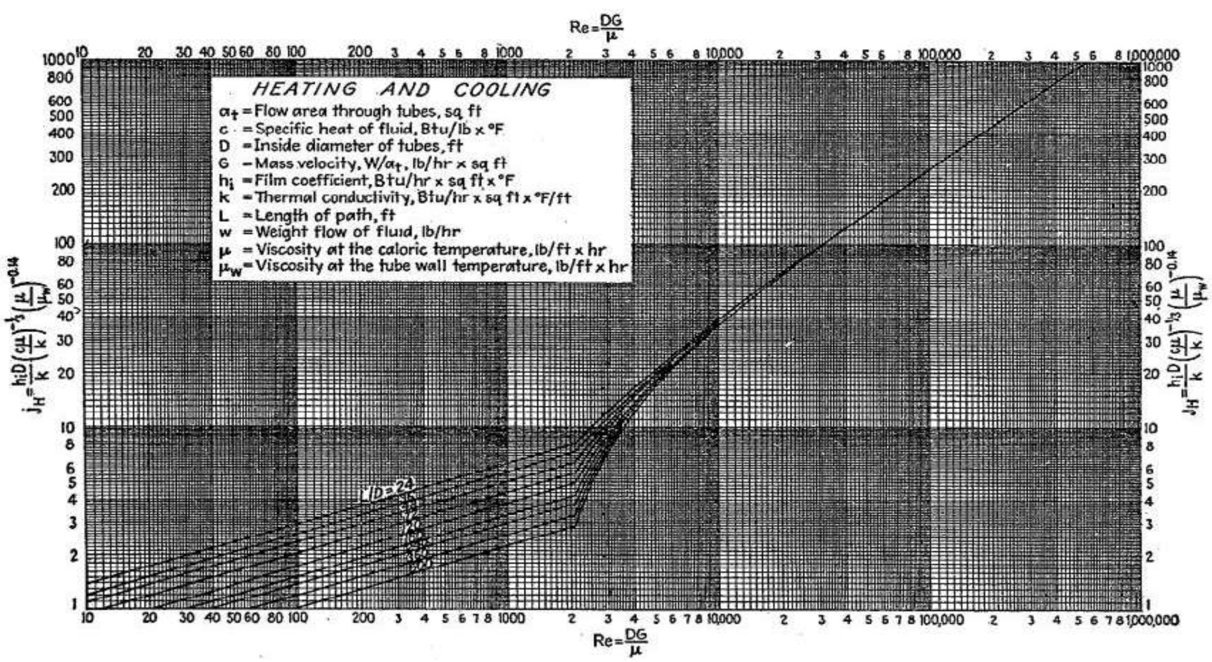


Figure B.16: Tube Side Heat Transfer curve

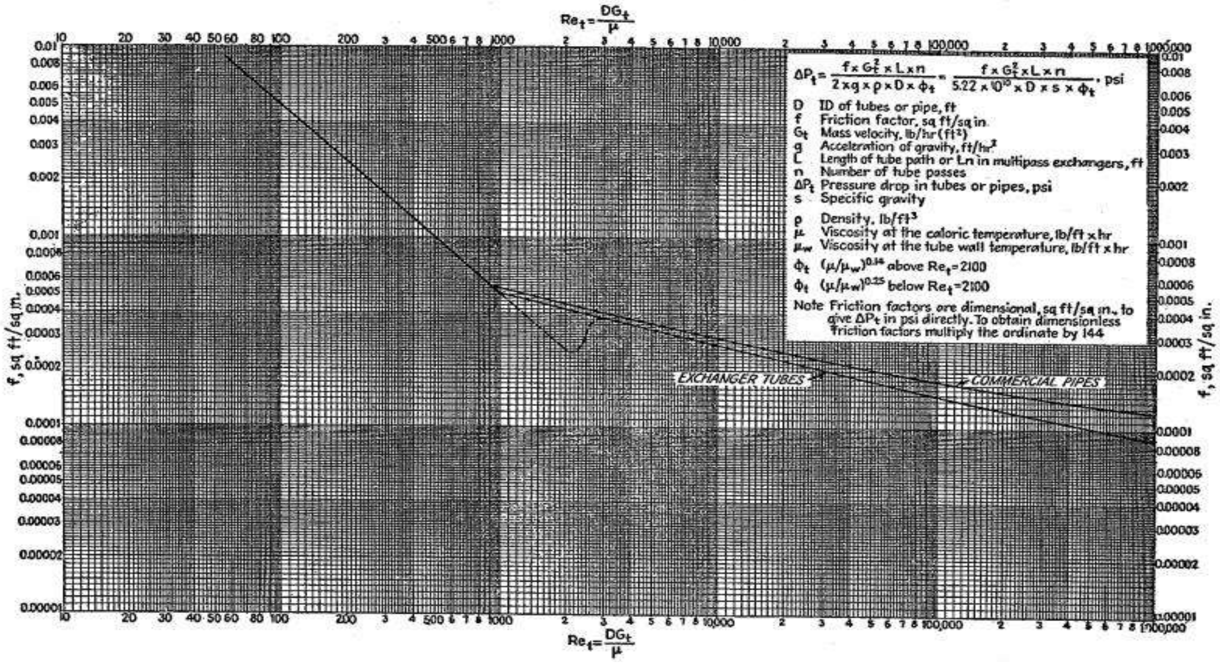


Figure B.17: Tube Side Friction factor

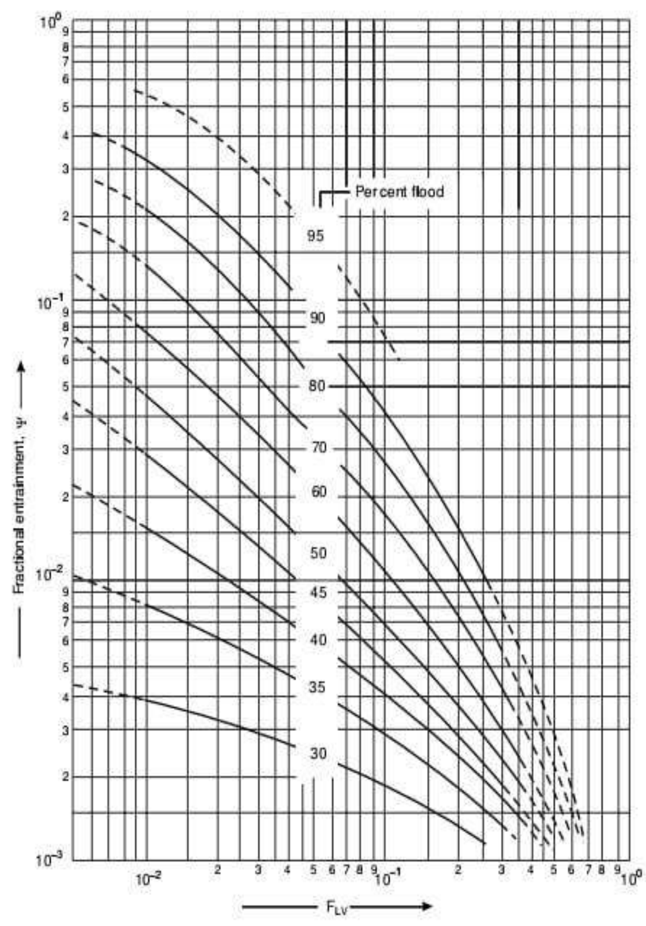


Figure B.18: Entrainment Correlation

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