PRODUCTION OF 35000 TPA OF 1-TETRADECENE BY THERMAL CRACKING OF PALMITIC ACID

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This report is submitted to the Department of Chemical Engineering, Wah Engineering College, University of Wah for the partial fulfilments of the requirement for the

Bachelor of Science
In
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ABSTRACT

1-Tetradecene, also known as alpha-tetradecene (C14H28), is a significant organic compound manufactured worldwide for its applications in lubricants, detergents, and specialty chemicals. This project focuses on the production of 1-Tetradecene through the thermal cracking of palmitic acid, distinct from the conventional method involving ethylene oligomerization ziegler processes. The manufacturing process involves thermal cracking of palmitic acid, followed by filtration and distillation steps for separation and purification.

The import data from the Pakistan Bureau of Statistics indicates that Pakistan imported 32,242 metric tons of alpha-tetradecene in 2022. Extrapolating this data suggests that the demand for alpha-tetradecene is projected to reach 35,000 metric tons annually by 2027. Therefore, the project aims to establish a production facility capable of manufacturing 35,000 metric tons per year of 1-Tetradecene.Palmitic acid, derived from palm oil, serves as the feedstock for this manufacturing process, making it resource-efficient. Detailed estimates were conducted for all equipment in the facility, including installation costs, considering the process requirements necessary to achieve the target production capacity of alpha-Tetradecene. Material balance calculations were performed to determine the raw material requirements for achieving the desired production rate.

Energy balance calculations were used to calculate the heating and cooling duties of different equipment in the facility. Material and energy balances played a crucial role in the design of various equipment, and their feasibility was assessed using simulation software, such as Aspen Plus, presented in separate chapters of this report.Economic analysis was conducted to estimate the payback period of approximately 3 years, taking into account equipment costs and compliance with environmental regulations. Furthermore, a Hazard and Operability (HAZOP) analysis was performed to ensure safety and mitigate potential hazards in the manufacturing process.

The report concludes with detailed references and appendices, providing readers with additional information, including standard tables and charts. The project's successful implementation will contribute to Pakistan's self-sufficiency in 1-Tetradecene production, reducing import dependency and promoting domestic industrial growth.

Keywords: 1-Tetradecene, Palmitic acid thermal cracking, Lubricant manufacturing

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CHAPTER 1

LITERATURE SURVEY

1.1 Introduction

Oils are generally chemicals that are used in various industries, especially in paints industries. There are three classifications of oils:

- Drying oils
- Non-drying oils
- Semi-drying oils

They are classified by their ability to absorb iodine per 100 grams of oil-also known as the iodine value (IV). Drying oils are majorly used as additives to chemical paints and varnishes in order to aid in the drying processes of these chemicals when applied onto the surface as finishes. Drying oil can be produced from various sources such as acetylated castor oil, ethylene. The feed is modelled as palmitic acid- or acetylated castor oil- for its availability and the ease of processing it into drying oil. The drying oil is modelled as 1-tetradecene

1.1.1 1-Tetradecene

The aim of the project is to design a chemical plant that can produce drying oil from Acetylated Castor Oil -also known as Palmitic Acid.

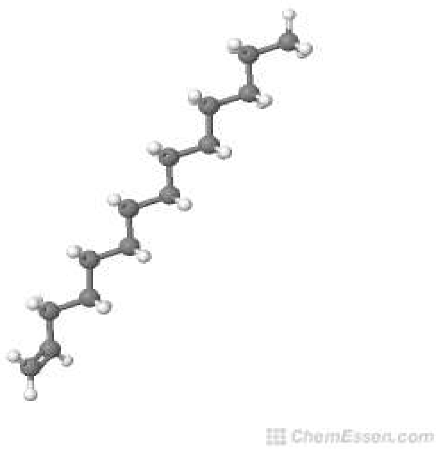


Figure 1-1: Structure of 1-Tetradecene

For the production of drying oil, there are two main reactions. First decomposition of Palmitic Acid into Acetic Acid and 1-tetradecene. Second reaction produces gum (1-octacosene) as a byproduct. Moreover, recent developed process introduced the production of the drying oil (1-tetradecene) through the thermal cracking of acetylated castor oil.

1.1.2 Acetic Acid

It is commonly called ethanoic acid. It is a clear transparent liquid organic compound which is also known as glacial acetic acid when diluted. It is fundamental ingredient of vinegar that is unique sour in taste and smell is pungent. The chemical formula of an acetic acid is CH_3COOH and has a methyl group combined with a carboxyl group which is important chemical reagent used in formation of photographic film called polyvinyl acetate for glue used for wood nonetheless cellulose acetate is used for production of synthetic fibers or fabrics.

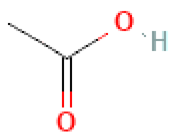


Figure 1-2: Structure of Acetic Acid

It is a weak acid, but the concentrated acetic acid is corrosive as well as harm as it attacks the skin. Acetic acid is also utilized as an important raw material. It is also used as a solvent in the manufacturing of many chemical products, oil, gas, food and pharmaceutical industry.

1.1.3 Palmitic Acid

Saturated long chains fatty acid palmitic acid has a 16-carbon backbone. It accounts for up to 44 percent of the total lipids in the oil extracted from oil palm fruit, In addition, palmitic acid, which makes up 50–60% of all fats in meat, cheese, butter, & other dairy items. Esters and salts of palmitic acid are known as palmitates. When the pH is physiological, palmitic acid is seen as the palmitate anion (7.4).

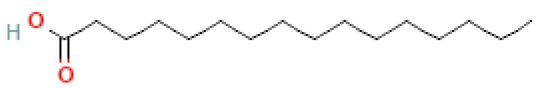


Figure 1-3: Structure of Palmitic Acid

A vast variety of different plants and species make palmitic acid, usually in little amounts. Along with cocoa butter, soybean oil, olive oil, and sunflower oil, it may be found in cheese, butter, milk, & meat. Palmitic acid makes for 44.90% of karukas. Spermaceti contain Cetyl palmitate, which is the acetyl ester of palmitic acid. Industrial mould release agents, cosmetics, and soaps are all made with palmitic acid. Sodium palmitate frequently produced by saponifying palm oil, is used in several applications. For this purpose, sodium hydroxide is used to process palm oil, which is extracted from palm trees. This causes the ester groups to hydrolyze, releasing sodium palmitate & glycerol.

1.2 Physical Properties & Thermodynamic data

1.2.1 Reactant

Table 1-1 Properties of Reactants

Property Name	Palmitic Acid
Molecular Formula	$C_{16} H_{32} O_2$
Molecular Weight	256.42
Boiling Point	351.5 °C
Density	0.8527 g/ml
Critical Temperature	785.22 K
Critical Pressure	14.68 bar
Melting Point	62.5 °C
Flash Point	206 °C
Appearance	White Crystals, liquids

1.2.2 Products

Table 1-2 Properties of Products

Name	Acetic Acid	1-Tetradecene
Molecular Formula	CH_3COOH	$C_{14}H_{28}$
Molecular Weight	60.05	196.38
Boiling Point	118 °C	252 °C
Density	1.049 g/ml	0.775 g/ml
Critical Temperature	594 K	678.61 K
Critical Pressure	57.8 bar	15.74 bar
Melting Point	16.6 °C	-13-11°C
Flash Point	39 °C	110 °C
Appearance	Colorless Liquid	Colorless Liquid

1.3 Reactions of the Product

$$C_{15}H_{31}COOH\ (l) \overset{k_1}{\rightarrow} CH_3COOH\ (g) + C_{14}H_{28}(l)$$

Acetylated Castor Oil   Acetic Acid   1-Tetradecene

(Drying Oil)

$$2C_{14}H_{28}\ (l) \overset{k_2}{\rightarrow} C_{28}H_{56}(s)$$

1-Tetradecene   1-octacosene

(Drying Oil)   (Gum)

1.4 Industrial Applications

1-Tetradecene, a long-chain linear alpha-olefin, finds applications across various industries. Here are some of the key applications:

1.4.1 Surfactants and Detergents:

1-Tetradecene is used as a key raw material in the production of surfactants, which are essential components in detergents, cleaning agents, and personal care products (Sánchez et al., 2017).

1.4.2 Lubricants and Additives:

It serves as a base oil and lubricant additive, providing improved lubricity and viscosity characteristics to enhance the performance of lubricants and industrial oils (Moser et al., 2014).

1.4.3 Polyethylene Production:

1-Tetradecene is employed as a comonomer in the production of high-density polyethylene (HDPE) and linear low-density polyethylene (LLDPE), contributing to improved mechanical properties and processability (Plaza et al., 2016).

1.4.4 Polymerization Reactions:

It serves as a reactive monomer in polymerization reactions, allowing the production of various specialty polymers such as high-performance elastomers, synthetic waxes, and adhesives (Zhang et al., 2018).

1.4.5 Cosmetics and Personal Care Products:

Due to its unique properties, 1-Tetradecene is used in the formulation of cosmetics, skincare products, hair care products, and other personal care items (Sharma et al., 2019).

1.4.6 Agricultural Applications:

It finds use in agricultural applications as an adjuvant in pesticide formulations, aiding in the dispersion and improved efficacy of active ingredients

1.4.7 Industrial Chemicals:

1-Tetradecene is utilized as a precursor in the synthesis of various industrial chemicals, including plasticizers, antioxidants, specialty chemicals, and fragrance compounds

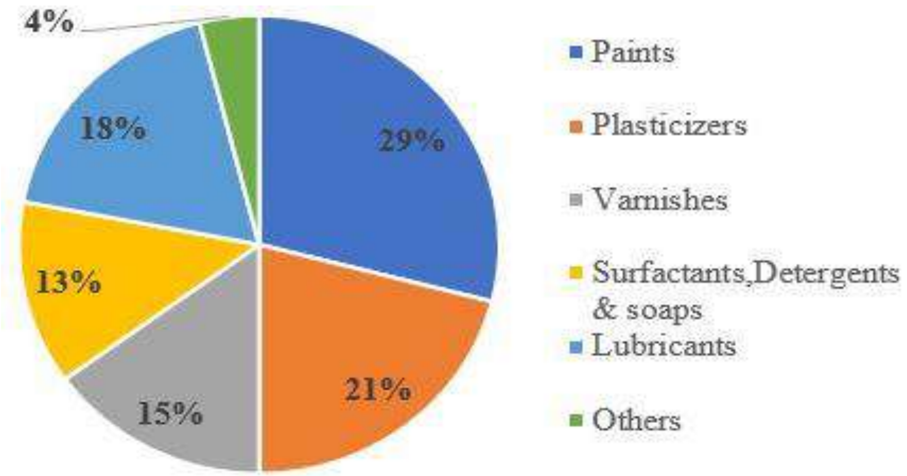


Figure 1-4: Applications of 1-Tetradecene

1.5 Handling, Storage & Safety Measures

1.5.1 Handling

Handling Advice on safe handling:

Handling Advice for handling safely: Avoid inhaling dust or mist. See section 8 for details on personal safety. The application area should be off-limits to eating, drinking, and smoking. In compliance with local and federal rules, dispose of rinse water. Advice on avoiding fire and explosions: common practices for fire prevention. Storage Conditions for storage: Keep the container securely shut and in a dry, well-ventilated area.

1.5.2 Storage

Keep away from heat, flame, oxidising substances, and sources of ignition. When not in use, keep containers closed.

1.5.3 Safety Measures

- INHALATION: Head for some fresh air. Get medical help right now.
- EYE CONTACT: Rinse eyes for 10-15 minutes with tap water. If inflammation continues, get immediate medical help.
- SKIN CONTACT: Wash the skin with water &soap after rinsing.
- IF SWALLOWED: Avoid making yourself throw up if you have. Aspirational Risk. Dial a doctor's number or a poison control center right away. Get medical help right now.

1.6 Shipping of the product

- ✓ US DOT: Not subject to regulation as a hazardous substance or dangerous good for transportation from this organization.
- ✓ IMDG (International Marine Dangerous Commodities): This organization does not regulate these items as hazardous materials or dangerous materials for transit.
- ✓ IATA, International Air Transport Association does not control the movement of risky products or hazardous materials.
- ✓ The organization does not regulate these items as hazardous materials or dangerous products for transportation, according to the ADR (Agreement for Dangerous Substances By Road (Europe)).
- ✓ The organization does not regulate any substances as hazardous materials or dangerous goods for shipment under RID (Regulations Concerning International Dangerous Goods Transport (Europe)).
- ✓ The ADN does not regulated as a dangerous materials, European Agreement Concerning International Carriage of Dangerous substances By Inland Waterways)

1.7 Production & Consumption data of Product

Following regions and respective countries data is covered by the scope 1 Tetradecene market research report

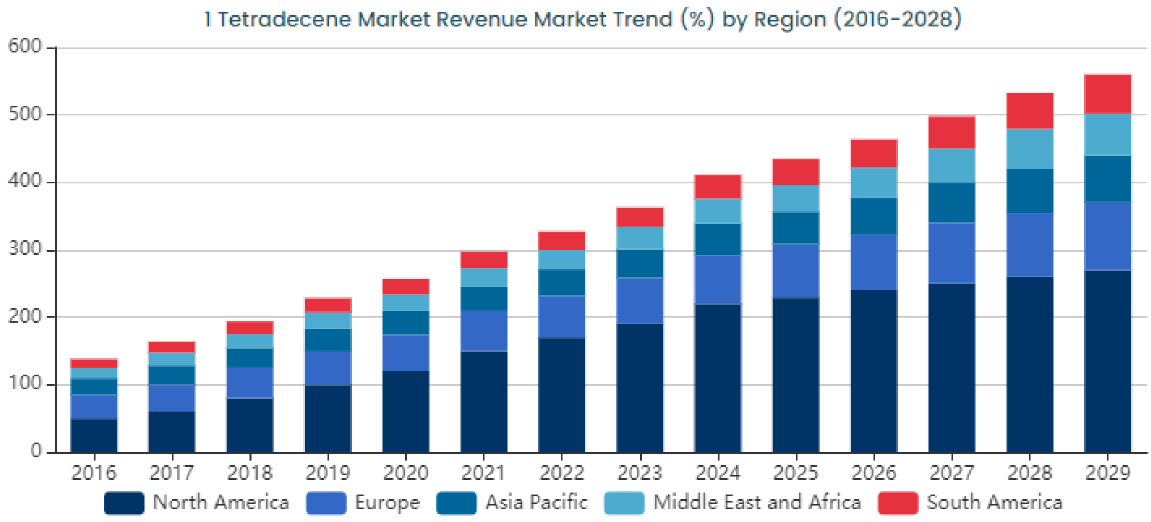


Figure 1-5 1Tetradecene Market revenue market trend (%) by Region (2016 – 2028)

The direct alpha olefins market has been sectioned into 1-butene/hexene/octene/decene, /dodecane/tetradecene/hexadecene, as well as other higher olefins. Expanding the use of poly alpha-olefins in the bundling business is projected to drive the worldwide straight alpha olefins market. Developing interests in research for the improvement of straight alpha-olefins are setting out new development open doors on the lookout.

Figure 1-6: Global Linear Alpha Olefins Market (2020-2026)

The market size of alpha-olefins is advocated to arrive at USD 13,464.2 million by 2022 from 8,761 million US dollars in around 2016, at Compound Annual Growth Rate, (C-A-G-R) of 7.8%. The highking of interest in enterprises like plastic as well as auto is leading the market for the alpha olefins.

Shell, Sasol LTD, Qatar Chemical Company Ltd, Chevron Phillips Chemical Company, Hidemitsu Kosan Co., Ltd., Linde, INEOS AG, and PJSC are a portion of the significant powers in the direct alpha olefins industry. To upgrade their territorial impression, they participate in consolidations and acquisitions, joint efforts, arrangements, associations, and item dispatches

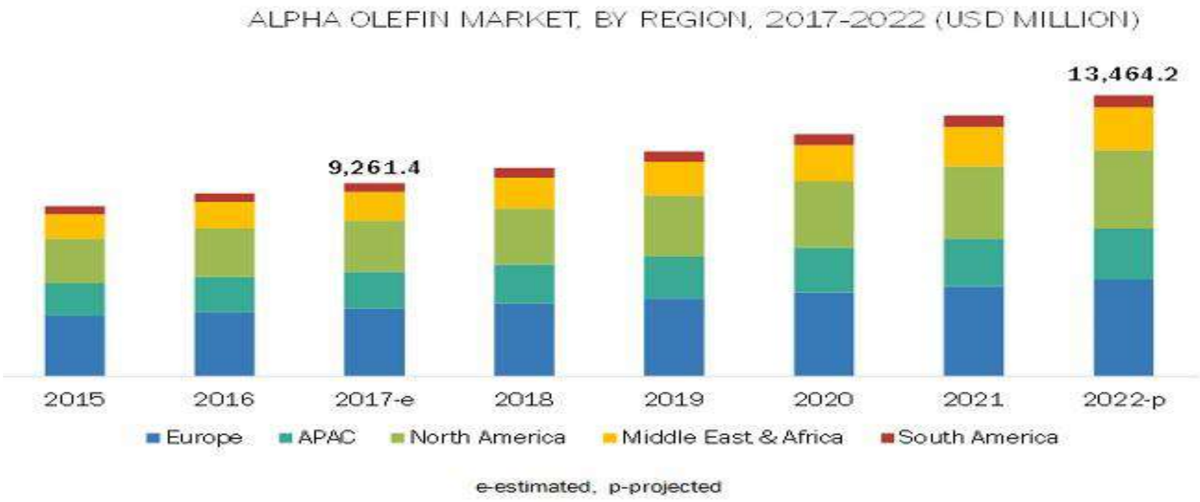


Figure 1-7: Global Alpha Olefins Market (2017-2022)

The worldwide paint and coatings industry is a significant subset of the global chemical industry. Coatings allude extensively to a covering that is applied to an item's surface for practical or aesthetic reasons or both. Paints are a subset of coatings that are likewise utilized as a defensive covering, beautiful covering, or both. Market development is chiefly determined by expanding requests in the development business, with the auto, generally modern, curl, wood, aviation, railing, and bundling coatings showcases additionally high demand growth.

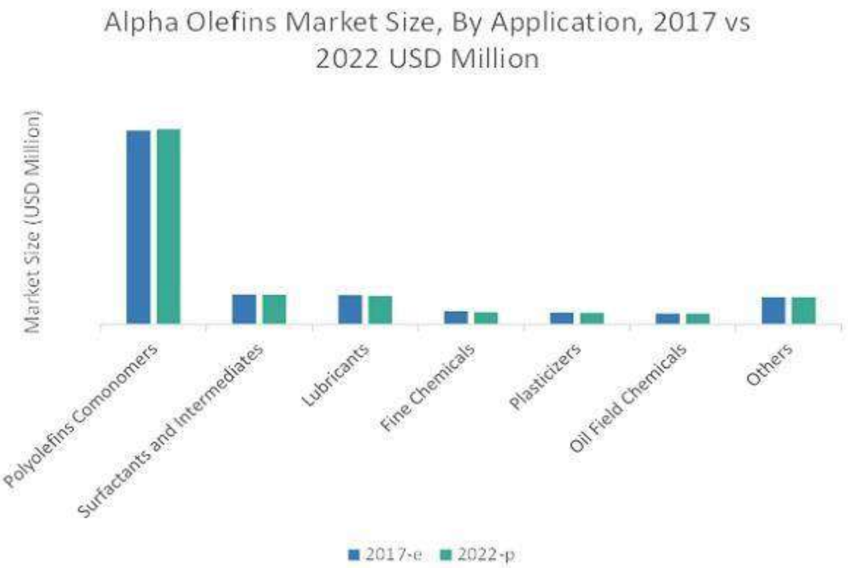


Figure 1-8: Applications of Linear Alpha Olefins

1.7.1 Major Players of Pakistan paint industry

1. Berger Paints Pakistan Limited
2. Brighto Paints
3. Diamond Paints
4. Nippon Paint
5. AkzoNobel

1.8 Market Assessment

During the projection period, a CAGR with over 4% is anticipated for Pakistani paints & coatings market.

- ♦ The market is primarily being driven by the expanding demand for paints & coatings from architectural coatings sector.
- ♦ • Increasing infrastructure development in Pakistan might present the market with a number of possibilities throughout the forecast period.
- ♦ Architectural applications are projected to lead the market because of the growth of rural regions and the rising construction industry, and acrylic resin is predicted to dominate the industry throughout the projection period.

Figure 1-9: Market Summary CAGR 3%

For large-cap companies, a CAGR in sales of 5-12% is good. Similarly, for small companies, it has been observed a CAGR between 15% to 30% is good. On the other hand, start-up companies have a CAGR ranging between 100% to 500%.

1.9 Project Motivation

1.9.1 Economic Growth:

By reducing the dependence on imports, Pakistan can create a self-sufficient industry and enhance its industrial development

1.9.2 Resource Utilization:

Pakistan has a significant palm oil industry, and utilizing locally available palmitic acid as a feedstock for 1-Tetradecene production promotes efficient resource utilization

This project can add value to the palm oil industry by utilizing palmitic acid derived from palm oil production, reducing waste, and promoting sustainability

1.9.3 Import Substitution:

Pakistan currently relies on imported 1-Tetradecene, and establishing a domestic production facility can lead to import substitution, reducing reliance on imports

Achieving import substitution enhances self-sufficiency, reduces the burden on foreign currency reserves, and strengthens the national economy

1.9.4 Foreign Exchange Savings:

Domestic production of 1-Tetradecene can significantly reduce Pakistan's foreign exchange expenditure on imports

The savings in foreign currency can be redirected to other essential sectors, such as healthcare, education, infrastructure development, and poverty alleviation (Khan et al., 2020).

1.9.5 Environmental Impact:

Producing 1-Tetradecene from palmitic acid offers environmental benefits compared to traditional petrochemical-based routes

Utilizing palmitic acid derived from sustainable sources like palm oil contributes to reducing greenhouse gas emissions and promotes sustainable practices

1.9.6 Market Potential:

The global demand for 1-Tetradecene is growing across various industries, providing an opportunity for Pakistan to tap into this market

Establishing a local production facility positions Pakistan as a regional supplier, boosting the national economy through export opportunities

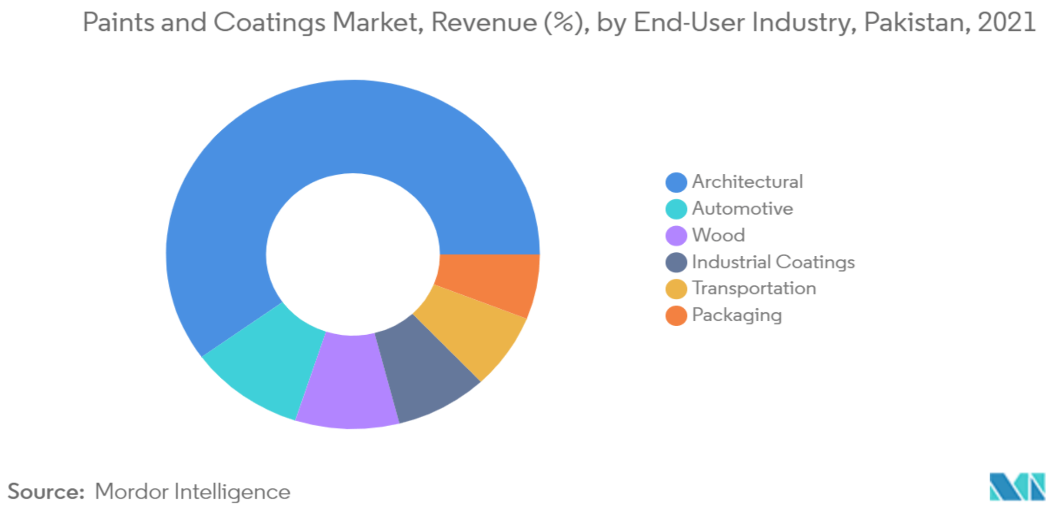


Figure 1-10: Paints and Coating Market 2021

CHAPTER 2

PROCESS SELECTION

2.1 Production Methods

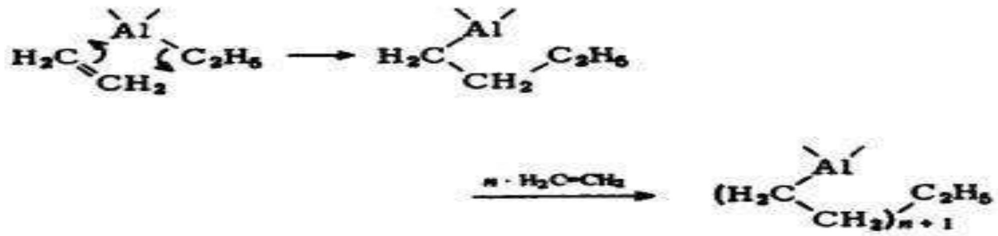
1-Tetradecene (Drying oil) is produced by two main processes on the commercial scale that includes:

1. Oligomerization of Ethylene using Triethylaluminum catalyst
2. Palmitic Acid Method

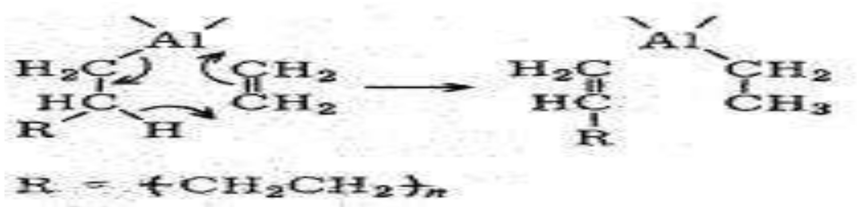
2.1.1 Oligomerization of Ethylene using Triethylaluminum catalyst

Oligomerization is a chemical process in which the smaller molecules (called as monomers) are converted to large molecular complexes (called as macromolecular complexes) by using a finite degree of polymerization. So, the reaction for the Oligomerization of Ethylene using the Triethylaluminum, alkyl catalyst, as catalyst mainly be constituted of a limited ethylene growth reaction. It consists of the following two steps:

In the first step, the building of the carbon chain takes place. In this, ethylene adds to Triethylaluminum at a pressure of 13.8MPa – 27.6MPa by injection among the aluminum atom and the alkyl groups as per the required average of alkyl size has got as well as mixture of higher trialkyl-aluminums has been produced. The corresponding olefin is formed by the displacement of alkyl with a lower olefin, which usually is ethylene. Alkyl groups grow and the rate of ethylene addition appears to be unaffected by the alkyl size; however, the molecular weight can be controlled by the amount of added ethylene. This development response is normally done at temperatures more prominent than 100^{o}C as at higher temperatures the rising extent of unreacted ethylene dislodges the alkyl bunch from the metal alkyl and, the response is:



Moreover, the high ethylene pressure favors the growth reaction. Hence, this growth reaction gives a mixture of alpha-olefins mostly C_6 - C_{20} as they are very important in the industries. From this mixture the required product (here C_{14}) is separated by the use of fractional distillation. In 2nd step, displacement reaction happens. The catalyst has recreated as per higher temperatures of 200-300°C and almost 5MPa. The reaction is as



2.1.2 Production by using Palmitic Acid

When paints and varnishes are applied to surfaces, drying oil is used as an additive to speed up the drying process. The factory turns acetylated castor oil into drying oil (DO). These two substances are mixes. However, for the sake of simulation, drying oil is used as 1-tetradecene and acetylated Castor oil is modelled as palmitic acid (hexadecanoic acid) ($C_{15}H_{31}COOH$) ($C_{14}H_{28}$). A gum that is modelled as 1-octacosene can arise in an unintended side reaction ($C_{28}H_{56}$)

2.2 Process Selection

Table 2-1 Comparison of processes

	Ethylene Oligomerization Method	**Palmitic Acid Method**
Raw Material	Ethylene **(C_2H_4)**	Palmitic acid **($C_{16}H_{32}O_2$)**
Catalyst	Triethylaluminum	Ni-Sn
Pressure	30 bar	1.95 bar
Temperature	120°C	300-380°C
Conversion	70%	90%
By-Product	Alpha-olefins other than required C_{14}	Gum **($C_{28}H_{56}$)**
Pros & cons	• Raw material is imported at high rates • Catalyst is expensive $4.8/Kg. • Lower olefins are converted into higher olefins	• Raw material is available in large quantity • Only gum is by product

For the commercial scale production of 1-Tetradecene (Drying Oil), we have chosen the Palmitic acid method as this process is adopted worldwide by the industries for the production of 1Tetradecene. Moreover, this process is more beneficial to carry out due its process conditions, raw material and the catalyst required as compared to the Ethylene Oligomerization.

2.3 Process Description

In Figure 2-12, the PFD is displayed. ACO is blended with recycled ACO after being supplied from a holding tank. In the heat exchanger, the acetylated castor oil is heated to reaction temperature. Since the reaction is started at a high temperature, no catalyst is needed. A vessel having inert packing to encourage radial mixing serves as the reactor. Heat exchanger quenches the reaction. Filtration is used to get rid of any generated gum. Two holding containers are present; one is used to store reaction byproducts, while the other supplies the filter (not shown). This makes it possible for content to enter Stream 7 continuously. Acetylated castor oil is separated & regenerated in T-501, while DO is refined from acetic acid in T-502. (Exchangers not visible.) The materials of Streams 11 & 12 are cooled and transferred to storage.

2.4 Capacity Selection

Market study let us learn about the current and future demand for product and let us determine the plant capacity for the production. Also, it helps in determining the cost and availability of raw materials. For the case of 1-Tetradecene production, the cost depends on multiple factors, but the most important of them all is energy, processing methods and the cost of raw materials.

Total Import of Alfa Olefins of Pakistan is around 32242.172 Tons/Year

And upto 2027 it increases at the rate of 5% so capacity becomes

- = 32,242 Tons/Year * 1.05
- = 33,854 Tons/Year
- The Requirement of 1-Tetradecene in Pakistan for year 2027 will be=**35,000 Tons/Year**

2.4.1 Raw Materials

Raw material for the production of drying oil (DO) is acetylated castor oil (ACO). Both of these compounds are mixtures. For convenience ACO is modeled as

- **Palmitic (hexadecanoic) acid ($C_{15}H_{31}COOH$)**

2.5 Flow Diagrams

2.5.1 Block Flow Diagram

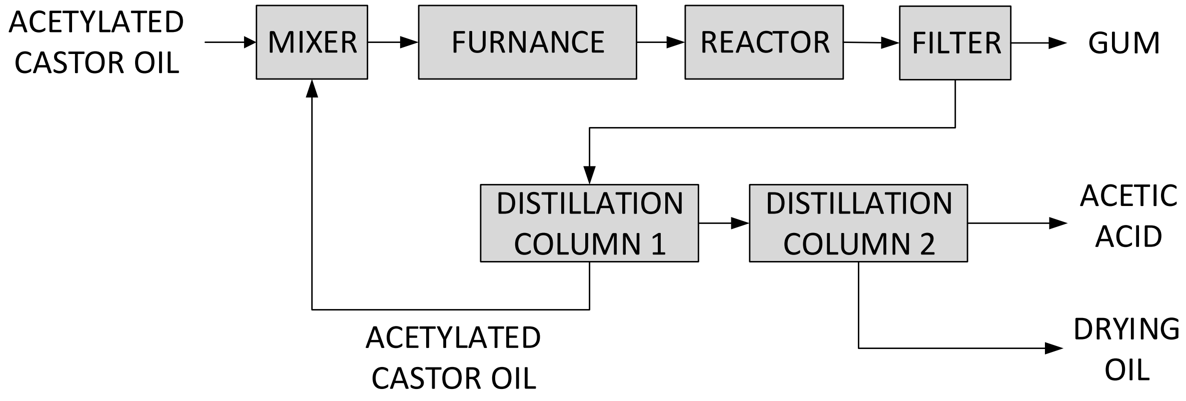


Figure 2-1: Block Flow Diagram for Production of 1-Tetradecene (drying oil) from palmitic acid

2.5.2 Process Flow Diagram

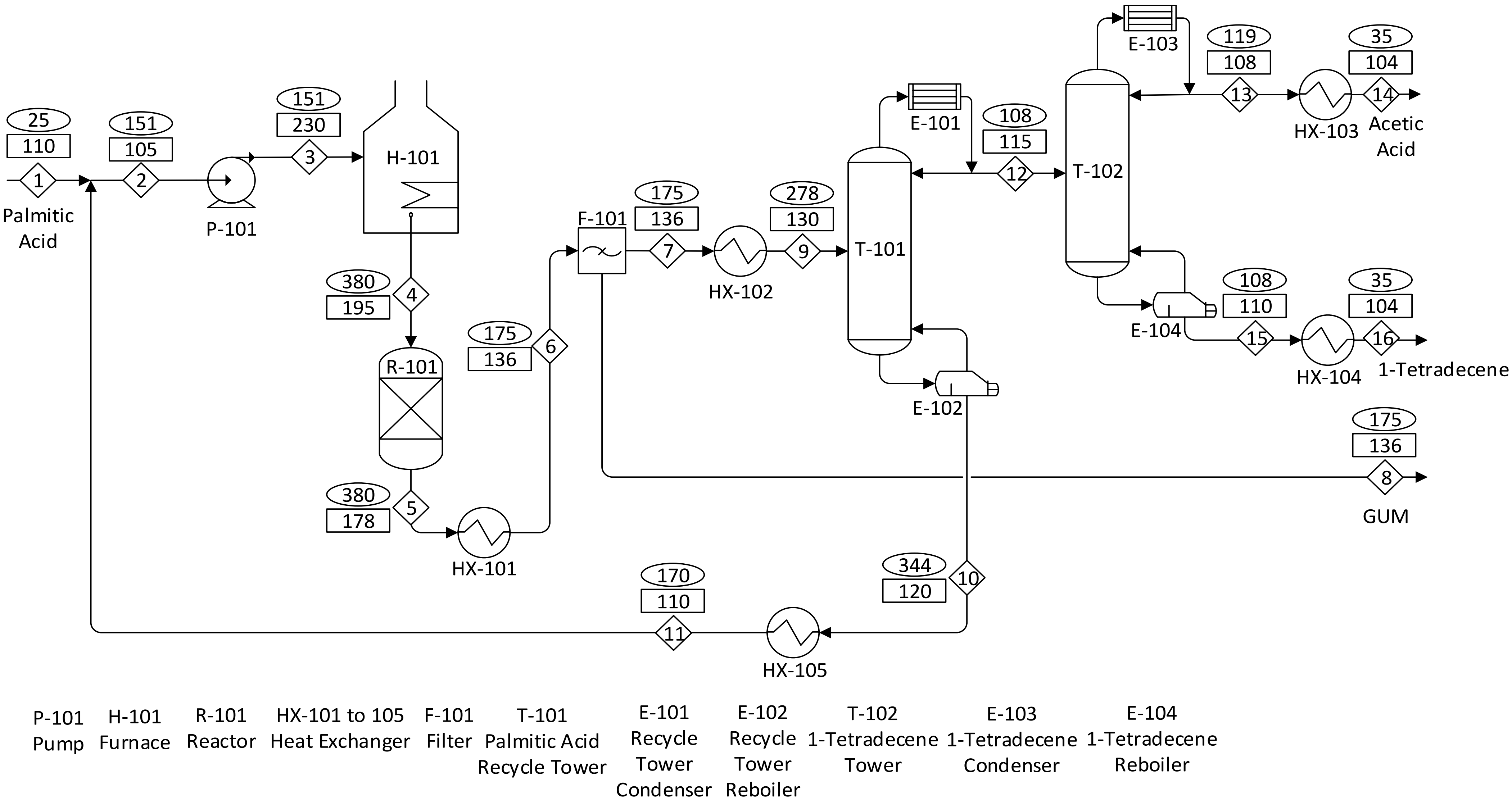


Figure 2-2: Process Flow Diagram for Production of 1-Tetradecene (drying oil) from palmitic acid

CHAPTER 3

MATERIAL BALANCE

3.1 Material Balance

Material balancing necessitates estimating the amounts of all materials which pass through and leave any system or process using the "law of conversation of mass" concept. According to this law, matter is neither formed nor destroyed during the operation, and the total mass remains constant. The main premise of material balancing calculations is to put together and solve a few independent equations involving a number of unknowns such as compositions and mass flow rates of streams entering and exiting the system or process. Mass fluxes that would have been unknown or difficult to assess without this approach can be detected by accounting for material entering and leaving a system. The specific Conservation law employed in the system analysis depends on the context of the problem, but all center on mass conservation, i.e., that matter cannot spontaneously disappear or be formed.

Mass balances are commonly utilized in engineering and environmental studies. The process may be described as one or a series of procedures that involve physical and chemical treatments to produce a desired output, such as distillation, drying, absorption, chemical manufacturing, and so on.

General Material Balance Equation:

(Rate of mass input) - (Rate of mass output) + (Rate of mass generation) - (Rate of mass Consumption/Depletion) = Accumulation

Assumptions:

- Steady state
- Non-reactive system

Basis:

330 Days in a year

Capacity of Plant:

35000 Tones/year or 4419.2 kg/hr.

Production Rate:

35000	Ton	1000	kg	1	year	1 day
	year	1	Ton	330	days	24 hrs

So, the production rate of Municipal Solid Waste for the working days of 300 days is 4419.2 kg/hr.

Production rate of Castor Oil per year = **35000 MT**

3.2 Molecular Weight of Component:

Table 3-1 Molecular weight of components

Component	MW (Kg/Kmol)
Palmitic acid	256.4
1-Tetradecene	196.37
Octacosane (Gum)	392.7
Acetic Acid	60.052

3.3 Material Balance on Reactor

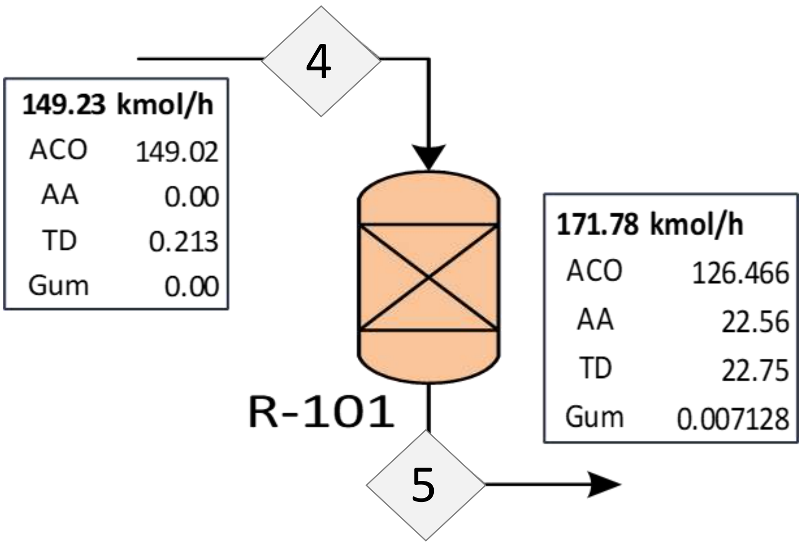


Figure 3-1 Material Balance on Reactor

3.3.1 Reaction

$$C_{15}H_{31}COOH\ (l) \xrightarrow{k_1} CH_3COOH\ (g) + C_{14}H_{28}(l)$$

Acetylated Castor Oil   Acetic Acid   1-Tetradecene

Conversion = 15.135%

$2C_{14}H_{28}\ (l) \overset{k_2}{\rightarrow} C_{28}H_{56}(s)$	
1-Tetradecene	1-octacosene

Conversion = 0.0626%

3.3.2 Calculations

3.3.2.1 For Acetic Acid

$$Sticometery = 1 : 1$$

$$no.of\ Moles\ of\ Acetic\ Acid = n_{PA} \times X_1$$

$$= 149.02 \times 0.15135$$

$$= 22.55 kmol/hr$$

3.3.2.2 For 1-Tetradecene

$$Sticometery = 1 : 1$$

$$no.of\ Moles\ of\ Tetradecene = (\ n_{TD}^{Gen} + n_{TD}) - [(\ n_{TD}^{Gen} + n_{TD}) \times X_1]$$

$$= (\ 22.55 + 0.214) - [(\ 22.55 + 0.214) \times 0.000626]$$

$$= 22.754 kmol/hr$$

3.3.2.3 For Gum

$$Sticometery = 2 : 1$$

$$no.of\ Moles\ of\ Gum = \frac{1}{2}[(\ n_{TD}^{Gen} + n_{TD}) \times X_2]$$

$$= \frac{1}{2}[(\ 22.55 + 0.214) \times 0.000626]$$

$$= 0.00713\ kmol/hr$$

3.3.2.4 For Palmitic Acid

$$Sticometery = 1 : 1$$

$$no.of\ Moles\ of\ unreacted\ Palmitic\ Acid = n_{PA} \times (1 - X_1)$$

$$= 149.02 \times (1 - 0.1514)$$

$$= 126.46\ kmol/hr$$

3.3.3 Mole Balance

Table 3-2 Mol balance across reactor

Reactor Balance		
Component	**mol flow (kmol/hr) across reactor**	
	in	**out**
	Stream 4	**Stream 5**
ACO	149.02	126.462
AA	-	22.55
TD	0.21	22.75
Gum	-	0.007
Total	**149**	**172**

3.3.4 Mass Balance

$$no.\,of\ moles\ of\ component = \frac{Mass\ of\ component}{Molecular\ Mass}$$

$$Mass\ of\ component = no.\,of\ moles\ of\ component\ \times molecular\ Mass$$

Table 3-3 Mass balance across reactor

Reactor Balance		
Component	**mass flow (kg/hr) across reactor**	
	in	**out**
	Stream 4	**Stream 5**
ACO	38208	32425
AA	-	1354
TD	42	4468
Gum	-	3
Total	**38250**	**38250**

3.4 Material Balance on Filter

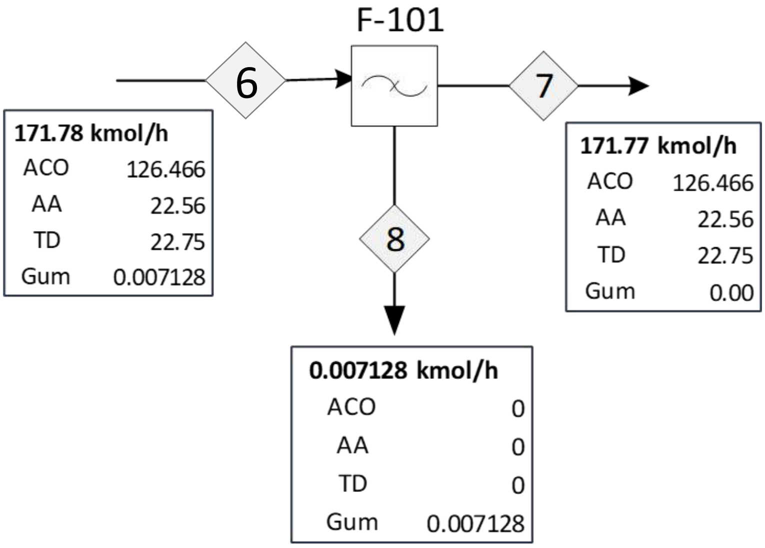


Figure 3-2 Material balance across Filter

Efficiency:

From literature review, efficiency of filter = **100%**

3.4.1 Mass Balance

Table 3-4 Mass Balance across Filter

Filter Balance			
Component	**mass flow (kg/hr) across filter**		
	in	**out**	
	Stream 6	**Stream 7**	**Stream 8**
ACO	32425	32425	-
AA	1354	1354	-
TD	4468	4468	-
Gum	3	-	3
Total	**38250**	**38247**	**3**

3.4.2 Mole Balance

$$no. of\ moles\ of\ component = \frac{Mass\ of\ component}{Molecular\ Mass}$$

$$Mass\ of\ component = no. of\ moles\ of\ component\ \times molecular\ Mass$$

Table 3-5 Mol balance across filter

Filter Balance			
Component	**mol flow (kmol/hr) across filter**		
	in	**out**	
	Stream 6	**Stream 7**	**Stream 8**
ACO	126.46	126.46	-
AA	22.55	22.55	-
TD	22.75	22.75	-
Gum	0.007133	-	0.0071
Total	**172**	**172**	**0.0071**

3.5 Material Balance on Distillation Column 1

3.5.1 Boiling Points of Component:

Table 3-6 Boiling points of components

Component	BP (^0C)
Palmitic Acid	323
1-Tetradecene	251
Octacosane (Gum)	451
Acetic Acid	118

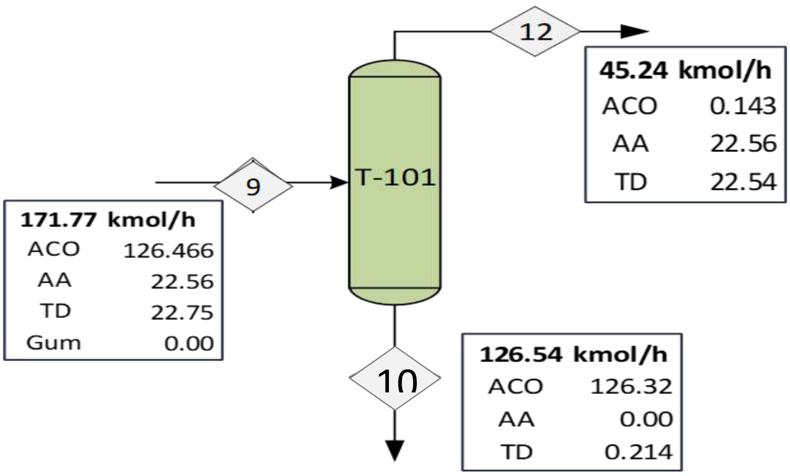


Figure 3-3 Material balance across distillation column 1

3.5.2 Mole Balance

Table 3-7 Mol balance across Distillation Column 1

1st Distillation Column Balance			
Component	**mol flow (kmol/hr) across DC 1**		
	in	**out**	
		Top	**bottom**
	Stream 9	**Stream 12**	**Stream 10**
ACO	126.46	0.14	126.32
AA	22.55	22.55	-
TD	22.75	22.54	0.21
Total	171.77	45.24	126.53

3.5.3 Mass Balance

$$no.of\ moles\ of\ component = \frac{Mass\ of\ component}{Molecular\ Mass}$$

$$Mass\ of\ component = no.of\ moles\ of\ component\ \times molecular\ Mass$$

Table 3-8 Mass balance across Distillation Column 1

1st Distillation Column Balance			
Component	**mass flow(kg/hr) across DC 1**		
	in	**out**	
		Top	**bottom**
	Stream 9	**Stream 12**	**Stream 10**
ACO	32425	37	32388
AA	1354	1354	-
TD	4468	4426	42
Total	**38247**	**5817**	**32430**

3.6 Material Balance on Recycle

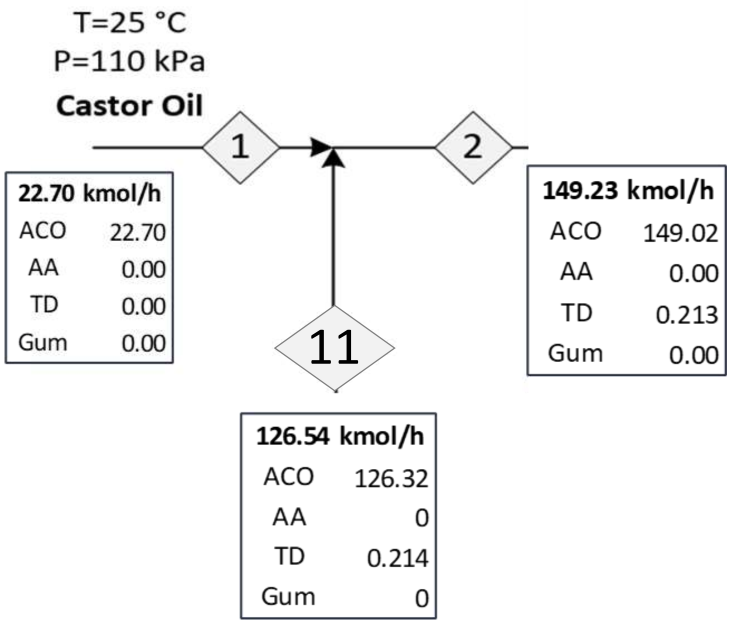


Figure 3-4 Material balance across Recycle Stream

3.6.1 Mole Balance

Table 3-9 Mol Balance across Recycle Stream

Recycle Stream			
Component	**mol flow (kmol/hr)**		
	in	**recycle**	**Reactor Feed**
	Stream 1	**Stream 11**	**Stream 2**
ACO	22.70	126.32	149.02
AA	-	-	-
TD	-	0.21	0.21
Gum	-	-	-
Total	**22.70**	**126.53**	**149**

3.6.2 Mass Balance

$$no.of\ moles\ of\ component = \frac{Mass\ of\ component}{Molecular\ Mass}$$

$$Mass\ of\ component = no.of\ moles\ of\ component\ \times molecular\ Mass$$

Table 3-10 Mass balance across Recycle Stream

Recycle Stream			
Component	mass flow (kg/hr)		
	in	recycle	Reactor Feed
	Stream 1	Stream 11	Stream 2
ACO	5,820	32388	38208
AA	-	-	-
TD	-	42	42
Gum	-	-	-
Total	**5,820**	**32430**	**38250**

3.7 Material Balance on Distillation Column-2

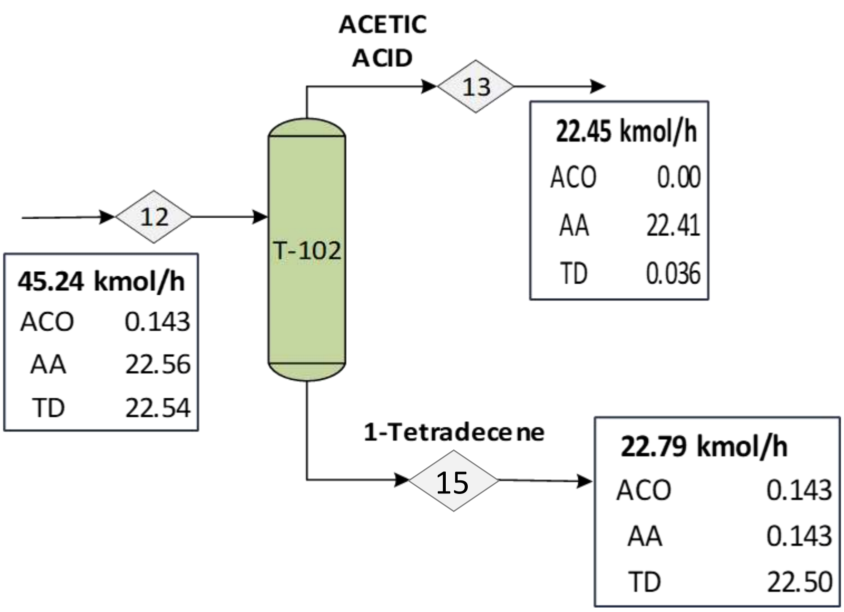


Figure 3-5 Material balance across Distillation column 2

3.7.1 Mole Balance

Table 3-11 Mol balance across Distillation Column 2

2nd Distillation Column Balance			
Component	mol flow (kmol/hr) across DC 2		
	in	out	
		Top	bottom
	Stream 12	Stream 13	Stream 15
ACO	0.14	-	0.14
AA	22.55	22.41	0.14
TD	22.54	0.04	22.50
total	45.24	22.45	22.79

3.7.2 Mass Balance

$$no.of\ moles\ of\ component = \frac{Mass\ of\ component}{Molecular\ Mass}$$

$$Mass\ of\ component = no.of\ moles\ of\ component\ \times molecular\ Mass$$

Table 3-12 Mass Balance across Distillation Column 2

2nd Distillation Column Balance			
Component	**mass flow (kg/hr) across DC 2**		
	in	**out**	
		Top	**bottom**
	Stream 12	**Stream 13**	**Stream 15**
ACO	37	-	37
AA	1354	1346	9
TD	4426	7	**4419**
Total	**5817**	**1353**	**4464**

CHAPTER 4

ENERGY BALANCE

4.1 Introduction:

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

Energy in + Generation – Consumption – accumulation = Energy out

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

Energy Balance:

Formula Used:

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

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

So by using above formula and by using the values of constants in table. We calculate $\mathbf{H^0}$ of the components of both inlet and the outlet streams. **Heat of reaction:**

In any process involves chemical reaction heat must be added or removed. The heat of reaction is released when the process is operating on standard conditions like 1atm pressure and 25 ^{O}C temperature. In process design normally heat of reaction is expressed in terms of moles of product produced.

The general form is

$\Delta H_{r,t} = \Delta H_r + \Delta H_{products} - \Delta H_{reactants}$

Where,

ΔH_r = Heat of reaction at temperature T (^{o}C)

ΔH reactants = Change of the reactant at standard temperature ΔH products = Change in enthalpy to get products to temperature T

4.2 Energy balance on Recycle Stream

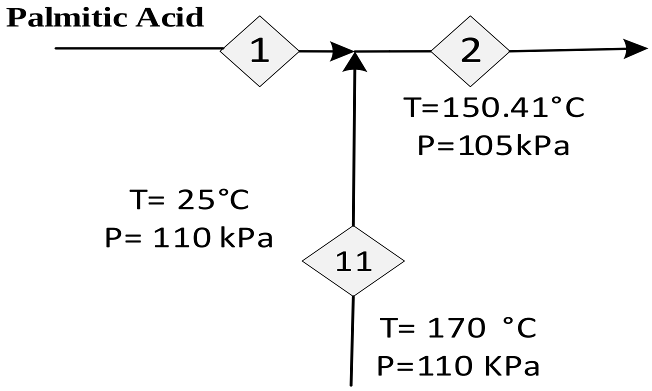


Figure 4-1 Energy Balance across Recycle Stream

Inlet temp = 25°C = 298K

Recycle temp = 170°C = 443K

Outlet temp = 150°C = 424K

Ref temp = 25°C = 298K

Mixer inlet

Specific enthalpy

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

Enthalpy

Molar flow rate * specific enthalpy

Compounds	Molar flow rate	Specific enthalpy	Enthalpy
Palmitic acid	23	-	-
Acidic acid	-	-	-
1-tetrdecene	-	-	-
1-octacosene	-	-	-
total	**23**	**-**	**-**

Recycle inlet steam

Specific enthalpy

Palmitic acid

C_p* (T-T_{ref}) = 69722 KJ/K.mol

Acidic acid

C_p* (T-T_{ref}) = 11241 KJ/K.mol

1-tetradecene

C_p* (T-T_{ref}) = 54606 KJ/K.mol

1-octacosene

C_p* (T-T_{ref}) = 115451 KJ/K.mol

Enthalpy

Palmitic acid

=126*69722

= 8807230 KJ/hr

1-tetradecne

= 0.2*54606

= 11685 KJ/hr

Compounds	Molar flow rate	Specific enthalpy	Enthalpy
Palmitic acid	126	69722	8807230
Acidic acid	-	11241	-
1-tetrdecene	0.2	54606	11685
1-octacosene	-	115451	-
total	**126.2**	**251021**	**8819916**

Mixer outlet

Specific enthalpy

Palmitic acid

C_p* $(T-T_{ref})$ = 59115 KJ/K.mol

Acidic acid

C_p* $(T-T_{ref})$ = 9459 KJ/K.mol

1-tetradecene

C_p* $(T-T_{ref})$ = 46248 KJ/K.mol

1-octacosene

C_p* $(T-T_{ref})$ =97847 KJ/K.mol

Enthalpy

Palmitic acid

149*59115

= 8809019

1-tetradecene

0.2*46248

= 9897

Compounds	Molar flow rate	Specific enthalpy	Enthalpy
Palmitic acid	149	59115	8809019
Acidic acid	-	9549	-
1-tetrdecene	0.2	46248	9897
1-octacosene	-	97847	-
total	**149.2**	**212759**	**8818916**

4.3 Energy balance on furnance (101):

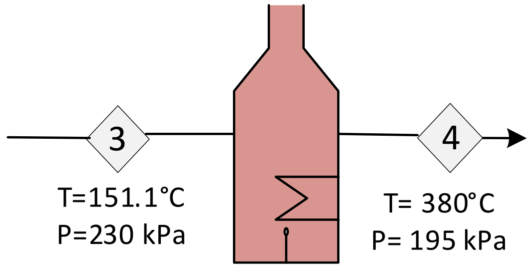


Figure 4-2 Energy balance across Furnace

Inlet temp = 151°C = 424K

Outlet temp = 380C = 653K

Ref temp = 25°C = 298K

Furnace inlet

Specific enthalpy

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

$Q_{in} = \dot{m}\,^{*}\,C_p * (T-T_{ref})$

m = Molar flow rate

C_p* $(T-T_{ref})$ = Specific Enthalpy

H=Molar flow rate*specific enthalpy

Palmitric acid

C_p* $(T-T_{ref})$ = 59431 KJ/Kmol

Acidic acid

C_p* $(T-T_{ref})$ = 9599 KJ/Kmol

1-tetradecene

C_p* $(T-T_{ref})$ = 46479 KJ/Kmol

1-octacosene

C_p* $(T-T_{ref})$ = 98371 KJ/Kmol

For enthalpy

Molar flow rate * specific enthalpy

Palmitic acid

= 149*59431

= 8856096 KJ/hr

1-tetradecene

= 0.2*46497

= 9950 KJ/hr

Compounds	Molar flow rate	Specific enthalpy	Enthalpy
Palmitic acid	149	59431	8856096
Acidic acid	-	9599	-
1-tetrdecene	0.2	46497	9950
1-octacosene	-	98371	-
total	**149.2**	**213898**	**8866045**

Furnace outlet

Specific enthalpy

Palmitic acid

C_p* (T-T_{ref}) = 204179 KJ/Kmol

Acidic acid

C_p* (T-T_{ref}) = 32172 KJ/Kmol

1-tetradecene

C_p* (T-T_{ref}) = 160520 KJ/Kmol

1-octacosene

C_p* (T-T_{ref}) = 736317 KJ/Kmol

For enthalpy

Palmitic acid

= 149*204179

= 30425868 KJ/hr

1-tetradecne

= 0.2*160520

= 34349 KJ/hr

Compounds	Molar flow rate	Specific enthalpy	Enthalpy
Palmitic acid	149	204179	30425868
Acidic acid	-	32172	-
1-tetrdecene	0.2	160520	34349
1-octacosene	-	339447	-
total	**149.2**	**736317**	**30460217**

Heat required

= 31587 MJ/hr

Calorific value

= 33.5 MJ/ m^3

Efficiency

= 0.7

Gas rate required

= 1347 m^3 /hr

4.4 Energy Balance on Reactor (R-101):

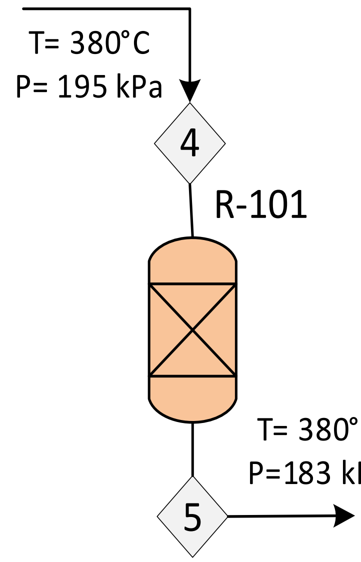


Figure 4-3 Energy balance across reactor

Inlet temp = 380°C = 653K

Outlet temp = 364°C = 638K

Ref temp = 25°C = 298K

Inlet of Reactor

$Q_{in} = \dot{m}^{*} C_p * (T-T_{ref})$

$Q_{in} = H$

Specific enthalpy

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

$Q_{in} = \dot{m}^{*} C_p * (T-T_{ref})$

m = Molar flow rate

$C_p * (T-T_{ref})$ = Specific Enthalpy

H=Molar flow rate*specific enthalpy

Palmitric acid

$C_p * (T-T_{ref})$ = 204179 KJ/Kmol

Acidic acid

$C_p * (T\text{-}T_{ref}) = 32172$ KJ/Kmol

1-tetradecne

$C_p * (T\text{-}T_{ref}) = 160520$ KJ/Kmol

1-octacosene

$C_p * (T\text{-}T_{ref}) = 339447$ KJ/Kmol

For enthalpy

Flow rate *specific enthalpy

Palmitric acid

$H = \dot{m} * C_p * (T\text{-}T_{ref})$

= 149*204179

= 30425868 KJ/hr

1-tetradecene

$H = \dot{m} * C_p * (T\text{-}T_{ref})$

= 0.2*160520

= 34349 KJ/hr

Description	**Molar flow rate**	**Specific enthalpy**	**Enthalpy**
Palmitic acid	149	204179	30425868
Acetic acid	-	32172	-
1-tetradecene	0.2	160520	34349
1-octacosene	-	339447	-
Total	**149**	**736317**	**30460217**

Outlet of Reactor

$H_{out} = C_p * (T\text{-}T_{ref})$

$Cp = a + bT + CT^2 + dT^3$

Specific enthalpy

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

Palmitric acid

$C_p * (T-T_{ref})$ = 193137 KJ/Kmol

Acidic acid

$C_p * (T-T_{ref})$ = 30489 KJ/Kmol

1-tetradecene

$C_p * (T-T_{ref})$ = 151862 KJ/Kmol

1-octacosene

$C_p * (T-T_{ref})$ = 321000 KJ/Kmol

For Enthalpy

Molar flow rate * specific enthalpy

Palmitic acid

= 126*193137

= 24424433 KJ/hr

Acidic acid

= 23*30489 KJ/hr

= 687652

1-tetradecene

= 23*151862

= 3455479 KJ/hr

1-octacosene

= 0.007*321000

= 2290 KJ/hr

Description	Molar flow rate	Specific enthalpy	Enthalpy
Palmitic acid	126	193137	24424433
Acetic acid	23	30489	687652
1-tetradecene	23	151862	3455479
1-octacosene	0.007	321000	2290
Total	**172**	**696488**	**28569853**

4.4.1 Heat of reaction:

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

1 Reaction

For reactant

Compound	Molar flow rate	Specific enthalpy	enthalpy
Palmitic acid	22.55	-204179	-4605115
Total	**22.55**	**-204179**	**-4605115**

For product

compound	Molar flow rate	Specific enthalpy	enthalpy
Acidic acid	22.55	32172	725617
1-tetradecene	22.55	160520	3620421
Total	**45**	**192692**	**4346038**

Equation for heat of reaction

$$\Delta H_{r1} = \sum_{Reactant} \left(\int_{T_{Rxn}}^{298} C_{pi} dT \right) + \Delta H_{r1}^{o} + \sum_{Product} \left(\int_{298}^{T_{Rxn}} C_{pi} dT \right)$$

ΔHf°	ΔHr1°	
kJ/mol	**kJ/mol**	**kJ/mol**
-7370.6		
-435.15	95.27	95270
-206.66		
-495.82		

Heat of Reaction 1 at Reaction temperature	**83,783**	kJ/kmol
Enthalpy of Reaction 1	**1,889,676**	kJ/hr

2 Reaction:

For Reactant

compound	Molar flow rate	Specific enthalpy	Enthalpy
1-tetradecne	0.014	-160520	-2290

For product

compound	Molar flow rate	Specific enthalpy	Enthalpy
1-octacosene	0.007	339447	2421

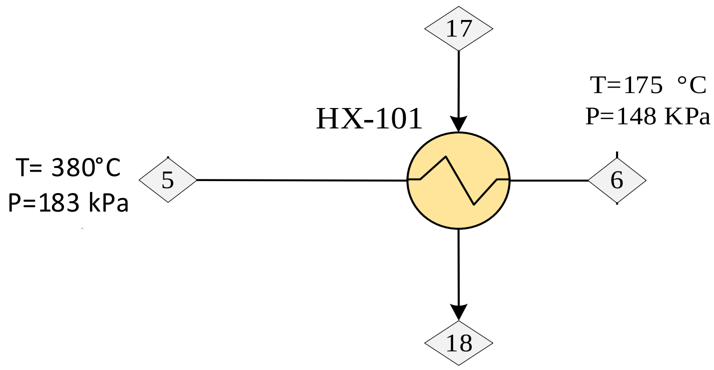
$$\Delta H_{r2} = \sum_{Reactant} \left(\int_{T_{Rxn}}^{298} C_{pi} dT \right) + \Delta H_{r2}^{o} + \sum_{Product} \left(\int_{298}^{T_{Rxn}} C_{pi} dT \right)$$

ΔHf°	ΔHr2°	
kJ/mol	**kJ/mol**	**kJ/mol**
-7370.6		
-435.15	-82.50	-82500
-206.66		
-495.82		

Heat of Reaction 2 at Reaction temperature	96,427	kJ/kmol	ΔHr_2
Enthalpy of Reaction 2	688	kJ/hr	Hr_2
Heat of Reactions at Reaction temperature	$\Delta Hr = \Delta Hr_1 + \Delta Hr_2$	180,210	kJ/kmol
Enthalpy of Reactions	Hr	1,890,364	kJ/hr

Qr Heat consumed by the system (endothermic reaction)	**1,890,364**	**kJ/hr**
$Q = H_{product} - H_{feed} + Qr$ (consumed)	**1,631,419**	**kJ/hr**

4.5 Energy Balance on Heat Exchanger (HX-101)



Enthalpy at the inlet Stream 5:

Inlet temp = T_{in} = 365°C = 638K

Ref temp = T_{ref} = 25°C = 298K

Inlet Pressure = P_{in} = 183kpa = 1.8bar

Specific Enthalpy:

We will find the specific enthalpies of the components of the inlet streams by the following equation:

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

Enthalpy:

Enthalpy = Molar flow rate * Specific enthalpy

$H = \dot{n} * \hat{H}$

For Palmitic Acid:

H = 126 * 193,137

H = 24424433 kJ/hr

For Acetic Acid:

H = 23 * 30,489

H = 687,652 kJ/hr

For 1-tetradecene:

H = 22.8 * 151,862

H = 3455479 kJ/hr

For 1- Octacoscene:

H = 0.007 * 321000

H = 2290 kj/hr

Total Enthalpy = 28569853 kJ/hr

Description	**Molar flow rate** $\dot{n}$ **(kmol/hr)**	**Specific enthalpy** $\widehat{H}$ **(kJ/kmol)**	**Enthalpy H (kJ/hr)**
Palmitic acid	126	204,179	25,820,753
Acetic acid	23	32,172	725,617
1-tetradecene	22.8	160,520	3,652,481
1-octacosene	0.007	339,447	2,421
Total	**171.8**	**736,317**	**30,201,272**

Enthalpy at the outlet Stream 6:

Outlet temp = T_{out} = 175°C = 448K

Ref temp = T_{ref} = 25°C = 299K

Outlet Pressure = P_{out} = 148kpa = 1.48bar

Specific Enthalpy:

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

Enthalpy:

Enthalpy = Molar flow rate * Specific enthalpy

$H = \dot{n} * \hat{H}$

For Palmitic Acid:

H = 126 * 72,486

H = 9166661 kj/hr

For Acetic Acid:

H = 23 * 11681

H = 263462 kJ/hr

For 1-tetradecene:

H = 22.8 * 56785

H = 1292092 kJ/hr

For 1- Octacoscene:

H = 0.007 * 120039

H = 10723072 kJ/hr

Total Enthalpy = 10723072 kJ/hr

Description	**Molar flow rate** $\dot{n}$ **(kmol/hr)**	**Specific enthalpy** $\hat{H}$ **(kJ/kmol)**	**Enthalpy** **H (kJ/hr)**
Palmitic acid	126	204,179	25,820,753
Acetic acid	23	32,172	725,617
1-tetradecene	22.8	160,520	3,652,481

1-octacosene	0.007	339,447	2,421
Total	**171.8**	**736,317**	**30,201,272**

Cold Inlet Temp = T_1 = 365ºC

Cold outlet Temp = T_2 = 175ºC

Hot Inlet Temp = t_1 = 25ºC

Hot outlet Temp = t_2 = 100ºC

Saturated steam temperature at the inlet = 350ºC

Saturated steam temperature at the outlet =

Heat = Q = Product Enthalpy – Reactant Enthalpy

Q = 28569853 – 10723072

Q = -17846782 kJ/hr

Cp = 4.187 kJ/kg.K

$\Delta T = t_2 - t_1$

$\Delta T = 100 - 25$

ΔT = 75K

λ = 895.9 kJ/kg

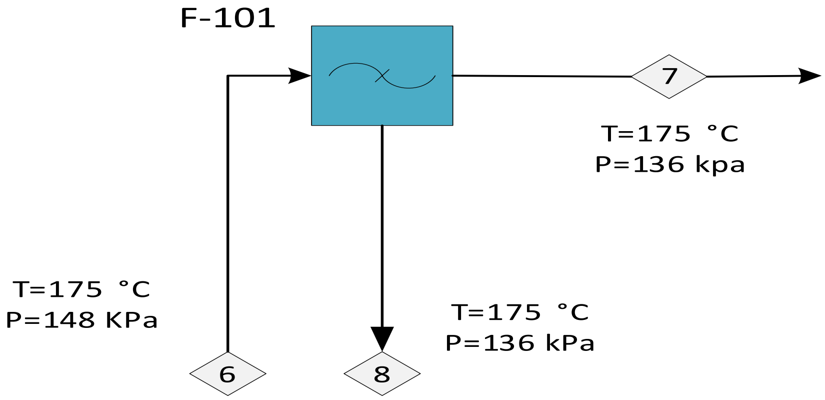
m = Q / (Cp ΔT + **λ)**

m = 17846782 / (4.187 * 75 + 895.9)

m = 14,750 kg/hr

= 15 T/hr

4.6 Energy Balance on Filter (F-101):



Enthalpy on Inlet Stream 6:

Inlet temp = T_{in} = 175°C = 448K

Ref temp = T_{ref} = 25°C = 298K

Inlet Pressure = P_{in} = 148kpa = 1.48bar

Specific Enthalpy:

We will find the specific enthalpies of the components of the inlet streams by the following equation:

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

Enthalpy:

Enthalpy = Molar flow rate * Specific enthalpy

H = $\dot{n} * \hat{H}$

For Palmitic Acid:

H = 126 * 72,486

H = 9,166,661 kJ/hr

For Acetic Acid:

H = 23 * 11,681

H = 263,462 kJ/hr

For 1-tetradecene:

H = 22.8 * 56,785

H = 1,292,092 kJ/hr

For 1- Octacoscene:

H = 0.007 * 120,039

H = 856 kJ/hr

Total Enthalpy = 10,723,072 kJ/hr

Description	**Molar flow rate** $\dot{n}$ **(kmol/hr)**	**Specific enthalpy** $\hat{H}$ **(kJ/kmol)**	**Enthalpy H (kJ/hr)**
Palmitic acid	126	72,486	9,166,661
Acetic acid	23	11,681	263,462
1-tetradecene	22.8	56,785	1,292,092
1-octacosene	0.007	120,039	856
Total	**171.8**	**260,991**	**10,723,072**

Enthalpy at the outlet Stream 7:

Outlet temp = T_{out} = 175°C = 448K

Ref temp = T_{ref} = 25°C = 299K

Outlet Pressure = P_{out} = 136kpa = 1.36bar

Specific Enthalpy:

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

Enthalpy:

Enthalpy = Molar flow rate * Specific enthalpy

H = $\dot{n} * \hat{H}$

For Palmitic Acid:

H = 126 * 72,486

H = 9,166,661 kj/hr

For Acetic Acid:

H = 23 * 11,681

H = 263,462 kJ/hr

For 1-tetradecene:

H = 22.8 * 56,785

H = 1,292,092 kJ/hr

Total Enthalpy = 10,722,215kJ/hr

Description	**Molar flow rate** $\dot{n}$ **(kmol/hr)**	**Specific enthalpy** $\hat{H}$ **(kJ/kmol)**	**Enthalpy H (kJ/hr)**
Palmitic acid	126	72,486	9,166,661
Acetic acid	23	11,681	263,462
1-tetradecene	22.8	56,785	1,292,092
1-octacosene	-	120,039	-
Total	**171.8**	**260,991**	**10,722,215**

Enthalpy at the outlet Stream 8:

Outlet temp = T_{out} = 175°C = 448K

Ref temp = T_{ref} = 25°C = 299K

Outlet Pressure = P_{out} = 136kpa = 1.36bar

Specific Enthalpy:

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

Enthalpy:

Enthalpy = Molar flow rate * Specific enthalpy

H = $\dot{n} * \hat{H}$

For 1- Octacoscene:

H = 0.007 * 120,039

H = 856 kJ/hr

Total Enthalpy = 856 kJ/hr

Description	**Molar flow rate** $\dot{n}$ **(kmol/hr)**	**Specific enthalpy** $\hat{H}$ **(kJ/kmol)**	**Enthalpy** **H (kJ/hr)**
Palmitic acid	-	72,486	-
Acetic acid	-	11,681	-
1-tetradecene	-	56,785	-
1-octacosene	0.007	120,039	856
Total	**0.007**	**260,991**	**856**

4.7 Energy balance on Distillation Column (T-101)

Inlet temp = 278°C = 448K

Outlet temp = 125°C = 398K

Outlet temp = 344°C = 619K

Ref temp = 25°C = 298K

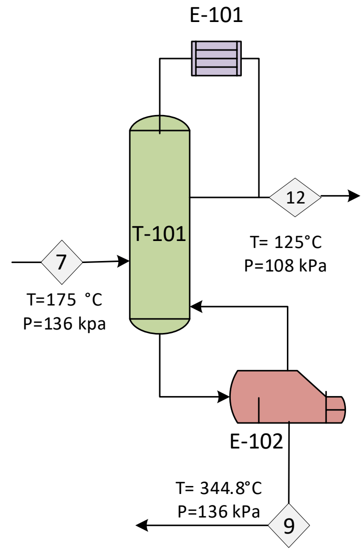
Formula Used:

Q = $\dot{m} C_p dT$

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

To find top and bottom temperatures of the column we use Antoine equation to find the pressure of individual components by using the formula which is mentioned below

$$\ln P = A - (B/(T+C))$$



Antoine Equation parameters

compounds	Temperature	A	B	C
n-hexdecanoic acid	426.8-626.9	5.35728	3061.422	-55.077
Acidic acid	290.26-391.1	4.68206	1642.54	-39.744
1-tetradecne	4.14495	4.14495	1745.001	-102.672

Bubble point

Species	X1	P1	K1	Y1
1-hexdecanoic acid	0.55	0.01	0.000	0.000
Acidic acid	0.3	0.45	0.001	0.000
1-tetradecene	0.15	0.05	0.000	0.000

$\Sigma Y_i = 0.000$

Dew point

Species	X1	P1	K1	Y1
1-hexdecanoic acid	0.55	212.15	0.558	0.985
Acidic acid	0.3	107.99	0.283	1.056
1-tetradecene	0.15	63.11	0.116	0.903

$\Sigma Xi = 2.9439$

Inlet of distillation

Specific enthalpy

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

$Q_{in} = \dot{m} * C_p * (T-T_{ref})$

m = Molar flow rate

$C_p * (T-T_{ref})$ = Specific Enthalpy

H=Molar flow rate*specific enthalpy

For enthalpy

$H=\dot{m} * Cp * (T-Tref)$

Palmitic acid

= 9166661 KJ/hr

Acidic acid

= 263432 KJ/hr

1-tetradecene

1292092 KJ/hr

Compound	**Molar flow rate**	**Specific enthalpy**	**enthalpy**
Palmitic acid	126	72486	9166661
Acidic acid	23	11686	263432
1-tetradecne	23	56785	1292092
1-octacosene	-	120039	-
total	**171.8**	**260991**	**10722215**

Outlet distillate steam

Compound	Molar flow rate	Specific enthalpy	enthalpy
Palmitic acid	0.14	45892	6561
Acidic acid	22.6	7430	167587
1-tetradecne	22.5	35845	807950
1-octacosene	-	75922	-
total	**45.2**	**260991**	**982099**

Outlet of recycle steam

Compound	Molar flow rate	Specific enthalpy	enthalpy
Palmitic acid	126	179139	22628646
Acidic acid	-	28346	-
1-tetradecne	0.21	140870	30145
1-octacosene	-	297626	-
total	**126.5**	**645982**	**22658791**

Condenser calculations

Distillate enthalpy is equal to total enthalpy

H_d = 982099 KJ/hr

Cp =121 KJ/Kmol.k

$\Delta T = 150\,^{O}C$

V= L+D

L=0

V=22

Total latent of vaporization of all componends

= 35412 KJ/hr

Hv = V*Cp*ΔT+ latent heat

= 2419705 KJ/hr

Condenser duty

$Qc = Hv + \text{latent heat} - H_D - H_L$

Qc = 1437607 KJ/hr

For water

Cp = 4.18 KJ/Kg.K

$\Delta T = 20\ ^{O}C$

$m = Qc/Cp*\Delta T$

= 17168 KJ/hr

Enthalpy at bottom

$H_B = m*Cp*\Delta T$

H_B = 22658791 KJ/hr

Reboiler duty

Enthalpy of Feed

H_F = 10722215 KJ/hr

$Qb = Qc + H_B + H_D - H_F$

Qb = 14356281 KJ/hr

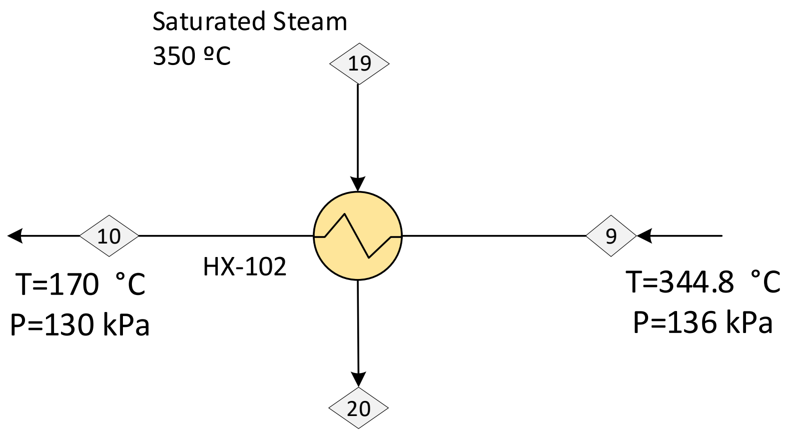
Latent heat steam

895.9 KJ/kg

$m = Qb/Cp*\Delta T$

$m = 16024\ KJ/hr$

4.8 Energy Balance on Heat Exchanger (HX-102):



Enthalpy at the inlet Stream 10:

Inlet temp = T_{in} = 344.8°C = 618K

Ref temp = T_{ref} = 25°C = 298K

Inlet Pressure = P_{in} = 136kpa = 1.36bar

Specific Enthalpy:

We will find the specific enthalpies of the components of the inlet streams by the following equation:

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

Enthalpy:

Enthalpy = Molar flow rate * Specific enthalpy

$$\mathbf{H} = \dot{n} * \hat{H}$$

For Palmitic Acid:

H = 126 * 179,139

H = 22,628,646 kJ/hr

For 1-tetradecene:

H = 0.21 * 140,870

H = 30,145 kJ/hr

Total Enthalpy = 22,658,791 kj/hr

Description	**Molar flow rate** $\dot{n}$ **(kmol/hr)**	**Specific enthalpy** $\hat{H}$ **(kJ/kmol)**	**Enthalpy H (kJ/hr)**
Palmitic acid	126	179,139	22,628,646
Acetic acid	-	28,346	-
1-tetradecene	0.21	140,870	30,145
1-octacosene	-	297,626	-
Total	**126.5**	**645,982**	**22,658,791**

Enthalpy at the outlet Stream 9:

Outlet temp = T_{out} = 170ºC = 443K

Ref temp = T_{ref} = 25ºC = 298K

Outlet Pressure = P_{out} = 130kpa = 1.3bar

Specific Enthalpy:

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

Enthalpy:

Enthalpy = Molar flow rate * Specific enthalpy

H = $\dot{n} * \hat{H}$

For Palmitic Acid:

H = 126 * 69,722

H = 8,807,230 kj/hr

For 1-tetradecene:

H = 0.21 * 54,606

H = 11,685 kj/hr

Total Enthalpy = 8,818,916 kJ/hr

Description	**Molar flow rate** $\dot{n}$ **(kmol/hr)**	**Specific enthalpy** $\hat{H}$ **(kJ/kmol)**	**Enthalpy H (kJ/hr)**
Palmitic acid	126	69,722	8,807,230
Acetic acid	-	11,241	-
1-tetradecene	0.21	54,606	11,685
1-octacosene	-	115,021	-
Total	**126.5**	**251,021**	**8,818,916**

Waste Heat Boiler Calculation:

Cold Inlet Temp = T_1 = 345^oC

Cold outlet Temp = T_2 = 170^oC

Hot Inlet Temp = t_1 = 25^oC

Hot outlet Temp = t_2 = 100^oC

Heat = Q = Product Enthalpy – Reactant Enthalpy

Q = 8,818,916 – 22,658,791

Q = -13,839,875 kJ/hr

Cp = 4.187 kJ/kg.K

$\Delta T = t_2 - t_1$

ΔT = 100 – 25

ΔT = 75K

λ = 895.9 kJ/kg

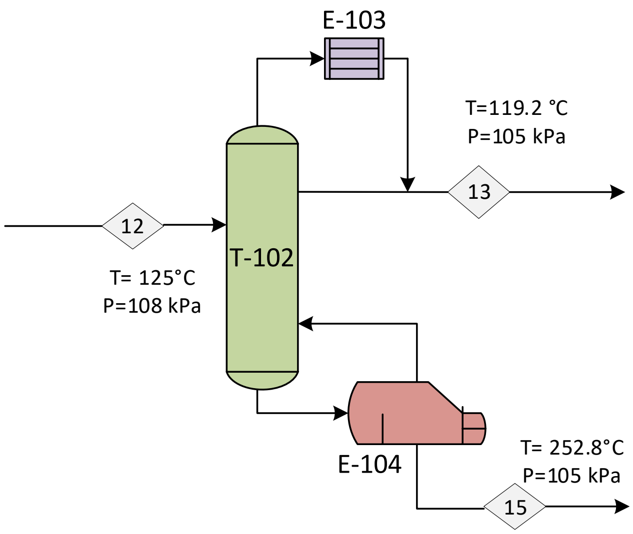
$m = Q / (Cp\ \Delta T + \lambda)$

m = 13839875 / (4.187 * 75 + 895.9)

m = 11,439 kg/hr

= 11 T/hr

4.9 Energy balance on Distillation Column (T-102)



Inlet temp = 125°C = 398K

Outlet temp = 119°C = 392K

Outlet temp = 252°C = 526K

Ref temp = 25°C = 298K

Inlet of distillation

Compounds	Molar flow rate	Specific enthalpy	Enthalpy
Palmitic acid	0.14	45892	6561
Acidic acid	22.55	7430	167587
1-tetrdecene	22.54	35845	807950
1-octacosene	-	75922	-
Total	**45.2**	**165090**	**982099**

Outlet of condenser

Compounds	Molar flow rate	Specific enthalpy	Enthalpy
Palmitic acid	-	42960	-
Acidic acid	22.41	6959	155966
1-tetrdecene	0.04	33541	1196
1-octacosene	-	71062	-
Total	**22.4**	**154521**	**157162**

Outlet of reboiler

Compounds	Molar flow rate	Specific enthalpy	Enthalpy
Palmitic acid	0.14	118342	16920
Acidic acid	0.14	18920	2701
1-tetrdecene	22.50	92972	2092285
1-octacosene	-	196276	-
total	**22.8**	**426511**	**2111906**

Condenser duty

Distillate enthalpy is equal to total enthalpy

$H_D = m*Cp*\Delta T$

H_D = 157162 KJ/hr

V = L+D

L=0

D=22.4

V=22.4

Cp of all components (wetted Cp)

= 34 KJ/Kmol.K

$\Delta T = 100$

Latent of vaporization

= 23734 KJ/hr

$H_v = V*Cp*\Delta T +$ latent heat

= 609587 KJ/hr

For duty

$Q_c = H_V - H_D - H_L$

$Q_c = 609587 - 157162$

$Q_c = 452425$ KJ/hr

For water steam

Cp = 4.187 KJ/Kg.K

$\Delta T = 20$ C

For mass flow rate of water

$m = Q_c/cp*\Delta T$

m = 5403 KJhr

For Reboiler Duty

$H_B = 2111906$ KJ/hr

$H_F = 982099$ KJ .hr

$Q_b = Q_c + H_B + H_B - H_F$

$Q_b = 1739392$ KJ/hr

Latent heat of steam

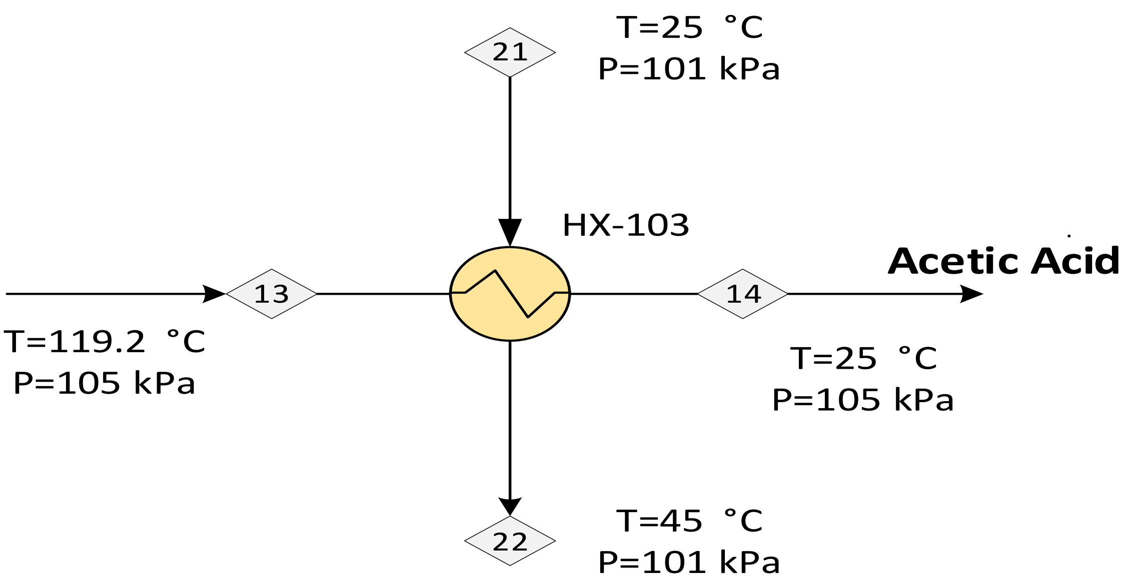
= 895.9 KJ/Kg

Mass flow rate of water

$m = Q_c/cp*\Delta T$

m = 1942 Kg/hr

4.10 Energy Balance on Heat Exchanger (HX-103):



Enthalpy at the inlet Stream 13:

Inlet temp = T_{in} = 119.2°C = 392K

Ref temp = T_{ref} = 25°C = 298K

Inlet Pressure = P_{in} = 105kpa = 1.05bar

Specific Enthalpy:

We will find the specific enthalpies of the components of the inlet streams by the following equation:

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

Enthalpy:

Enthalpy = Molar flow rate * Specific enthalpy

$H = \dot{n} * \hat{H}$

For Acetic Acid:

H = 22 * 6,959

H = 155,966 kJ/hr

For 1-tetradecene:

H = 0.04 * 33,541

H = 1,196 kJ/hr

Total Enthalpy = 157,162 kj/hr

Description	**Molar flow rate** $\dot{n}$ **(kmol/hr)**	**Specific enthalpy** $\hat{H}$ **(kJ/kmol)**	**Enthalpy** **H (kJ/hr)**
Palmitic acid	-	42,960	-
Acetic acid	22	6,959	155,966
1-tetradecene	0.04	33,541	1,196
1-octacosene	-	71,062	-
Total	**22.4**	**154,521**	**157,162**

Enthalpy at the outlet Stream 14:

Outlet temp = T_{out} = 25°C = 298K

Ref temp = T_{ref} = 25°C = 298K

Outlet Pressure = P_{out} = 105kpa = 1.05bar

Specific Enthalpy:

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

Enthalpy:

Enthalpy = Molar flow rate * Specific enthalpy

$H = \dot{n} * \hat{H}$

Description	**Molar flow rate** $\dot{n}$ **(kmol/hr)**	**Specific enthalpy** $\hat{H}$ **(kJ/kmol)**	**Enthalpy H (kJ/hr)**
Palmitic acid	-	-	-
Acetic acid	22.4	-	-
1-tetradecene	0.04	-	-
1-octacosene	-	-	-
Total	**22.4**	**-**	**-**

Cooling Water Flow Rate Calculation:

Cold Inlet Temp = T_1 = 119°C

Cold outlet Temp = T_2 = 25°C

Hot Inlet Temp = t_1 = 25°C

Hot outlet Temp = t_2 = 45°C

Heat = Q = Product Enthalpy – Reactant Enthalpy

Q = -157,162 kJ/hr

Cp = 4.187 kJ/kg.K

$\Delta T = t_2 - t_1$

$\Delta T = 45 - 25$

$\Delta T = 20K$

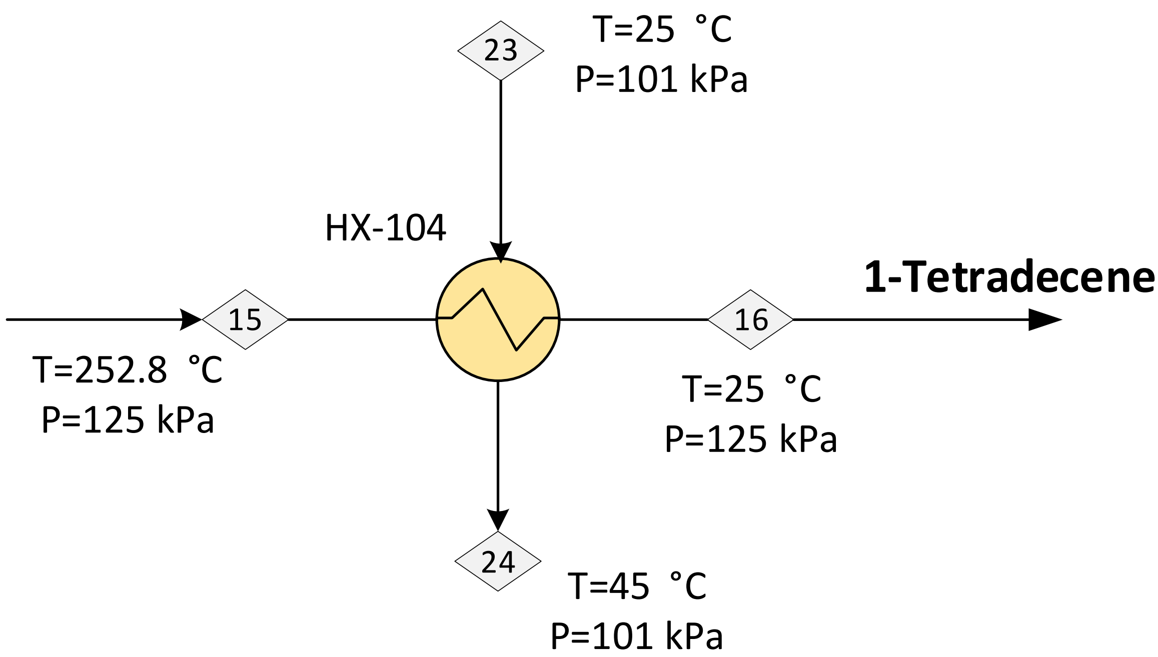
$m = Q / Cp\ \Delta T$

m = 157162/ (4.187 * 20)

m = 1,877 kg/hr

= 2 T/hr

4.11 Energy Balance on Heat Exchanger (HX-104):



Enthalpy at the inlet Stream 15:

Inlet temp = T_{in} = 252.8°C = 526K

Ref temp = T_{ref} = 25°C = 298K

Inlet Pressure = P_{in} = 125kpa = 1.25bar

Specific Enthalpy:

We will find the specific enthalpies of the components of the inlet streams by the following equation:

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

Enthalpy:

Enthalpy = Molar flow rate * Specific enthalpy

H = $\dot{n} * \hat{H}$

For Palmitic Acid:

H = 0.143 * 118,342

H = 16,920 kJ/hr

For Acetic Acid:

H = 0.143 * 18,920

H = 2,701 kJ/hr

For 1-tetradecene:

H = 22.5 * 92,972

H = 2,092,285 kJ/hr

Total Enthalpy = 2,111,906 kJ/hr

Description	**Molar flow rate** $\dot{n}$ **(kmol/hr)**	**Specific enthalpy** $\hat{H}$ **(kJ/kmol)**	**Enthalpy H (kJ/hr)**
Palmitic acid	0.143	118,342	16,920
Acetic acid	0.143	18,920	2,701
1-tetradecene	22.5	92,972	2,092,285
1-octacosene	-	196,276	-
Total	**22.8**	**426,511**	**2,111,906**

Enthalpy at the outlet Stream 16:

Outlet temp = T_{out} = 25°C = 298K

Ref temp = T_{ref} = 25°C = 298K

Outlet Pressure = P_{out} = 125kpa = 1.25bar

Specific Enthalpy:

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

Enthalpy:

Enthalpy = Molar flow rate * Specific enthalpy

$H = \dot{n} * \hat{H}$

Description	**Molar flow rate** $\dot{n}$ **(kmol/hr)**	**Specific enthalpy** $\hat{H}$ **(kJ/kmol)**	**Enthalpy H (kJ/hr)**
Palmitic acid	0.143	-	-
Acetic acid	0.143	-	-
1-tetradecene	22.5	-	-
1-octacosene	-	-	-
Total	**22.8**	**-**	**-**

Cooling Water Flow Rate Calculation:

Cold Inlet Temp = T_1 = 253^{o}C

Cold outlet Temp = T_2 = 25^{o}C

Hot Inlet Temp = t_1 = 25^{o}C

Hot outlet Temp = t_2 = 45^{o}C

Heat = Q = Product Enthalpy – Reactant Enthalpy

Q = 0 – 2,111,906

Q = -2,111,906 kJ/hr

Cp = 4.187 kJ/kg.K

$\Delta T = t_2 - t_1$

ΔT = 45 – 25

ΔT = 20K

m = Q / Cp ΔT

m = 2111906/ (4.187 * 20)

m = 25,220 kg/hr

CHAPTER 5

EQUIPMENT DESIGN

5.1 Furnace (F-01)

5.1.1 Introduction:

An industrial furnace, also known as a fired heater refers to equipment which is used to provide heat for a certain process or reaction. Typically, higher than 350 degrees Celsius. Heat is generated by an industrial furnace by mixing fuel with air or oxygen.

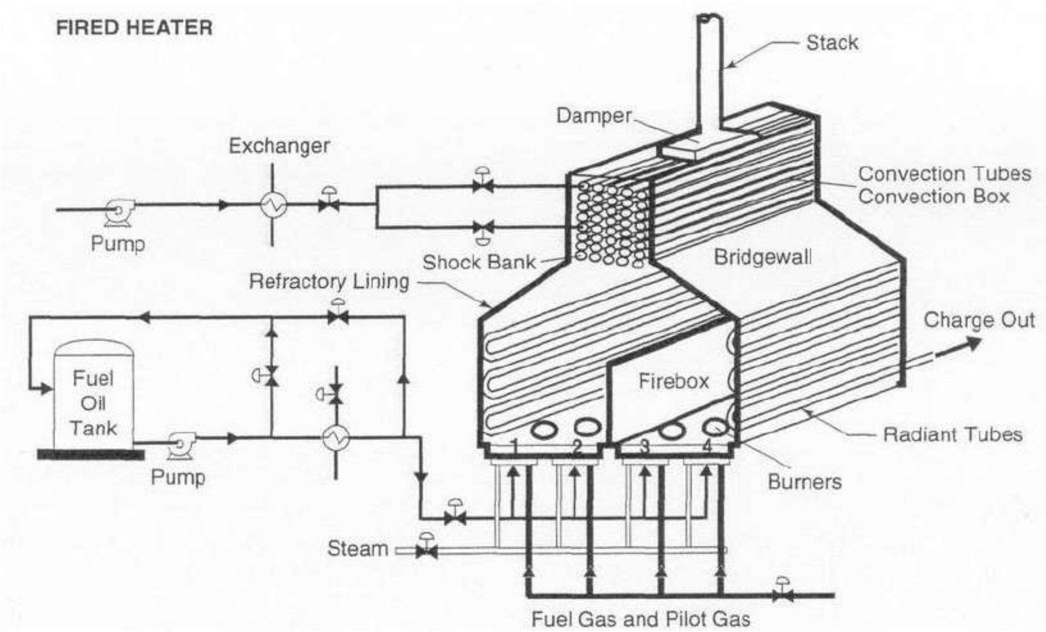


Figure 5-1 Typical diagram of fired heater

5.1.2 Types of Furnaces

There are two types of furnaces:

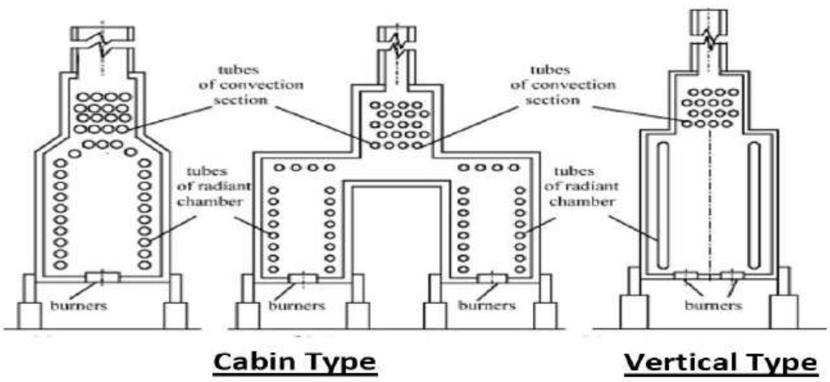


Figure 5-2Types of furnace

5.1.3 Selection of Furnace

I have Selected **Vertical Fired Heater** based on the following comparison.

Table 4-1: Shows comparison of different types of furnaces

Parameters	Box and Cabin Fired Heater	Vertical Fired Heater
Heat Duty	20MW or above	1-10 MW
Cost	High Capital Cost	Low Capital Cost
Thermal Efficiency	Low	High
Tube Length	Large	Small
Operating Pressure	High	Low
Tubes Arrangement	Horizontal	Vertical
Heat Transfer Rate	Non-Uniform	Uniform

5.1.4 Fuel Selection

I select **Furnace Oil** as fuel based on these parameters.

Table 4-2:Shows comparison of different types of fuel

Parameters	Natural Gas	Furnace Oil
Maintenance	Less	More
Cost	Economical	Expensive
Efficiency	More Efficient	Less Efficient
Storage	Gas Line Require	On site Tank to Store
Environmental Impact	Less Toxic	Highly Toxic
Btu per gallon	103050 Btu	138600 Btu
CO emission	Low	High

5.1.5 Furnace Design Steps

❖ **Calculation of Thermal Design**

- Heat Liberated by Fuel

- Inlet Heat by Air
- Heat of Leaving Exhaust Gas
- Heat Absorbed by Furnace Wall
- Net Heat Liberated by Fuel
- No of Tubes
- Actual Flue Gas Temp

5.1.6 Thermal Design Calculation

We have calculated the following parameter in thermal design.

The total hourly duty of cold plane area of furnace is calculated by following formula:

$$\frac{Q}{\alpha Acp f} = 0.173\left[\left(\frac{T_g}{100}\right) - \left(\frac{T_S}{100}\right)\right] + (T_g - T_S)$$

where,

- f is overall exchange factor
- T_G is the temperature of flue gases
- T_S is surface temperature of tubes
- A_{CP} is cold plane area

❖ Required Data for Design Calculation of F-01

Table 4-3:Shows Required Data for Design Calculation of F-01

No.	Factors	Values	Units
1	Total Require Heat Duty	20,467,326	Btu/hr
2	Fuel Name	Furnace Oil	
3	Efficiency	75	%
4	Temperature of Inlet Air	400	°F
5	Average tube temperature in radiant section, T_S	720	°F

6	Air to Fuel Ratio	17.44	lb air/ lb fuel
7	Heating value of air	82	Btu/lb
8	Lower heating value of flue gas	476	Btu/lb
9	Lower heating value of fuel	17130	Btu/lb
10	Steam for atomization	0.3	lb steam /lb oil
11	Outside Diameter of Tube	5	inches
12	Exposed Length of Tube	38.5	ft
13	Center to Center Distance	8.5	inches

Total Require Furnace Duty=20,467,326 Btu/hr

Radient section average flux (assumed) = **10,000 Btu /hr ft^2**

As in all trial-and-error solutions, a starting point must be assumed and checked. With experience, the first choice may come very close to meeting the desired conditions. For orientation purposes, one can make an estimate of the number of tubes required in the radiant section by assuming that

❖ **Effective Flux**

$$\frac{Q}{\alpha A_{cp}} = 2 \times Average\ flux = 20{,}000\ \frac{Btu}{hr\ ft^2}$$

Effective Flux = 20,000 Btu/hr ft^2

❖ **Surface Temperature of Tube**

$$T_S = \frac{T_{in} - T_{out}}{2} + T_{in}\ of\ air$$

$$T_s = \frac{44.5 - 385}{2} + 200$$

T_S = 414.75 °C =778.5 ^{0}F

❖ Exchange factor $\mathcal{F}$

Assumed exchange factor $\mathcal{F} = 0.66$

❖ **Flue Gas Temperature**

if the overall exchange factor is 0.66; from Fig. 19.14 it can be seen that with a tube temperature of 720°F, an exit-gas temperature of 1525°F will be required to effect such a flux. The duty in cooling the furnace gases to 1525°F can be calculated, and from it the required number of tubes determined for the first approximation of the design

$\frac{Q}{\alpha A_{cp}\mathcal{F}}$ = 30,303 Btu /hr ft^2

T_S =720 °F

From Graph,

T_G = 1525^{0}F

❖ **Heat Liberated by Fuel**

The duty in cooling the furnace gases to 1630°F can be calculated, and from it the required number of tubes determined for the first approximation of the design

$$Q_F = \frac{Total\ heat\ duty}{Efficiency} = \frac{Q}{\varepsilon}$$

$$Q_F = \frac{20{,}467{,}326}{0.75} = 28{,}792{,}229\frac{Btu}{hr}$$

Q_F = 28,792,229 Btu/hr

❖ **Fuel quantity**

Fuel quantity = $\frac{Q_F}{Lower\ heating\ value\ of\ fuel}$

Fuel quantity = $\frac{28{,}792{,}229}{17{,}130}$

Fuel quantity = 1681 lb/hr

❖ **Air required**

Air required = fuel quantity × air to fuel ratio

Air required = 1681 × 17.44

Air required = 29313 lb/hr

❖ **Steam for atomizing**

Steam for atomizing = Fuel quantity × Ratio

Steam for atomizing = 1681 × 0.3

Steam for atomizing = 504 lb/hr

- **Sensible heat above 60°F in combustion air Q_A**

Q_A = air required × heating value of air

Q_A = 29313 × 82

Q_A =2,403,689 Btu/hr

- **Heat loss through furnace walls Q_W**

Q_W = 2% of Q_F

Q_W = 2% (2,403,689)

Q_W=575,845 Btu/hr

- **Net heat Q_{net}**

Q_{net} = Q_F + Q_A- Q_w

Q_{net} = 28,792,229 + 2,403,689 - 575,845

Q_{net} = 30,620,074 Btu/hr

- **Heat leaving the furnace radiant sections in the flue gases, Q_G**

Q_G = Heating value of flue gas (Fuel required + Air required + Steam required)

Q_G = 476 (1681+ 29313 + 504)

Q_G = 14,993,205 Btu/hr

- **Net Heat Liberated By Fuel**

Q= Q_{net} – Q_G

Q= 30,620,074 – 14,993,205

Q = 15,626,869 Btu/hr

- **Surface per tube**

A= πDL

$$A = 3.14 \times \frac{5}{12} \times 38.5$$

$A = 50.4 ft^2$

❖ **No. of Tubes**

$$Number\ of\ tubes = \frac{Q}{A}$$

$$Number\ of\ tubes = \frac{15{,}626{,}869}{50.4}$$

$$Number\ of\ tubes = 31$$

The layout of the cross section of the furnace may be as shown in figure

Length = 38.5 ft

Width = 11.33 ft

Height = 7.79 ft

Bridge wall Height = 4.96 ft

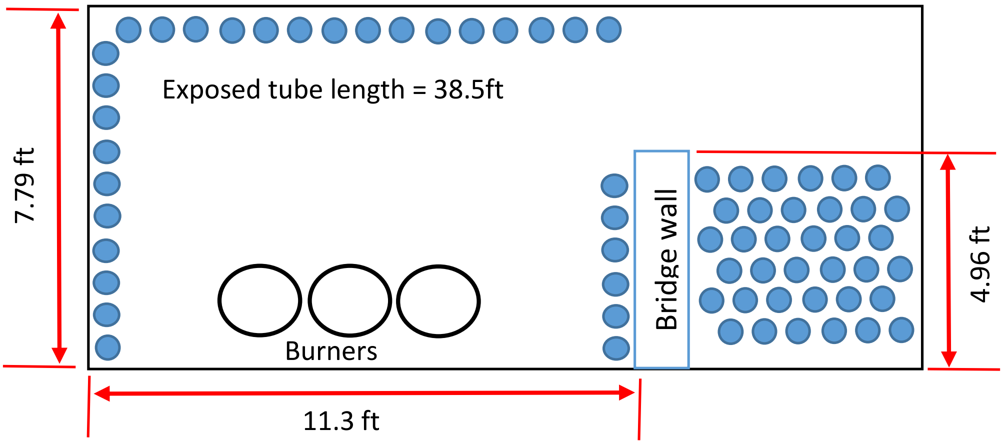


Figure 5-3 Furnace Dimensions

❖ **Equivalent Cold plane Surface A_{CP}**

Center to center distance = 8.5 inch

$$A_{cp}\ per\ tube = center\ to\ center\ distance \times Exposed\ tube\ length$$

$$A_{cp}\ per\ tube = \frac{8.5}{12} \times 38.5$$

$$A_{cp}\ per\ tube = 27.3 ft^2$$

❖ **Factor of comparison with two parallel planes α**

$$Ratio = \frac{\text{Center to center distance of tubes}}{Outside\ diameter\ of\ tubes}$$

$Ratio = \frac{8.5}{5}$

$Ratio = 1.7$

α = 0.937

$\alpha A_{cp}\ per\ tube\ =\ A_{cp}\ per\ tube \times \alpha$

$\alpha A_{cp}\ per\ tube\ =\ 27.3 \times 0.937$

$\alpha A_{cp}\ per\ tube\ =\ 25.6\ ft^2$

$\alpha A_{cp} = \alpha A_{cp}\ per\ tube\ \times Number\ of\ tubes$

$\alpha A_{cp} = 25.6\ \times 31$

$\alpha A_{cp} = 792\ ft^2$

- **Dimension of Furnace:**

As, L:H:W = 4:2:1. So,

L=38.5ft H= 7.79ft W= 11.33ft H_{BW} = 4.96ft

End Wall = 2 x H x W = 177 ft^2

Side Wall = W x L = 300 ft^2

Bridge Wall = L x H_{BW} =191 ft^2

Floor & Arch= 2 x W x L = 873 ft^2

- **Total Exposed Area of Radiant Section:**

A_T = End Wall + Side Wall + Bridge Wall + Floor & Arch

A_T = 177+ 300+ 191+ 873

A_T=1540 ft^2

- **Effective Refractory surface A_R:**

$A_R = A_T - \alpha A_{cp}$

$A_R = 1540 - 792$

$A_R = 748\ ft^2$

$\frac{A_R}{\alpha A_{cp}} = \frac{748}{792}$

$$\frac{A_R}{\alpha A_{cp}} = 0.94$$

❖ **Mean Beam Length:**

$$Mean\ Beam\ lenght, L = \frac{2}{3}\sqrt[3]{V}$$

$$L = \frac{2}{3}\sqrt[3]{L \times W \times H}$$

$$L = \frac{2}{3}\sqrt[3]{38.5 \times 11.33 \times 7.79}$$

$$L = 10\ ft$$

❖ **Gas Emissivity & Overall Exchange Factor:**

P_{CO2} = 0.2697 atm

P_{H20} = 0.2921 atm

P_{CO2} x L = 2.7032 atm ft

P_{H20} x L = 2.9285 atm ft

❖ **Radiant Heat transfer fluxes at T_G:**

q_C = 5500

q_W = 10900

q_b = 26000

❖ **Radiant Heat transfer fluxes at T_S :**

q_C = 600

q_W = 1950

q_b = 3500

❖ **Emissivity of gas ϵ_G:**

The emissivity of the gas can be evaluated

$$\epsilon_G = \left[\frac{(q_c + q_w)_{T_G} - (q_c + q_w)_{T_S}}{(q_b)_{T_G} - (q_b)_{T_S}}\right]\frac{100 - \%}{100}$$

$$\epsilon_G = \left[\frac{(5500 + 10900) - (600 + 1950)}{(26000) - (3500)}\right]\frac{100 - 8}{100}$$

% correction at $\frac{p_{CO_2}}{p_{CO_2}+p_{H_2O}}$

$$\frac{p_{CO_2}}{p_{CO_2} + p_{H_2O}} = \frac{0.2697}{0.5618} = 0.480$$

$p_{CO_2}L + p_{H_2O}L = 0.2697 + 0.2928 = 0.563$

% correction = 8

ϵ_G = 0.566

- **Over all Exchange factor $\mathcal{F}$:**

$$\frac{A_R}{\alpha A_{cp}} = 0.94$$

Flame emissivity ϵ_G = 0.566

The overall exchange factor from figure will be

$\mathcal{F}$ =0.6

Table 5-1 Specification sheet of furnace (H-101)

Thermal Design Specifications	
IDENTIFICATION	
Item	Fired Heater
Type	Box type
Fuel	Fuel Oil
DESIGN ASPECTS	
Inlet Temperature	303°F
Outlet Temperature	720°F
Efficiency	75
Flue gas temperature	1525°F
Heat Liberated by Fuel	28,792,229 Btu/hr
Heat of Leaving Exhaust Gas	14,993,205 Btu/hr
Net Heat Liberated	30,620,074 Btu/hr
No of Tubes	31
Length	38.5 ft
Width	11.33 ft
Height	7.79 ft
Height of bridge wall	4.96 ft

Mean beam length	10 ft
Overall exchange factor $\mathcal{F}$	0.66

5.2 Fixed Bed Reactor (R-01)

5.2.1 Introduction

Chemical reactors are the vessels, designed to perform chemical reactions in chemical engineering. To maximize the present value for the given reaction, chemical engineer designs the reactor. The responsibility of a reactor designer is to maximize the efficiency of reactor with producing the highest yield of desired output products while using least number of sources like energy, raw materials etc.

5.2.2 Types of Reactors

There are some types of reactors used in reactions commonly:

1. Continuous Stirred Tank Reactor (CSTR)
2. Batch Reactor
3. Plug Flow reactor (PFR)
4. Fixed Bed Reactor (FBR

5.2.3 Selection of Reactor

The reactor is selected on the bases on following points:

- Heterogeneous reaction
- Low endothermic reaction

Due to the facts mentioned above as our catalyst is the solid and we are dealing with the large production rate and the type of reaction is heterogeneous in which the liquid phase reactant reacts over the solid bed catalyst. We have selected the FBR reactor for our system.

Further there are two classifications in the FBR reactor based upon the operation.

- Isothermal reactor
- Adiabatic reactor

❖ **Comparison of Isothermal and Adiabatic reactor:**

Table 5-2 Comparison of isothermal and adiabatic reactor

Isothermal Reactor	Adiabatic Reactor
Transfer of heat occur in this process.	No heat goes inside or leaves the system.

At a given volume of the substance, the pressure remains high.	At a given volume of the substance, the pressure remains low.
In an isothermal process, the temperature remains invariant.	The temperature varies because of the internal system changes.
The isothermal process has a slower transformation flow.	The adiabatic process has a faster transformation flow.
Good for temperature sensitive reactions.	Good for temperature insensitive reactions.

Due to the above-mentioned differences, we have selected the adiabatic system because our catalyst can withstand the temperature up to 375-385 ^{0}C.

Major reactions that take place in the reactor are:

Main Reaction: **(ΔH^{o}_{rxn} at 25 ^{o}C = 181.52 kJ/mol)**

$$CH_{15}H_{31}COOH_{(l)} \rightarrow C_{14}H_{28\,(l)} + CH_3COOH_{(g)}$$

Palmitic Acid Drying Oil

AceticAcid

Side Reaction:

$$2C_{14}H_{28\,(l)} \rightarrow C_{28}H_{56\,(s)}$$

Drying Oil Gum

❖ **Reaction Conditions:**

Temperature = 375-385 °C

Pressure = 195 kPa

5.2.4 Fixed Bed Reactor Design Steps

❖ **Calculation of Process Design**

- Volume of reactor
- Weight and Volume of catalyst
- Space time

❖ **Calculation of Thermal Design**

- Pressure Drop

❖ **Assumptions**

There are following assumptions as:

- Steady-State Flow.
- One Dimensional Plug Flow.
- Distribution of Concentration, Heat, Pressure, and Temperature is uniform in each crossection of the reactor.
- Isothermal Operation.
- No Side reaction is occurring in the system.

❖ **Required Data for Design Calculation of R-01**

Properties of Catalyst:

Shows properties of catalyst

TYPE	**Ni-Tn**
BED POROSITY	0.5
BULK DENSITY	960 kg/m^3
PARTICLE DIAMETER	5 mm
SHAPE	Spherical

5.2.5 Process Design Calculation of Reactor

❖ **Volume of Reactor**

Pressure = 195 kPa

Temperature = 380°C = 653 K

Flow rate of PA= F_{Ao} = 149.02 kmol/hr

=0.0414 kmol/s

Reactor Design Equation:

$$\frac{W}{F_{Ao}} = \int_0^{X_1} \frac{dX_A}{(-r_A)}$$

1st Reaction:

Table 5-3 Information of 1st reaction

Reaction Temperature,T	653	K
Ideal gas constant, R	1.987	cal/K mol
density,ρ	853	kg/m^3
mass flow rate	38208	kg/h
Volumetric flow rate	44.8	m^3/h
	0.012	m^3/s
Initial molar feed rate, F_{Ao}	149.02	kmol/h
Initial concentration, C_{Ao}	3.3	$kmol/m^3$

$-r_1 = k_1 C_A$

$$k_1 = 5.538 \times 10^{13} e^{-(\frac{44500}{RT})}$$

Now,

C_{AO} = Molar Flowrate/ Volumetric Flowrate

Molar Flowate =149.02 kmol/h

Volumetric Flowrate = 44.8 m^3/h

Putting these values in equation , we get

C_{AO} =3.3 kmol/ m^3

Table 5-4 Data points for Levenspil plot of 1st reaction

Levenspiel plot of 1st Reaction Data points		
X_1	**$(-r_1)$**	**$1/(-r_1)$**
0.00	0.26	3.78
0.04	0.25	3.93
0.08	0.24	4.09

0.11	0.23	4.27
0.15	0.22	4.46

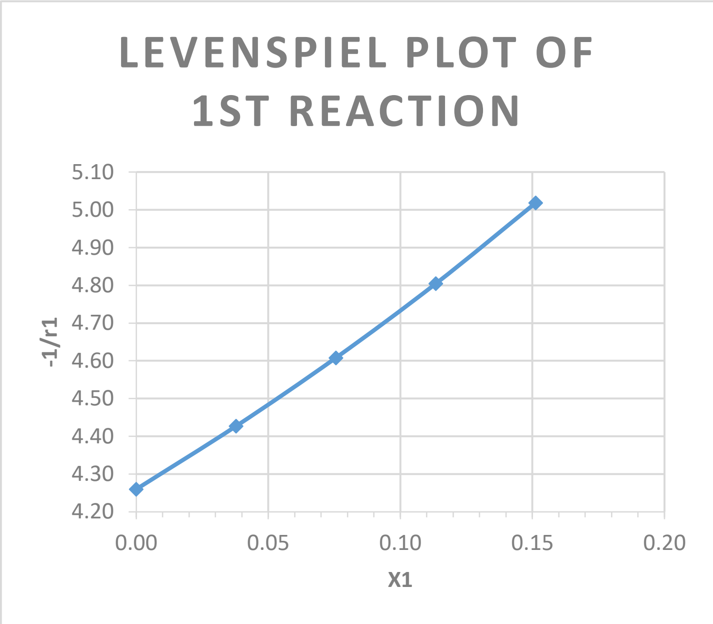


Figure 5-4 Levenspiel plot of 1st reaction

$$\int_{X_0}^{X_4} f(X)dX = \frac{h}{3}[f(X_0) + 4f(X_1) + 2f(X_2) + 4f(X_3) + f(X_4)]$$

$$h = \frac{X_4 - X_0}{4}$$

$$\frac{W_1}{F_{PAo}} = \int_0^{X_1} \frac{dX_1}{(-r_1)}$$

$$\frac{W_1}{F_{PAo}} = 0.699$$

Weight of catalyst, W_1 = 104 kg

2nd Reaction:

Table 5-5 Information of 2nd reaction

Reaction Temperature	653	K
Ideal gas constant, R	1.987	cal/K mol
Density,ρ	775	kg/m^3
Mass flow rate	55	kg/h
Volumetric flow rate	0.071	m^3/h
	0.000020	m^3/s

Initial molar feed rate, F_{Bo}	0.21	kmol/h
Initial concentration, C_{Bo}	3.0	$kmol/m^3$

$-r_2 = k_2 C_B^2$

$$k_2 = 1.55 \times 10^{26} e^{-(\frac{88000}{RT})}$$

C_{BO} = Molar Flowrate/ Volumetric Flowrate

Molar Flowate = 0.21 kmol/h

Volumetric Flowrate = 0.071 m^3/h

Putting these values in equation , we get

C_{BO} =3 kmol/ m^3

Table 5-6 Data points for Levenspiel plot of 2nd reaction

Levenspiel plot of 2nd Reaction		
X_2	**$(-r_2)$**	**$1/(-r_2)$**
0.00E+00	1.610E-03	621.3
1.57E-04	1.609E-03	621.4
3.13E-04	1.609E-03	621.5
4.70E-04	1.609E-03	621.6
6.27E-04	1.609E-03	621.7

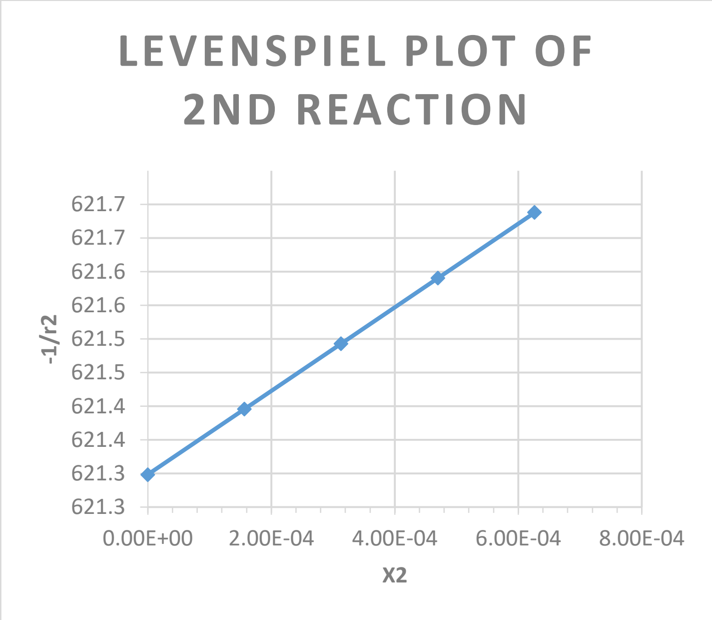


Figure 5-5 Levenspiel plot of 2nd reaction

$$\int_{X_0}^{X_4} f(X)dX = \frac{h}{3}[f(X_0) + 4f(X_1) + 2f(X_2) + 4f(X_3) + f(X_4)]$$

$$\frac{W_2}{F_{TDo}} = \int_0^{X_2} \frac{dX_2}{(-r_2)}$$

$$\frac{W_2}{F_{TDo}} = 0.389$$

Weight of catalyst, W_1 = 0.1 kg

- **Weight of catalyst:**

$W_T = W_1 + W_2$

$W_T = 104.2 + 0.1$

$W_T = 104.3$kg

- **Volume of Catalyst:**

$$Volume\ of\ Catalyst = \frac{Total\ Weight}{Bulk\ density\ of\ catalyst}$$

Bulk density of Ni-Tin catalyst = 960 kg/m^3

$$V_{cat} = \frac{W_T}{\rho_{bulk}}$$

$$V_{cat} = \frac{104.3}{960}$$

$V_{cat} = 0.11m3$

- **Volume of Reactor:**

$$Volume\ of\ Reactor\ = \frac{V_{cat}}{1 - Voidage}$$

$$Volume\ of\ Reactor\ = \frac{0.11}{1 - 0.79}$$

$V_R = 0.52\ m^3$

- **Diameter of Reactor:**

As volume of a cylinder is obtained by using

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

Diameter of reactor D = 0.5m

- **Length of Reactor:**

As L/D is 5

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

Length, L= 2.5m

- **Volume of Bed:**

Assumption: The volume of bed is 10% less than volume of reactor

$$V_B = V_R - 10\%\ V_R$$

Volume of Bed = 0.097 – (10%*0.097)

Volume of Bed = 0.47 m^3

- **Space Time:**

Density of PA = 853 kg/m^3

Molar flow rate of PA = 149.02 kmol/hr

Density of DO = 775 kg/m^3 =2.163 $kmol/m^3$

Molar flow rate of DO = 0.191 kmol/hr

Density of mixture = 853 kg/m^3

Total volumetric flowrate = 45m^3/h

Since space time is related with volume as follows:

$$\tau = \frac{V_R}{Vo}$$

$$\tau = \frac{0.52}{45}$$

$$\tau = 0.012h$$

$$\tau = 41s$$

5.2.6 Thermal Design Calculation:

Particle diameter Dp =1.5mm

Fluid viscosity μ =1.5x10^{-4} kg/ms

Fluid Density ρ =685kg/m^3

Area = πDL = 4.1m^2

Superficial velocity u_o= Area / Volumetric flowrate

Superficial velocity u_o= 0.003 m/s

Mass Velocity G = u_o ρ =2.1kg/m^{2}s

Using Ergun Equation for the pressure drop of bed.:

$$\frac{\Delta P}{L} = \frac{150\mu G(1-\varepsilon)^2}{\rho D^2 \varepsilon^3} + \frac{1.75G^2(1-\varepsilon)}{\rho D \varepsilon^3}$$

Putting all the values in equation, we get:

$$\Delta \boldsymbol{P} = 7\ \boldsymbol{kPa}$$

Table 5-7 Specitication sheet of Fixed bed Reactor (R-101)

SPECIFICATION SHEET	
Identification	
Item	Reactor
Item No	R-101
Operation	Continuous
Type	Isothermal Packed Bed Reactor
Function	
Palmitic acid to 1-Tetradecene	
Chemical Reaction	
$C_{15}H_{31}COOH_{(l)} \xrightarrow{k_1} CH_3COOH_{(g)} + C_{14}H_{28(l)}$ Palmitic acid Acetic acid 1-Tetradecene $C_{14}H_{28(l)} \xrightarrow{k_2} C_{28}H_{56(s)}$ 1-Tetradecene Gum	
Catalyst	Ni-Sn
Weight of Catalyst	104 kg
Volume of Catalyst	$0.11m^3$
Volume of Reactor	$0.52m^3$
Diameter of Reactor	0.5m
Length of Reactor	2.5m
Space Time τ	41s
Pressure drop ΔP	7 kPa

5.3 Distillation Column:

5.3.1 Introduction:

Distillation is the process that is used for the separation of different components on the basis of their boiling points and relative volatilities. Distillation column is used for such separation purposes and it separates the components in terms of distillate and bottom. Distillate and bottom are the products that achieved from the top and bottom of the distillation column. In the mixture, the components that are main focus of separation are termed as key components. The key components include the light key that is more volatile and contains greater purity in the distillate, and the heavy key that is less volatile and contains greater purity in the bottom.

5.3.2 Type of Column:

There are two main categories of distillation column on the basis of column internals that are Tray Column and Packed Column. We have selected tray/plate column as it has the ability to handle wide range of flowrates, it is easier to clean and use, it is more economical as compared to packed column as packed column is only suitable for a diameter up to 2ft and above all tray columns are more in commercial use.

And among different types of trays, our selection is sieve tray due to its low relative cost with low pressure drop and high vapor capacity

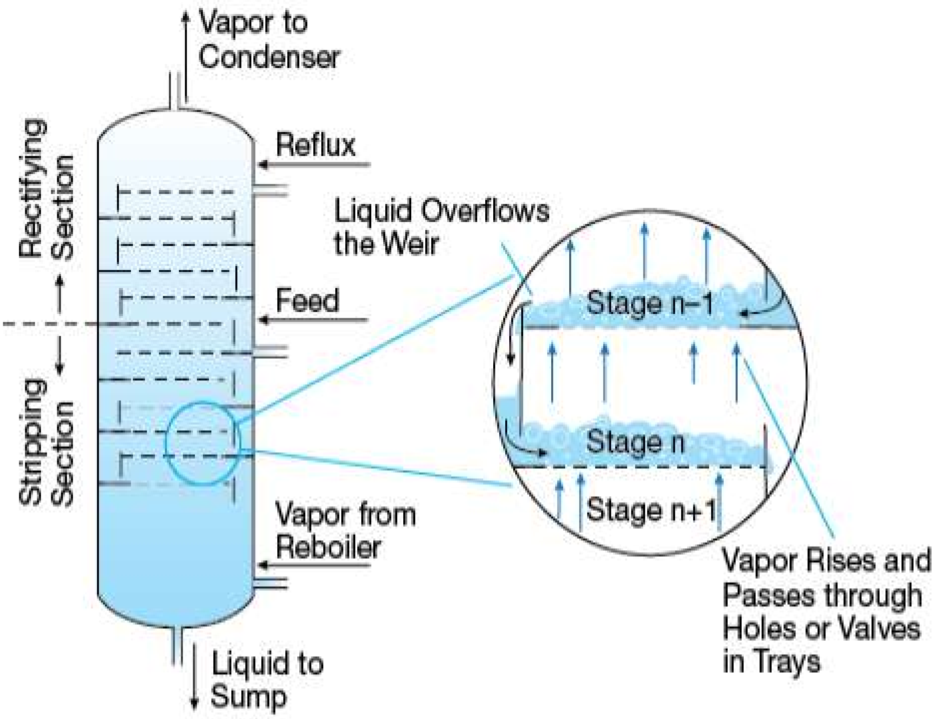


Figure 5-6 Distillations column working

5.3.3 Objective:

To separate the desired product of 1-Tetradecene (Drying Oil) from the mixture of Acetic acid and unreacted Palmitic acid and get 99% purity of 1-Tetradecene.

5.3.4 Distillation Column Design Steps:

Following are the steps to follow/things to calculate for the design calculations of distillation column:

- Calculation of Minimum Reflux Ratio R_m.
- Calculation of optimum reflux ratio.
- Calculation of theoretical number of stages.
- Calculation of actual number of stages.
- Calculation of diameter of the column.
- Calculation of weeping point.
- Calculation of pressure drop.
- Calculation of thickness of the shell
- Calculation of the height of the column.

5.3.5 Distillation Column Design:

Temperature of feed = 265° C

Temperature of top product = 296° C

Temperature of bottom product = 300° C

P = 1 atm

Components	Feed (Kg/hr)	Distillate (Kg/hr)	Bottom (Kg/hr)
Palmitic Acid	32425	37	32388
1-Tetradecene	4468	4426	42
Acetic acid	1354	1354	0
	38247	**5817**	**32430**

Components	Feed (Kmol/hr)	Distillate (Kmol/hr)	Bottom (Kmol/hr)
Palmitic Acid	126.46	0.14	126.32
1-Tetradecene	22.75	22.54	0
Acetic acid	22.55	22.5	0.21
	172	**45.25**	**126.5**

Heavy Key Component = Acetic Acid

Light Key Component = Palmitic Acid

5.3.5.1 Calculation of Minimum Reflux Ratio R_m:

Table 5-8 Minimum reflux ration

Components	Mole Fraction	K	α
Palmitic Acid	0.85	0.4605	1
1-Tetradecene	0.04	0.9712	2.109
Acetic acid	0.12	14.011	0.47415

Using Underwood equation,

$$\frac{\alpha_A x_{fA}}{\alpha_A - \theta} + \frac{\alpha_B x_{fB}}{\alpha_B - \theta} = 1 - q$$

As feed is entering as vapors so, q = 0

By trial, θ = 0.061

Using eq. of min. reflux ratio,

$$\frac{\alpha_A x_{fA}}{\alpha_A - \theta} + \frac{\alpha_B x_{fB}}{\alpha_B - \theta} = R_m + 1$$

Putting all values $R_m = 1.14$

5.3.5.2 Actual Reflux Ratio:-

The rule of thumb is:

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

$$R = 1.2\, R_{min}$$

$$R = 1.4$$

5.3.5.3 Calculation of Minimum no. of Plates:-

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

$$N_{min} = \frac{\log\left[\left(\frac{X_B}{X_C}\right)_D \left(\frac{X_C}{X_B}\right)_B\right]}{\log(\alpha_{BC})_{ave}}$$

$N_{min} = 13$

5.3.5.4 Theoretical no. of Plates:-

Gilliland related the number of equilibrium stages and the minimum reflux ratio and the no. of equilibrium stages with a plot that was transformed by Eduljee into the relation;

$$N - N_{\min} / N + 1 = .75 \left[1 - \left(R - R_{\min} / R + 1 \right)^{0.566} \right]$$

From which the theoretical no. of stages to be,

N = 26

One plates is removed for reboiler, so N = 26 - 1 = 25

5.3.5.5 Location of feed Plate:-

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

$$\log\left(N_D / N_B \right) = .206 \log\left[\left(B / D \right) \left(x_{HK} / x_{LK} \right) \left((x_{LK})_B / (x_{HK})_D \right)^2 \right]$$

From which,

Feed Enter on plate = 22

Number of Plates above the feed tray = N_B = 22

Number of Plates below the feed tray = N_D = 13

5.3.5.6 Calculation of actual number of stages:-

- **<u>Tray Efficiency:</u>**

Average temperature of column = T = 265^{o}C

Feed viscosity at average temperature = μ_{ave} = 0.062 Cp

(Relative volatility of key component) × μ_{ave} = 2.1 × 0.062 = 0.131

E_o = 70% (O' Connell's Correlation)

Reference Vol-6-P-723-(Figure.11.19)

$$E_o = 51 - 32.5 \log(\mu_{ave} * \alpha_a)$$

E_o = 70% (Eduljee)

Reference Vol-6-P-723-(Eq-11.34)

So, No. of actual trays =

$$N_{Actual} = \frac{34}{0.70} = 36$$

Location of feed point $= \frac{36}{1.45} = 22$

5.3.5.7 Determination of the Column Diameter

Table 5-9 Calculations for column diameter

Top Conditions	Bottom Conditions
L_n = D* Rmin	$L_m = L_n + F$
L_n = 51.8 Kmol/hr	L_m = 223.8 Kmol/hr
$V_n = L_n + D$	$V_m = L_m – B$
V_n = 97.37 Kmol/hr	V_m = 97.37 Kmol/hr
Average mol.Wt. = 165 g/mol	Average mol. Wt. = 256 g/mol
T = 296 ^{0}C	T = 300 ^{0}C
ρV = 4.75 Kg/m3	ρV = 6.23 Kg/m3
ρL = 600 Kg/m3	ρL = 640 Kg/m3

- **Maximum Volumetric Flowrate of Vapors:**

$$\text{Top of Column} = \frac{D \times Molecular\ Weight}{\rho_v}$$

Top of Column = 0.51 m3/s

$$\text{Base of Column} = \frac{D \times Molecular\ Weight}{\rho_v}$$

Base of Column = 1.44 m3/s

- **Maximum Volumetric Flowrate of Liquid:**

$$\text{Top of Column} = \frac{W \times Molecular\ Weight}{\rho_L}$$

= 0.0034 m3/s

$$\text{Base of Column} = \frac{W \times Molecular\ Weight}{\rho_L}$$

= 0.0014 m3/s

❖ Flow Parameter:

Table 5-10 Flow rate parameters

Top Conditions	Bottom Conditions
• $F_{\mathrm{LV}} = \left(\frac{L_n}{V_n}\right)\left(\frac{\rho_v}{\rho_L}\right)^{0.5}$ $= 0.044\ m/s$	• $F_{\mathrm{LV}} = \left(\frac{L_n}{V_n}\right)\left(\frac{\rho_v}{\rho_L}\right)^{0.5}$ $= 0.226\ m/s$
Figure 11.34 Volume 06	Figure 11.34 Volume 06
$find\ k_1\ across\ F_{LV}$	$find\ k_1\ across\ F_{LV}$
$(k_1 = 0.065)$	$(k_1 = 0.045)$
Correction for Surface Tension	Correction for Surface Tension
$k_{1\,(Corrected)} = k_1 \times \left(\frac{\sigma}{20}\right)^{0.2}$	$k_{1\,(Corrected)} = k_1 \times \left(\frac{\sigma}{20}\right)^{0.2}$
$(k_{1\,(corrected)} = 0.0607)$	$(k_{1\,(corrected)} = 0.0445)$
• $u_f = K_1\sqrt{\frac{\rho_L-\rho_v}{\rho_v}}$ $= 0.725\ m/s$	• $u_f = K_1\sqrt{\frac{\rho_L-\rho_v}{\rho_v}}$ $= 0.448\ m/s$
For 85% flooding	For 85% flooding
• $U_n = u_f \times \%flooding$ $= 6.16\ m/s$	• $U_n = u_f \times \%flooding$ $= 0.38\ m/s$
Maximum Volumetric Flow	Maximum Volumetric Flow
$\hat{V} = 1.\dot{2}\ m^3/s$	$\hat{V} = 1.2\dot{4}\ m^3/s$
Net Area	Net Area
• $A_n = \hat{V}/U_n$ $A_n = 1.94\ m^2$	• $A_n = \hat{V}/U_n$ $A_n = 3.25\ m^2$
Take A_d = 12% of A_c	Take A_d = 12% of A_c
• $A_n = A_c - A_d$ $A_n = A_c - 0.12A_c$	• $A_n = A_c - A_d$ $A_n = A_c - 0.12A_c$

$= 2.2\ m^2$ Column Diameter • $D_c = \sqrt{\frac{4 \times A_c}{\pi}}$ $= 1.67\ m^2$	$= 3.7\ m^2$ Column Diameter • $D_c = \sqrt{\frac{4 \times A_c}{\pi}}$ $= 2.16\ m^2$

Assumed tray spacing = 30 mm = 0.3 m

Plate spacing

The overall height of the column will depend on the plate spacing. Plate spacings from 0.15 m (6 in.) to 1 m (36 in.) are normally used. The spacing chosen will depend on the column diameter and operating conditions. Close spacing is used with small-diameter columns, and where head room is restricted; as it will be when a column is installed in a building. For columns above 1 m diameter, plate spacings of 0.3 to 0.6 m will normally be used, and 0.5 m (18 in.) can be taken as an initial estimate. This would be revised, as necessary, when the detailed plate design is made.

A larger spacing will be needed between certain plates to accommodate feed and side-streams arrangements, and for manways.

❖ Provisional Plate Design:

Column Area Ac

$$Ac = \frac{\pi}{4} D^2$$

$$Ac = 3.7\, m^2$$

Down comer area, $A_d = 0.12 \text{ x } A_c = 0.432\, m^2$

$$\text{Net area } A_n = A_c - A_d$$

$$\text{Net area } A_n = 3.7 - 0.436$$

$$A_n = 3.1\, m^2$$

Active area,

$$A_a = A_c - 2A_d = 3.7 - (2 \times 0.46)$$

$$A_a = 2.68\, m^2$$

Hole area A_h take 10% A_a as first trial = 0.1 × 2.81

$$A_h = 0.28\, m^2$$

- **Weir length:**

$$\frac{A_d}{A_c} = \frac{0.432}{3.7} = 0.12$$

$$\frac{l_w}{D_c} = 0.76$$

$$l_w = 0.76 \times 2.5$$

$$l_w = 1.9 \text{ m}$$

Take weir height $h_w = 50$ mm

Hole diameter $d_h = 5$ mm

Plate thickness $= 5$ mm

- **Check Weeping:**

$$\text{Liquid flowrate} = \text{RD} + \text{F}$$

$$\text{Maximum liquid flowrate} = \frac{\text{Liquid flowrate} \times \text{M.W}}{3600}$$

Maximum liquid rate $= 14$ kg/s

Minimum liquid rate at 70% turn down $= 9.8$ kg/s

Height of liquid crest over segmental weir

$h_{ow} =$ weir crust

For segmental down comer

$$\text{Maximum} \quad h_{ow} = 750\left(\frac{Lw}{\ell_l \times Ad}\right)^{2/3}$$

$h_{ow(\max)} = 50$ mm

$h_{ow(\min)} = 40$ mm

at minimum $h_w + h_{ow} = 50 + 40 = 90$ mm liquid

K_2 = 30.9

$$\breve{U}_{(\min)} = \frac{K_2 - 0.9(25.4 - a_n)}{(p_v)^{\frac{1}{2}}}$$

$$\breve{U}_{(\min)} = 4.9\, m/s$$

$$\text{Actual minimum vapour velocity} = \frac{0.07\times \text{minimumvapor vol rate}}{A_h}$$

$Minimum\ liquid\ rate, at\ 70\ per\ cent\ turn - down$

$$= \frac{0.7 \times 1.24}{0.249} = 3.08 \text{ m/s}$$

$Reduce\ the\ hole\ Area\ to\ 4\%\ of\ active\ area$

$= 2.81 \times 0.04 = 0.1126\ m$

$$= \frac{0.7 \times 0.44}{0.249} = 7.72 \text{ m/s}$$

$It\ is\ above\ the\ weep\ point$

5.3.5.8 Plate Pressure Drop:

Maximum vapor velocity through holes

$$\widehat{U}_{h(max)} = \frac{\text{Max vapor volumetric flow Rate}}{\text{Hole Area}}$$

$$\widehat{U}_{h(max)} = \frac{1.240}{0.1124} = 11\ m/s$$

Plate thickness / hole dia = 5 / 5 = 1.0 = 10%

And

$$\frac{A_h}{A_p} = \frac{A_h}{A_a} = \frac{0.281}{2.81} \times 100 = 10\%$$

$C_o = 0.84$

$$h_d = 51 \left[\frac{\widehat{U}_h}{C_o}\right]^2 \frac{\delta_V}{\delta_L}$$

$h_d = 91$ mm

- **Residual Head:**

$$h_r = \frac{12.5 \times 10^3}{\rho_l}$$

$$h_r = \frac{12.5 \times 10^3}{620}$$

$$h_r = 20\ mm$$

❖ **Total Pressure Drop:**

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

$$h_t = 91 + 50 + 51 + 20$$

$$h_t = 136\ mm$$

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

$= 9.81 \times 104 \times 78.9 \times 701$

= 1250 Pa

= 0.07 psi

5.3.5.9 Down comer Liquid Backup:

Take $h_{ap} = h_w - 10$

$h_{ap} = 50 - 10 = 40$ mm

Area under apron $= h_{ap} \times l_w$

$h_{ap} = 40 \times 10^{-3} \times 1.87 = 0.075\ m^2$

$h_{dc} = 166\ \left[\frac{l_{wd}}{\rho_L A_n}\right]$

$h_{dc} = 14$ mm liq.

5.3.5.10 Backup in down comer:

$h_b = h_{dc} + (h_w + h_{ow}) + h_r$

$h_b = (50 + 51) + 136 + 14$

$= 197$ mm liquid $= 0.2$ liquid m

½ (Tray spacing + weir height)

= [½ * (300 + 50)] = 0.175m

0.2 < ½ (Tray spacing + weir height)

So tray spacing is acceptable

5.3.5.11 Check Residence Time

$$t_r = \frac{(A_d \times h_{bc} \times \rho_L)}{L_{wd}}$$

$= 6.6s > 3$ (acceptable)

5.3.5.12 Check Entrainment:

$$U_n = \frac{1.45}{3.31} = 0.54\, m/s$$

$$percentage\ flooding = \frac{0.5}{0.7} \times 100$$

$$percentage\ flooding = 71\ \%$$

As $F_{LV} = 0.226$

From Figure, we calculate

Ψ = 0.005

Ψ = Fractional Entrainment factor

Since Ψ < 0.1, so now process is satisfactory

- **Perforated Area:**

$$\frac{l_w}{D_c} = \frac{1.87}{2.5} = 0.75$$

$$\theta_c = 100\ ℃$$

$Angle\ subtended\ by\ the\ edge\ of\ the\ plate$

$$= 180 - 100 = 80℃$$

$Mean\ length, unperforated\ edge\ strips$

$$= \pi \frac{80}{180} \times (D_c - h_w)$$

$$Mean\ length, unperforated\ edge\ strips = 3.41\ m$$

$Area\ of\ unperforated\ edge\ strips$

$$= 50 \times 10^{-3} \times 3.41$$

$$Area\ of\ unperforated\ edge\ strips = 0.17\ m^2$$

$Mean\ length\ of\ calming\ zone, appro = \ weir\ length\ \ width\ of\ unperforated\ strip$

$Mean\ length\ of\ calming\ zone, approx = 1.92\ m$

$Area\ of\ calming\ zones = 2\ (ML\ of\ Calming\ \times w\ )$

$Area\ of\ calming\ zones = 0.192m$

$Total\ area\ for\ perforations,$

$A_p = \ A_a - A_{unperforated} - A_{calming\ zone}$

$Total\ area\ for\ perforations, A_p = 2.318\ m$

$\frac{A_n}{A_p} = \frac{0.268}{3.174}$

$\frac{A_n}{A_p} = 0.08\ and\ \ \frac{l_p}{d_h} = 3.1$

$\frac{l_p}{d_h}\ (\ 2.5 - 4.0)\ satisfactory$

- **No of Holes:**

Diameter of one hole = 5 mm =0.005 m

Area of one hole = 22/7*(0.005 /2)^2 = 1.9635 *10^{-5}

$Total\ Hole\ Area\ = 0.268\ m^2$

$$Number\ of\ Holes = \frac{hole\ area}{area\ of\ one\ hole}$$

$$Number\ of\ Holes = \frac{0.268}{1.965 \times 10^5}$$

$$Number\ of\ Holes\ =\ 5734\ holes$$

5.3.5.13 Height of Column

$No. of\ plates\ =\ 36$

$Spacing\ between\ each\ plate\ =\ 300\ mm = 0.3\ m$

$Space\ for\ disengagement\ of\ vapor\ and\ liquid\ on\ top\ =\ 300\ mm$

$Space\ for\ disengagement\ of\ vapor\ and\ liquid\ in\ bottom\ =\ 300\ mm$

$$Height\ of\ column = [(No.of\ plates - 1) \times (space\ between\ each\ plate)] + (space\ for\ disengagement\ on\ top\ and\ bottom)$$

$$Height\ of\ column = [(36 - 1) \times 0.3) + 0.5\,]$$

$$So\ \ height\ of\ column = 131\,m$$

Table 5-11 Specification sheet of Distillation column (T-101)

SPECIFICATION SHEET	
Identification	
Item	Distillation Column (T-101)
Type	Sieve Tray
Function	
Separation of Unreacted glycerol	
Material Balance	
Feed In	38247 kg/hr.
Top Product	5817 kg/hr.
Bottom Product	32430 kg/hr.
Operating Condition	
Pressure	1.36 atm
Number of trays	35
Reflux Ratio	1.4
Tray spacing	0.3 m
Height of column	11 m
Diameter of column	2.5 m
Pressure drop per tray	0.189psi
Tray thickness	5 mm

Hole diameter	5 mm
Weir height	50 mm
Weir length	1.87 m
Active area	2.812 m^2
Number of holes	5734 holes
Percentage flooding	85%

Table 5-12 S Specification sheet of Distillation column (T-102)

SPECIFICATION SHEET	
Identification	
Item	Distillation Column (T-102)
Type	Sieve Tray
Function	
Separation of desired product 1-tetradecene	
Material Balance	
Feed In	5817 kg/hr.
Top Product	1353 kg/hr.
Bottom Product	4464 kg/hr.
Operating Condition	
Pressure	1.25 atm
Number of trays	25
Reflux Ratio	1.8
Tray spacing	0.3 m
Height of column	0.915 m
Diameter of column	0.107 m

Streams	T_1(ºF)	T_2(ºF)
Mixture (Hot Fluid)	716	347
Lube oil (Cold Fluid)	77	450

Pressure drop per tray	0.0092 atm / 0.13psi
Tray thickness	5 mm
Hole diameter	5 mm
Weir height	50 mm
Weir length	0.694 m
Active area	0.291 m^2
Number of holes	1481 holes
Percentage flooding	85%

5.4 Heat Exchanger Design

5.4.1 Heat Exchanger HX-101:

Design Calculations

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

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

5.4.1.1 Thermal Design Calculation:

Step 1: Heat Balance

$\dot{Q} = W\ Cp\ (T_1 - T_2)$

$\mathbf{\dot{Q} = 27078996\ Btu/h}$

Step 2: True Temperature Difference

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

LMTD = 268 °F

Caloric Temperature:

Hot Fluid

$$Tc = T_2 + Fc\ (T_1 - T_2)$$

$$T_c = 457^oF$$

Cold Fluid

$$tc = t_1 + Fc\ (t_2 - t_1)$$

$$tc = 189°F$$

Corrected LMTD:

$$R = \frac{T_{1-}T_2}{T_2 - t_1}$$

R = 0.90

$$S = \frac{t_2 - t_1}{T_1 - t_1}$$

S = 0.51

Ft = 0.86 (Fig. 18)

Corrected LMTD = Δt = Δt × Ft

= 268 × 0.86

= 230 °F

Tc and tc:

$$= \frac{\Delta t_c}{\Delta t_h}$$

$$= \frac{270}{266}$$

$$= 1.01$$

Kc = 0.20

Fc = 0.48 (Fig. 17)

Step 3: Overall heat transfer coefficient 'U' (Table. 08)

UD assumed = 40 Btu/hr ft^2 °F

Step 4: Area

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

$$A = \frac{27078996}{40 * 268}$$

Area = 2526 ft^2

a= 0.2618 ft^2 (Table 10) (Tube O.D. 1 in.)

Number of tubes:

$$N_t = \frac{A}{L * a}$$

N_t= 603

Nearest Count N_t= 608 , ID of Shell= 35 in.

Corrected U_D:

A= N_t*L*a

A= 2546 ft^2

$$U_D = \frac{Q}{A * \Delta t}$$

$$U_D = \frac{27078996}{2546 * 268}$$

U_D= 40 BTU/hr.ft^2.^{o}F

As the Area is above than 200 ft^2 thus we are doing calculations of shell and tube heat exchanger.

Dimensions:

Shell Side	Tube Side
ID = 35 in	N_t = 608
Baffle Spacing =5 in	Length = 16 ft
Passes = 1	OD = 1 in
Clearance = 1.25 in.	13 BWG
	Pitch = 1 ¼ Triangular
	Passes = 4

Shell side	Tube side
Flow Area a_s = ID x C.B/144 $a_s = 0.148$ ft^2	a_t= 0.515 in^2 (Table 10) $a_t = \frac{N_t * a_t}{144 * n}$ $a_t = 0.561$ft^2
Mass Velocity $\mathbf{G_s} = \frac{\boldsymbol{W}}{\mathbf{a_s}}$	$G_t = \frac{W}{a_t}$

$G_s = 556786 \frac{lb}{hr.ft^2}$	$G_t = 146926 \frac{lb}{h\ ft^2}$
Reynold Number De = 0.72/12 = 0.06 ft (Fig. 28) μ = 1.1cp * 2.42 = 2.6 lb/ft.hr (Fig. 14) $\mathbf{Re_s} = \frac{\mathbf{De\ G_s}}{\mu}$ $\mathbf{Re_s} = 19641$	D = 0.81/12 = 0.0675 ft (Table 10) μ = 0.9cp * 2.42 = 2.1 lb/ft.hr $Re_t = \frac{D\ G_t}{\mu}$ $Re_t = 5072$
j_H = 70 **Prandtl Number** cp = 0.53 Btu/lb.°F (Fig. 4) $(Pr_a)^{\frac{1}{3}} = \left(\frac{C\ \mu}{k}\right)^{\frac{1}{3}}$ $(Pr_a)^{\frac{1}{3}} = 9.05$	**j_H = 25** cp = 0.69 Btu/lb.°F (Fig. 4) $(Pr_p)^{\frac{1}{3}} = \left(\frac{c\ \mu}{k}\right)^{\frac{1}{3}}$ $(Pr_p)^{\frac{1}{3}} = 2.98$
$h_o = 9209$	$h_i = 77.20. \frac{Btu}{hr\ ft^2\ °F}$ $h_{io} = h_i \left(\frac{D}{D_1}\right)$ $h_{io=}62.53 \frac{Btu}{hr\ ft^2\ °F}$

Clean overall coefficient

$$\mathbf{U_c} = \frac{\mathbf{h_{io}\ h_o}}{\mathbf{h_{io} + h_o}} \qquad \mathbf{U_c} = \mathbf{61.6} \frac{Btu}{hr\ ft^2\ °F}$$

Design overall coefficient

$$\mathbf{U'_D} = \frac{\dot{Q}}{\mathbf{A}\ LMTD} \qquad \mathbf{U'_D} = \mathbf{38} \frac{Btu}{hr\ ft^2\ °F}$$

Dirt factor

$$\mathbf{R'_D} = \frac{U_C - U_D}{U_C\ U_D} \qquad \mathbf{R'_D} = \mathbf{0.0100}$$

5.4.1.2 Hydraulic Calculations

Hydraulic Calculations	
Shell side	**Tube side**
For $\boldsymbol{Re_s = 19641}$ $f_s = 0.002$ ft²/in.² (Fig. 29)	$\boldsymbol{For\ Re_t = 5072}$ $f_t = 0.00031$ ft²/in.² (Fig. 26)
N+1 = 38.40	
Pressure Drop $\Delta P_s = \frac{f G_S^2 D_S (N+1)}{5.22 \times 10^{10} D_e s}$ $\Delta P_a = 9.8$ psi Allowable	$\Delta P_1 = \frac{f G_t^2 L n}{5.22 \times 10^{10} D_L}$ $\Delta P_1 = \mathbf{0.10}$ $\Delta P_2 = \frac{4nv^2}{2gs}$ $\Delta P_2 = 0.02$ $\Delta P_T = \Delta P_1 + \Delta P_2$ $\Delta P_T = 0.12$ Allowable

Table 5-13 Specification sheet of Heat exchanger (HX-101)

SPECIFICATION SHEET	
IDENTIFICATION	
Item	Heat Exchanger (HX-101)
Type	Shell & Tube Heat Exchanger
FUNCTION	
Heat Duty	27078996 Btu/hr.
Actual Surface Area	2526 ft^2

Uc Calculated	61.6 Btu/hr.ft^2. ˚F			
U_D Calculated	38 Btu/hr.ft^2. ˚F			
Dirt Factor	0.0101 Btu/hr.ft^2. ˚F			
FLUID ALLOCATION	SHELL SIDE	TUBE SIDE		
Fluid Name	Heavy Organics	Lube Oil		
Temperature (in/out)	380 ˚C to 175 ˚C	25 ˚C to 232 ˚C		
Pressure	1.83 bar	1 bar		
Viscosity	2.6 lb/ft.hr.	2.1 lb/ft.hr.		
Thermal Conductivity	1.2 Btu/hr. ft. ˚F	0.067 Btu/hr. ft. ˚F		
Pressure Drop	9.80 psi	0.12 psi		
Tubes No: 608	OD: 1in.	BWG:13	Pitch:1.25-in Triangle	
Shell ID: 21.25 in				

5.4.2 Heat Exchanger HX-102:

Design Calculations

5.4.2.1 Thermal Design Calculation:

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

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

Hot fluid	T_1	652	°F	T_2	338	°F	T_{avg}	495	°F	T_c	496	°F
Temperature differences	Δt_2 , Δt_h	202	°F	Δt_1, Δt_c	261	°F	Bulk mean Temperature	Caloric Temperature				
Cold fluid	t_2	450	°F	t_1	77	°F	t_{avg}	263	°F	t_c	233	°F

LMTD:

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

$$\mathrm{LMTD} = 230°\mathrm{F}$$

Caloric Temperature

Hot Fluid

$Tc = T_2 + Fc\,(T_1 - T_2)$

$Tc = 469°F$

Cold Fluid

$tc = t_1 + Fc\,(t_2 - t_1)$

$tc = 233°F$

Properties

Cold fluid **Hot fluid**

Cp	340 (Btu/lb.F)	Cp	0.88 (Btu/lb.F)
U	4.114 (lb/ft.hr)	u	2.1 (lb/ft.hr)
K	0.9 (Btu/hr.F)	K	0.07 (Btu/hr.F)
Density	18 (lb/ft3)	density	55.6 (lb/ft3)

Heat Balance:

$\dot{Q} = WC(T_1 - T_2)$

$\dot{Q} = 21476390$ Btu/h

Area, A

U_D= 40 Btu/hr ft^2 °F

PHT by kern table 8

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

$A = 1556\ ft^2$

As the Area is above than 200 ft^2 thus we are doing calculations of shell and tube heat exchanger.

Pipe Specifications

(Pipe specification are taken from table 11 Process heat transfer by kern)

Shell side	Tube side
Flow Area a_s = ID x C.B/144 $a_s = 0.1476\ ft^2$	a_t = (No of tubes x flow area/tube) / No of passes $a_t = 0.3460\ ft^2$
Mass Velocity $G_s = \frac{W}{a_s}$ $G_s = 483031$	$G_t = \frac{W}{a_t}$ $G_t = 189098 \frac{lb}{h\ ft^2}$
Reynold Number $Re_s = \frac{De\ G_s}{\mu}$ $Re_s = 9697$	$Re_t = \frac{D\ G_t}{\mu}$ $Re_t = 6078$
Prandtl Number $(Pr_a)^{\frac{1}{3}} = \left(\frac{C\ \mu}{k}\right)^{\frac{1}{3}}$ $(Pr_a)^{\frac{1}{3}} = 11.58$	$(Pr_p)^{\frac{1}{3}} = \left(\frac{c\ \mu}{k}\right)^{\frac{1}{3}}$ $(Pr_p)^{\frac{1}{3}} = 2.96$
$h_o = 7527$	$h_i = 90. \frac{Btu}{hr\ ft^2\ °F}$ $h_{io} = h_i \left(\frac{D}{D_1}\right)$ $h_{io} = 72 \frac{Btu}{hr\ ft^2\ °F}$
Clean overall coefficient	

$\mathbf{U_c} = \frac{\mathbf{h_{io}\ h_o}}{\mathbf{h_{io} + h_o}}$ $\mathbf{U_c} = 71.3 \frac{\text{Btu}}{\text{hr ft}^2\ °\text{F}}$
Design overall coefficient $\mathbf{U'_D} = \frac{\dot{Q}}{\mathbf{A}\ \text{LMTD}}$ $\mathbf{U'_D} = \mathbf{60} \frac{\text{Btu}}{\text{hr ft}^2\ °\text{F}}$
Dirt factor $\mathbf{R'_D} = \frac{U_C - U_D}{U_C\ U_D}$ $\mathbf{R'_D} = \mathbf{0.00264}$

5.4.2.2 Hydraulic Calculations

Hydraulic calculations	
Shell side	**Tube side**
$f_s = 0.0021$	$f_t = 0.00031$
N+1 = 38.40	
Pressure Drop $\Delta P_s = \frac{f G_S^2 D_S (N+1)}{5.22 \times 10^{10} D_e s}$ ΔP_a 4.36 psi Allowable	$\Delta P_1 = \frac{f G_t^2 L n}{5.22 \times 10^{10} D_L}$ $\Delta P_1 = \mathbf{0.19}$ $\Delta P_2 = \frac{4nv^2}{2gs}$ $\Delta P_2 = 0.07$ $\Delta P_T = \Delta P_1 + \Delta P_2$

	$\Delta P_T = 0.26$ Allowable

The heat exchanger is hydraulically feasible.

Table 5-14 Specification sheet of Heat exchanger (HX-102)

Specification sheet Identification	
Item	**Heat Exchanger (H-102)**
Type	**Shell and tube Heat Exchanger**
Tube Side	Shell Side
Cold fluid	Hot fluid
Temperature: 77-450°F	Temperature :652-338°F
Flowrate: 65428 lb\hr	Flowrate: 71496 lb\hr
Pressure Drop: 0.26 psi	Pressure Drop: 4.36
Tubes: 580	Shell ID: 21.25 in
Passes: 04	Baffle Spacing: 5 in
Pitch: 1.25 in triangle	Passes: 01
U_D assumed: 40 Btu\lb ft^2 °F	U_D calculated: 38.4 Btu\lb ft^2 °F
	R_d= 0.00557

5.4.3 Heat Exchanger HX-103:

Design Calculations

5.4.3.1 Thermal Design Calculation:

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

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

Hot fluid	T_1	246	°F	T_2	95	°F	T_{avg}	170	°F	T_c	158	°F
Temperature differences	Δt_2 , Δt_h	16	°F	Δt_1, Δt_c	18	°F	Bulk mean Temperature	Caloric Temperature				
Cold fluid	t_2	230	°F	t_1	77	°F	t_{avg}	153	°F	t_c	141	°F

LMTD

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

$$LMTD = \frac{104 - 18}{\ln\left(\frac{104}{18}\right)} = 58°F$$

Caloric Temperature

Hot Fluid

$$Tc = T_2 + Fc\,(T_1 - T_2)$$

$$Tc = 95°F$$

Cold Fluid

$$tc = t_1 + Fc\,(t_2 - t_1)$$

$$tc = 77°F$$

Properties

Cold fluid **Hot fluid**

cp	111 (Btu/lb.F)	Cp	0.88 (Btu/lb.F)
u	0.44 (lb/ft.hr)	u	2.1 (lb/ft.hr)
k	1.03 (Btu/hr.F)	K	0.07(Btu/hr.F)
density	0.33 (lb/ft3)	density	55.6 (lb/ft3)

Heat Balance:

$\dot{Q} = WC(T_1 - T_2)$

$\dot{Q}$ = 148961 btu/hr

$\dot{Q}$ = 148961Btu/h

Area, A

U_D= 40 Btu/hr ft^2 °F

Allowable dirt factor R_d =0.003 on both sides

PHT by kern table 8

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

$$A = \frac{(148961\ Btu/h)}{\left(40\frac{Btu}{h\ ft^2\ °F}\right)(58°F)}$$

$$A = 42.8\ ft^2$$

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

Pipe Specifications

(Pipe specification are taken from table 11 Process heat transfer by kern)

Annulus : (lube oil)	**Inner pipe (heavy organics)**
Flow Area $a_a = \frac{\pi(D_2^2 - D_1^2)}{4}$ $a_a = 0.0204\ ft^2$	$a_p = \frac{\pi D^2}{4} = \frac{\pi(0.1341)^2}{4}$ $a_p = 0.0233\ ft^2$
Mass Velocity $G_a = \frac{W}{a_a}$ $G_a = 30328$	$G_p = \frac{W}{a_p}$ $G_p = 64005\frac{lb}{h\ ft^2}$
Reynold Number $Re_a = \frac{De\ G_a}{\mu}$ $Re_a 9857$	$Re_p = \frac{D\ G_p}{\mu}$ $Re_p = 5242$
$h_o = 800$ Btu/hr ft^2 °F	

	$h_i = 18 \frac{Btu}{hr\ ft^2\ °F}$ $h_{io} = h_i \left(\frac{D}{D_1}\right)$ $h_{io} 16 \frac{Btu}{hr\ ft^2\ °F}$
Clean overall coefficient $\mathbf{U_c} = \frac{\mathbf{h_{io}\ h_o}}{\mathbf{h_{io} + h_o}} = \frac{\mathbf{(16)(800)}}{\mathbf{16 + 800}}$	$\mathbf{U_c} = 15 \frac{Btu}{hr\ ft^2\ °F}$
Design overall coefficient $\frac{1}{U_D} = \frac{1}{U_c} + R_d = \frac{1}{15 \frac{Btu}{hr\ ft^2\ °F}} + 0.003$	$U_D = 14 \frac{Btu}{hr\ ft^2\ °F}$
Required Area $A = \frac{\dot{Q}}{U_D\ LMTD}$ $A = 183.0\ ft^2$	
Required Length of hairpin $L = \frac{Area}{\text{External surface per lin ft}} = \frac{183\ ft^2}{0.622\ ft}$	$L = 289\ ft$
Required number of hairpin $n = \frac{\text{Required length of hairpin}}{\text{Heat transfer surface of hairpin}} = \frac{289\ ft}{40\ ft}$	$n = 7.23$
Actual number of hairpin	$n' = \mathbf{8}$
Actual Length of hairpin $L = (\text{Actual number of hairpin})(\text{Heat transfer surface of hairpin}) = 8 \times 40ft$ $L = 320\ ft$	

Actual Area of hairpin $A = (\text{External surface per lin ft})(\text{Actual length of hairpin}) = (0.622\ \text{ft})(320\ \text{ft})$ $= 199\ \ \text{ft}^2$
Design overall coefficient $\mathbf{U'_D} = \dfrac{\dot{Q}}{\mathbf{A}\ \ \text{LMTD}}$ $\mathbf{U'_D} = \mathbf{12.7}\dfrac{\text{Btu}}{\text{hr}\ \ \text{ft}^2\ {}^\circ\text{F}}$
Dirt factor $\mathbf{R'_D} = \dfrac{U_\mathbf{C} - U_D}{U_\mathbf{C}\ U_D}$ $\mathbf{R'_D} = \mathbf{0.0132}$ As $\mathbf{R'_D} > \mathbf{R_D}$,(0.0132 >0.003) Thus the heat exchanger selected is thermally feasible

5.4.3.2 Hydraulic Calculations

Hydraulic Calculations	
Annulus : (lube oil)	**Inner pipe (heavy organics)**
Re=9857	$Re_{\boldsymbol{p}}$ =5242
Friction Factor $f_a\ = 0.0064$	$f_p = 0..0107$
$\Delta F_a = \dfrac{4f_a {G_a}^2 L}{2g\rho^2 D'_e}$ $\Delta F_a = 1742.2\ \text{ft}$	$\Delta F_p = \dfrac{4f_p {G_p}^2 L}{2g\rho^2 D}$ $\Delta F_p = 0.13\ \text{ft}$
Velocity head per hairpin	

$V = \frac{G_a}{3600\ \rho}$ $V = 0.15\frac{ft}{s}$	
Entrance & exit losses $\Delta F_l = \frac{nV^2}{2g'}$ $\Delta \mathbf{F}_l = \mathbf{215.3}\boldsymbol{E}\hat{} - \mathbf{12}\frac{ft}{hairpin}$	
Pressure Drop $\Delta P_a = \frac{(\Delta \mathbf{F}_a + \Delta \mathbf{F}_l)\rho}{144}$ ΔP_a 3.6 psi Allowable	$\Delta P_p = \frac{\Delta \mathbf{F}_p\ \rho}{144}$ $\Delta P_p = \mathbf{0.05}$ psi Allowable

The heat exchanger is hydraulically feasible

Table 5-15 Specification sheet of Heat exchanger (HX-103)

SPECIFICATION SHEET	
IDENTIFICATION	
Item	**Heat Exchanger (HX-103)**
Type	**Double pipe heat exchanger**
UD assumed	**40 Btu/hr. ft ^{2}(F)**
Heat Duty	**148961 Btu/hr**
Actual surface area	**64 ft^2**
Uc Calculated	**15 Btu/hr. ft ^{2}(F)**
UD Calculated	**14 Btu/hr. ft ^{2}(F)**
Fouling Factor	**0.0132 h.ft^2.F/Btu**

Required Length	289 ft

5.4.4 Heat Exchanger HX-104:

Design Calculations

5.4.4.1 Thermal Design Calculation:

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

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

Hot fluid	T_1	480	°F	T_2	95	°F	T_{avg}	290	°F	T_c	258	°F
Temperature differences	Δt_2 , Δt_h	130	°F	Δt_1 , Δt_c	18	°F	Bulk mean Temperature		Caloric Temperature			
Cold fluid	t_2	350	°F	t_1	77	°F	t_{avg}	213	°F	t_c	191	°F

LMTD

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

$$\text{LMTD} = \frac{273 - 80}{\ln\left(\frac{273}{80}\right)} = 157°\text{F}$$

Caloric Temperature

Hot Fluid

$$\text{Tc} = T_2 + \text{Fc}\,(T_1 - T_2)$$

$$\text{Tc} = 258°\text{F}$$

Cold Fluid

$$\text{tc} = t_1 + \text{Fc}\,(t_2 - t_1)$$

$$\text{tc} = 191°\text{F}$$

Properties

Cold fluid **Hot fluid**

Cp	229 (Btu/lb.F)	Cp	0.88 (Btu/lb.F)
U	0.37 (lb/ft.hr)	u	2.1 (lb/ft.hr)
K	1.162 (Btu/hr.F)	K	0.07 (Btu/hr.F)
Density	21 (lb/ft3)	density	55.6 (lb/ft3)

Heat Balance:

$\dot{Q} = WC(T_1 - T_2)$

$\dot{Q}$ = 2001700 Btu/h

Area, A

U_D=40 Btu/hr ft^2 °F

PHT by kern table 8

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

$A = 318\ ft^2$

As the Area is above than 200 ft^2 thus we are doing calculations of shell and tube heat exchanger.

Pipe Specifications

(Pipe specification are taken from table 11 Process heat transfer by kern)

Shell side	Tube side
Flow Area a_s = ID x C.B/144 $a_s = 0.1476\ ft^2$	a_t = (No of tubes x flow area/tube) / No of passes

	$a_t = 0.071\ \text{ft}^2$
Mass Velocity $G_s = \frac{W}{a_s}$ $G_s = 41323$	$G_t = \frac{W}{a_t}$ $G_t = 79766 \frac{\text{lb}}{h\ \text{ft}^2}$
Reynold Number $Re_s = \frac{\text{De}\ G_s}{\mu}$ $Re_s = 10653$	$Re_t = \frac{\text{D}\ G_t}{\mu}$ $Re_{\boldsymbol{t}} = 2563$
Prandtl Number $(\boldsymbol{Pr_a})^{\frac{1}{3}} = \left(\frac{\mathbf{C}\ \mu}{\boldsymbol{k}}\right)^{\frac{1}{3}}$ $(\boldsymbol{Pr}_a)^{\frac{1}{3}} = 4.55$	$(\boldsymbol{Pr}_p)^{\frac{1}{3}} = \left(\frac{\mathbf{c}\ \mu}{\boldsymbol{k}}\right)^{\frac{1}{3}}$ $(\boldsymbol{Pr}_p)^{\frac{1}{3}} = 3.26$
$h_o = 1921$	$h_i = 111. \frac{\text{Btu}}{\text{hr ft}^2\ °\text{F}}$ $h_{io} = h_i \left(\frac{D}{D_1}\right)$ $h_{io=}90 \frac{\text{Btu}}{\text{hr ft}^2\ °\text{F}}$
Clean overall coefficient $\mathbf{U_c} = \frac{\mathbf{h_{io}\ h_o}}{\mathbf{h_{io} + h_o}}$ $\mathbf{U_c} = 86 \frac{\text{Btu}}{\text{hr ft}^2\ °\text{F}}$	
Design overall coefficient $\mathbf{U'_D} = \frac{\dot{Q}}{\mathbf{A}\ \text{LMTD}}$ $\mathbf{U'_D} = \mathbf{57.7} \frac{\text{Btu}}{\text{hr ft}^2\ °\text{F}}$	
Dirt factor $\mathbf{R'_D} = \frac{U_C - U_D}{U_C\ U_D}$ $\mathbf{R'_D} = \mathbf{0.00570}$	

5.4.4.2 Hydraulic Calculations

Hydraulic Calculations	
Shell side	**Tube side**
f_s $= 0.0024$	$f_t = 0.00049$
N+1 = 38.40	
Pressure Drop $\Delta P_s = \frac{f G_S^2 D_S (N+1)}{5.22 \times 10^{10} D_e s}$ ΔP_a 0.05 psi Allowable	$\Delta P_1 = \frac{f G_t^2 L n}{5.22 \times 10^{10} D_L}$ $\Delta P_1 = \mathbf{0.04}$ $\Delta P_2 = \frac{4nv^2}{2gs}$ $\Delta P_2 = 0.02$ $\Delta P_T = \Delta P_1 + \Delta P_2$ $\Delta P_T = 0.07$ Allowable

The heat exchanger is hydraulically feasible.

Table 5-16 Specification sheet of Heat exchanger (HX-104)

Specification sheet
Identification

Item Type	Heat Exchanger (H-104) Shell and tube Heat Exchanger
Tube Side	Shell Side
Hot fluid	Cold fluid
Temperature: 485-95 °F	Temperature: 77-350 °F
Flowrate: 9842 lb\hr	Flowrate: 6098 lb\hr
Pressure Drop: 0.07 psi	Pressure Drop: 0.05
Tubes: 79	Shell ID: 21.25 in
Passes: 04	Baffle Spacing: 5 in
Pitch: 1.25 in triangle	Passes: 01
U_D assumed: 40 Btu\lb ft^2 ^{o}F	U_D calculated: 38 Btu\lb ft^2 ^{o}F
U_C calculated: 86 Btu\lb ft^2 ^{o}F	R_d= 0.0057

5.4.5 Heat Exchanger HX-105:

Design Calculations

5.4.5.1 Thermal Design Calculation:

Hot Fluid

Stream 25 →Stream 26

Cold Fluid

Stream 7 → Stream 27

Cold Fluid Components:

- Acetic Acid
- Palmitic Acid
- 1-Tetradecene

Hot Fluid component:

- Steam

Design of Heat Exchanger:

Hot Fluid

350 ^{O}C ⟶ 350^{O}C

Cold Fluid

175^{O}C ⟶ 278^{O}C

Cold Fluid	Hot Fluid
$C = 0.661 \frac{Btu}{lb.°F}$	$C = 1 \frac{Btu}{lb.°F}$
$W = 32425 \frac{kg}{hr}$	$W = 3469 \frac{kg}{hr}$
$W = 71485 \frac{lb}{hr}$	$W = 7648 \frac{lb}{hr}$

Heat Balance:

$$\dot{Q} = WC\Delta T = WC(T_1 - T_2) = WCWC(t_2 - t_1)$$

$$\dot{Q} = 42746525 \frac{Btu}{hr}$$

LMTD:

Hot Fluid 662^{O}F ⟶ 662^{O}F

Cold Fluid 532^{O}F ⟵ 347^{O}F

$$\Delta t_1 = T_2 - t_1 = 315°F$$

$$\Delta t_2 = T_1 - t_2 = 130°F$$

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

$$LMTD = 209°F$$

$U_D = 60\frac{Btu}{hr.ft^2°F}$

$\dot{Q} = U_D A F_T LMTD$

$A = \frac{\dot{Q}}{U_D F_T LMTD}$

$A = 5\ ft^2$

Selection of Tubes:

$OD = \frac{3}{4} in$

$BWG = 16$

$Tube\ Pitch = P_T = 1\ in\ triangular$

$Tube\ Length = L = 16\ ft$

$N_T = \frac{A}{L \times Surface\ per\ line\ ft, ft^2}$

$N_T = 108$

From Table 9

$Corrected\ number\ of\ tubes = 110$

$Shell\ ID = 39\ in$

$Tube\ Passes = 6$

$Baffle\ Spacing = 5in$

$Actual\ Area = N_T \times L \times Surface\ per\ lin.$

$A = 345\ ft^2$

$\dot{Q} = U_D A F_T LMTD$

$U_D = \frac{\dot{Q}}{A F_T LMTD}$

$U_D = 59.2\ \frac{Btu}{lbft^2°F}$

Rating of Heat Exchanger:

$N_T = 110$

$Tube\ Passes = n = 6$

$Shell\ ID = D_S = 39\ in$

$Baffle\ Spacing = B = 5in$

$Tube\ Pitch = P_T = 1in\ Square$

$Tube\ OD = \frac{3}{4} in$

$T_{avg} = 662$°F

$t_{avg} = 440$ °F

Heat Balance:

$\dot{Q} = 42746552\ \frac{Btu}{hr}$

LMTD:

$LMTD = 209$ °F

Shell Side (cold Fluid)	Tube Side (hot Fluid)
$a_S = D_S \times \frac{CB}{144P_T}$	$a_t = \frac{N_T a'_t}{144n}$
$C = P_T - Tube\ OD$	$a'_t = 0.302\ in^2$
$C = 1 - 0.75$	$a_t = 0.384\ ft^2$
$C = 0.25in$	
$a_S = 0.338ft^2$	
$G_S = \frac{W}{a_S}$	$G_t = \frac{W}{a_t}$
$G_S = 211155.698 \frac{lb}{hr\ ft^2}$	$G_t = 19891 \frac{lb}{hr\ ft^2}$
$\mu = 0.93 \frac{lb}{ft\ hr}$	$\mu = 0.054 \frac{lb}{ft\ hr}$
$D_e = 0.95in$	$D = 0.620\ in$

$D_e = 0.079 ft$

$Re_S = \frac{D_e G_S}{\mu}$

$Re_S = 17974$

$k = 0.067 \frac{Btu}{hr\ ft^2\ °F/ft}$

$(\text{Pr})^{1/3} = \left(\frac{c\mu}{k}\right)^{1/3}$

$(\text{Pr})^{1/3} = 2.09$

$j_H = 65$

$h_o = j_H \frac{k}{D_e} (\text{Pr})^{1/3}$

$h_o = 115\ \frac{Btu}{lb\ ft^2 °F}$

$D = 0.01567 ft$

$Re_t = \frac{D G_t}{\mu}$

$Re_t = 19031$

$h_{io} = 1500 \frac{Btu}{lb\ ft^2 °F}$

$U_C = \frac{h_{io} \times h_o}{h_{io} + h_o}$

$U_C = 107\ \frac{Btu}{lb\ ft^2 °F}$

$A = N_T \times L \times Surface\ per\ lin.$

$A = 137 \times 16 \times 0.1963$

$A = 3454\ ft^2$

$\dot{Q} = U_D A F_T LMTD$

$U_D = \frac{\dot{Q}}{A F_T LMTD}$

$U_D = 59.2 \frac{Btu}{lbft^2 °F}$

$$R_d = \frac{U_C - U_D}{U_C U_D}$$

$$R_d = 0.0075$$

5.4.5.2 Hydraulic Calculations

Shell Side (Hot Fluid)

From Fig. 29

$$f = 0.002$$

$$Number\ of\ cross = N + 1 = 12\frac{L}{B}$$

$$Number\ of\ cross = N + 1 = 12\frac{16}{5}$$

$$Number\ of\ cross = N + 1 = 38.4$$

$$Specific\ gravity = s = 0.71$$

$$D_S = 3.25ft$$

$$\Delta P = \frac{fG_S^2 D_S(N+1)}{5.22 \times 10^{10} D_e s}$$

$$\Delta P = 0.31\ psi$$

Tube Side (Clod Fluid)

From Fig. 26

$$f = 0.0002$$

$$Specific\ gravity = s = 1$$

$$\Delta P_1 = \frac{fG_t^2 Ln}{5.22 \times 10^{10} D_L}$$

$$\Delta P_1 = 0.0028\ psi$$

$$\Delta P_2 = \frac{4nv^2}{2gs}$$

$$\Delta P_2 = 7.58\ psi$$

$$\Delta P_T = \Delta P_1 + \Delta P_2$$

$$\Delta P_T = 0.00281psi$$

Specification sheet of Heat Exchanger 105:

Table 5-17 Specification sheet of Heat exchanger (HX-105)

Specification sheet **Identification**	
Item	Heat Exchanger (H-105)
Type	1-2 Shell and tube Heat Exchanger
Tube Side	**Shell Side**
Fluid: process liquid	Fluid: Hot (Steam)
Flowrate: 71485 lb\hr	Flowrate: 7648 lb\hr
Pressure Drop: 0.316 psi	Pressure Drop: 0.0028
Tubes: 110	Shell ID: 15.25 in
110 number of tubes each 16ft long	Baffle Spacing: 5 in
Passes: 06	Passes: 06
Pitch: 1 in square	U_D calculated: 58 Btu\lb ft^2 ^{o}F
U_D assumed: 60 Btu\lb ft^2 ^{o}F	R_d= 0.0075
U_C calculated: 58 Btu\lb ft^2 ^{o}F	

CHAPTER 6

MECHANICAL DESIGN

6.1 Mechanical Design Calculation for Reactor

6.1.1 Material Selection:

Austenitic Stainless-Steel Grade 304 is selected because of :

- High strength then Grade 301-303 because of carbon content
- Used for high temperature and pressure
- Resistant to scaling at high temperatures
- Resistant to corrosion
- Compositions Cr = 18 Ni = 8

6.1.2 Thickness Calculation:

- **<u>Wall or shell Thickness:</u>**

D_i = 1.0 m

L = 2.5 m

P_i = 1.95 bar

Design Pressure = 2.15 bar

Corrosion allowance = 2 mm

Maximum Allowable Stress

S = 80.6 N/mm^2

Joint Efficiency = E = 1

6.1.2.1 Cylindrical Section:

$$t = \frac{D_i \times P_i}{(2SE - P_i)}$$

t = **1.34 + 2**

t = 3.34 mm

6.1.3 Outer diameter of shell:

$$D_o = D_i + 2t$$

Do = 1.0026 m

6.1.4 Design of Domed Head End:

6.1.4.1 Ellipsoidal Heads:

$$\boldsymbol{t = \frac{D_i \times P_i}{(2SE - 0.2P_i)}}$$

t = **1.56 + 2**

t = 3.56 mm

6.1.4.2 Torisphere Head:

$$\boldsymbol{t} = \frac{0.885RcP_i}{\boldsymbol{(SE - 0.1P_i)}}$$

t = **2.77+2**

t = 4.77 mm

6.1.4.3 Hemispherical Heads:

$$\boldsymbol{t = \frac{D_i \times P_i}{(2SE - P_i)}}$$

t = 1.56 × 0.6 mm

t = 0.94+2 = 2.94 mm

6.1.5 Design Load Calculations:

6.1.5.1 Dead Weight of Vessel:

$$W_v = 240 \times C_v \times Di \times (L + 0.8D_i) \times t$$

W_v = 4.303 KN

6.1.5.2 Weight of fitting:

Caged Ladders, steel, 360 N/m length

= 0.900 KN

Platform, steel, for vertical column, 1.7 KN/m^2 Area

= 24.021 KN

6.1.5.3 Total weight of vessel:

= Dead Weight of vessel + Weight of fitting

= 4.303 kN + 0.900 kN + 24.021 kN

= 29.224 kN

6.1.5.4 Wind Loads:

$F = P_w \times D_o$ (P_w = 1280 N/m^2)

F = 1030 N/m

6.1.5.5 Bending Moment:

$$M_x = \frac{W\,x^2}{2}$$

M_x = 3218 N/m

6.1.6 Stresses Calculations:

Pressure stresses:

6.1.6.1 Longitudinal Stress:

$$\sigma_L = \frac{D_i \times P_i}{4t}$$

σ_L = 10.75 N/mm^2

6.1.6.2 Circumferential Stress:

$$\sigma_h = \frac{D_i \times P_i}{2t}$$

σ_h = 21.5 N/mm^2

6.1.6.3 Dead Weight Stress:

$$\sigma_w = \frac{W}{\pi(D_i + t)t}$$

σ_w = 0.2727 N/mm^2

6.1.6.4 Bending Stress:

$$\sigma_b = \frac{M_x}{I_v}\left(\frac{D_i}{2} + t\right)$$

σ_b = 2.75 N/mm^2

$l_v = second\ moment\ of\ area\ of\ vessel$

Second Moment Area

$$I_v = \frac{\pi\left({D_o}^4 - {D_t}^4\right)}{64}$$

I_v = 5.91 × 108 mm^4

$Di = Inner\ Dia\ of\ Reactor$

$Do = Outer\ Dia\ of\ Reactor$

$t = Thickness\ of\ shell$

CHAPTER 7

PUMPS & COMPRESSORS

Pump

A pump is a mechanical device that is used to move various types of liquids or gases from one location to another. Typically, these devices transform electrical energy into hydraulic energy. Pumps, in general, are powered by a mechanism (reciprocating or rotary) and use energy to do mechanical work that propels the working fluid. The aforementioned device can elevate liquids from low to high levels and move fluids from low to high pressure locations.

Pumps are powered by a variety of sources, including human labour, electricity, an engine, wind power, and others. Pumps typically operate by creating a vacuum in which air pressure drives the liquid out. All pumps function by producing a low-pressure zone. Pumps have been around for a long time, so it's no surprise that they come in a broad range of sizes and varieties. So, let's go over them one by one, as detailed below.

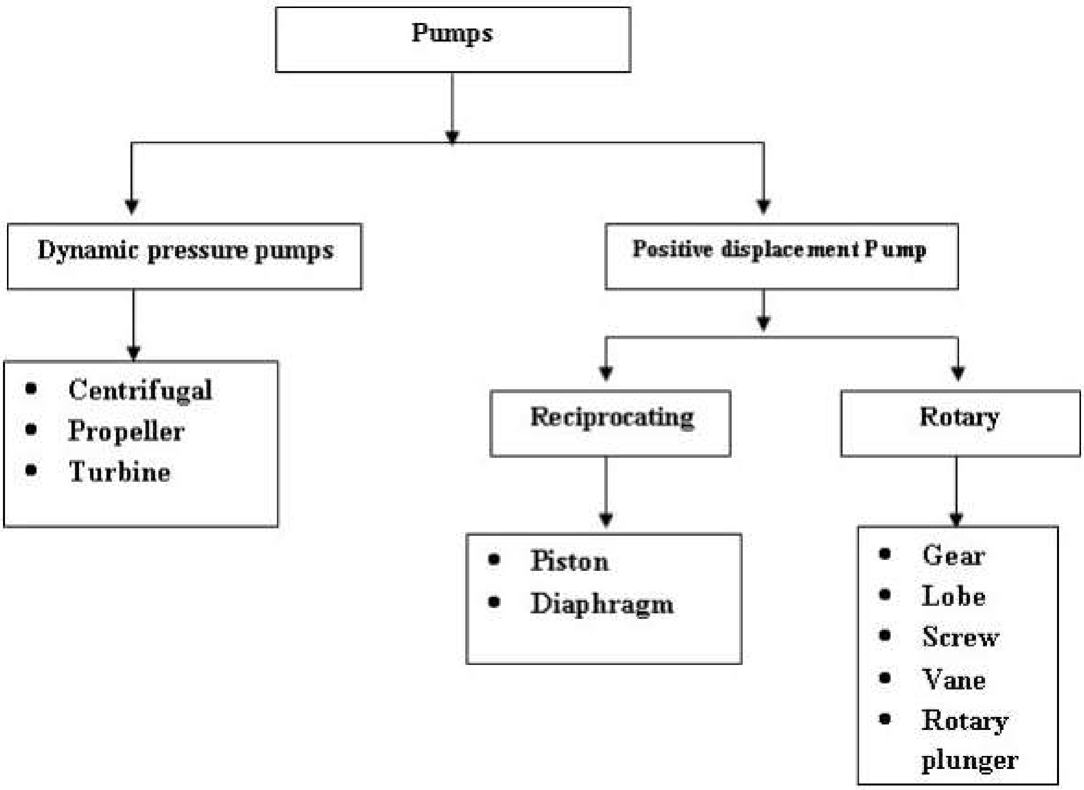


Figure 7-1 Types of pumps

PD (Positive Displacement) Pumps

Because such pumps are designed to displace a more or less fixed volume of fluid throughout each cycle of operation, the name positive displacement pump is highly descriptive. The volumetric flow rate is calculated by multiplying the displacement per cycle of the moving part (spinning or reciprocating) by the cycle rate (e.g. rpm). The flow capacity is thus determined by the pump's design, size, and operating speed. The pump's pressure (or head) is determined by the flow resistance of the system in which it is mounted and is only limited by the size of the driving motor and the strength of the components.

As a result, the discharge line from the pump should never be turned off without allowing for recycling around the pump, otherwise the pump may be damaged. They are further categorised as follows:

7.1 Types of pumps

RC (Reciprocating pumps)

Pumping is achieved by the piston or diaphragm in the cylinder moving back and forth. It is commonly used when a little volume of liquid must be handled and a high delivery pressure is required.

PP (Piston pump) : The piston of a piston pump, which is a type of positive displacement pump, reciprocates with the high-pressure seal. Piston cylinders make up the pump. Following the delivery stroke, the piston pulls away from the cylinder, creating a low pressure that opens the suction valve. The fluid inside the cylinder is compressed during the forward stroke, which opens the delivery valve for liquid delivery.

DP (Diaphragm pump): Pumps a fluid by employing a rubber, thermoplastic, or Teflon diaphragm and proper non-return check valves. A membrane pump is another name for this type of pump.

RP (Rotary pumps)

The relative movement of the spinning elements and the pump's fixed element causes the pumping action of rotary pumps. The operation is not the same as that of reciprocating pumps, which include valves and a piston. They differ from centrifugal pumps in that they transfer high velocity into pressure. The pumping components' action and position, as well as the pump's tight running clearances, are designed to provide a continuous seal between a rotary pump's input and exit ports. As a result, rotating pumps, unlike reciprocating pumps, do not require valve designs.

GP (Gear pumps): Pumps fluid through displacement utilising gear meshing. They are among the most common types of hydraulic fluid power pumps. Very high pressures and the ability to pump very viscous fluids are feasible due to the sturdy design of the gears and housing.

LP (Lobe pump): Lobe pumps function similarly to external gear pumps in that fluid flows inside the casing. The lobes that protrude from the mesh increase the volume on the pump's input side. The revolving lobes capture liquid as it pours into the hole. Liquid flows around the interior of the casing in the pockets between the lobes and the casing. Finally, under pressure, the lobe meshing forces liquid through the output port.

SP (Screw Pump): These are positive displacement rotary pumps having one or more screws that may transfer fluids with high or low viscosity along an axis. Although progressive cavity pumps are sometimes referred to as single screw pumps, screw pumps typically include two or more intermeshing screws that move axially clockwise or anticlockwise. Each screw thread is made to retain a certain amount of fluid. Screw pumps give a constant quantity with each cycle and can be used for metering.

VP (Vane pump) : A rotary vane pump is a positive-displacement pump composed of vanes connected to a rotor that circulates within a hollow. In certain cases, these vanes can be changeable in length and/or tensioned to maintain contact with the walls while the pump spins.

PP (plunger pump): A spinning rotor and a reciprocating plunger perform the pumping motion. In a rotary plunger rotary pump, the plunger axes are perpendicular to the rotor's rotational axis or at an angle of not less than 45° to the axis; the rotor is eccentrically situated with respect to the case axis.

DPP (Dynamic Pressure Pumps)

Tangential force is imparted during the pumping operation of a dynamic pressure pump, which normally accelerates the fluid via impeller rotation. Some dynamic pump systems may necessitate the use of a positive displacement pump for priming. They are frequently used for moderate to high discharge rates. The pressure difference range for this type of pump is modest to considerable. They are frequently used in systems that use low viscosity fluids.

CP (Centrifugal pumps)

To increase fluid pressure, they use a revolving impeller. Centrifugal pumps are widely used in pipe systems to transport liquids. The fluid enters the pump impeller along or near its rotating axis and is driven by it before flowing radially outward through a diffuser or volute chamber (casing) and exiting into the downstream pipe system. Centrifugal pumps are used to convey massive volumes of water via small apertures. These pumps are used in dairy operations to deliver water and handle milk.

PP (Propeller pump)

A propeller pump has a linear flow channel with a high flow, low lift impeller. The propeller pump can be installed vertically, horizontally, or inclined, with the engine typically above water and the impeller below. A propeller bladed impeller head in these pumps draws water up an outer casing and out of a discharge outlet.

TP (Turbine pump)

Turbine pumps are centrifugal pumps that use a revolving mechanism to transport fluid by combining pressure and flow. They usually employ blade geometry to generate pressure from input to exit by causing fluid to circulate around the vanes. Turbine pumps transmit fluid through an impeller using kinetic energy. Centrifugal force draws the liquid to the housing wall towards the vanes of the impeller or propeller. The cyclical movement of the impeller produces pressure in the pumping bowl. The shape of turbine pumps influences both suction and discharge rates.

7.2 Selection 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 because of the pump's action.
- Different types of flow distributions
- Different types of power supplies.
- The pump's cost and mechanical efficiency.

7.3 Pump Design Calculations

Inlet and Outlet Pressures:

P1 = 1 bar = 1 atm = 105 Pa

P2 = 2 bar = 1 atm = 2×105 Pa

Density of solvent: Density of solvent fluid is 1030 kg/m3

Head:

As we know that

$$Head = \Delta P/\rho g$$

$$Head = 22 \text{ m} = 72.17 \text{ ft}$$

Capacity = 142 gallon per minutes

From Reference book

Selected High Speed Reciprocating Pump

Pump work:

As we know that

$W = \Delta P \times Q$

Where Q = volumetric flowrate = 0.00899 m3 /s

Putting values will give us

W = 1441 w = 2 hp

Table 7-1 Pump Specification sheet

Specification Sheet	
Type	Positive Displacement Gear Pump
Pressure at the Inlet	0.65 bar
Discharge pressure	2.3 bar
Capacity	32388 kg/hr.
Pump work	2 hp

CHAPTER 8

COST ESTIMATION

8.1 Introduction:

Cost estimation is a specialized subject and a profession in its own right. The design engineer needs to be able to make quick, rough, cost estimates. Chemical plants are built to make a profit.

8.1.1 Classification of cost estimation

Capital cost estimates can be broadly classified in to 3 types:

1. Preliminary (approximate)

2. Authorization (Budgeting)

3. Detailed (Quotation)

Preliminary estimate has been used in this project

8.1.2 Working Capital:

Working capital refers to the money needed to keep the plant running. The following items should be considered when calculating working capital.

1. Stockpiles of raw materials and equipment
2. Semi-finished products in the manufacturing process and finished products in store.
3. Receivables (accounts receivable)
4. Cash is kept on hand to cover monthly running costs including pensions, bonuses, and raw material acquisitions.
5. Accounts receivable
6. Taxes to compensate

8.1.3 Cost Estimates:

A capital cost estimation for a method may range from a pre-design estimate based on no details other than the planned project's scale to a precise estimate based on full drawings and specifications. Between these two extremes of capital expenditure forecasts, there are a plethora of other estimates that differ in precision based on the project's level of growth. These estimates go by a number of names, but the five groups below reflect the standard precision set and classification for design purposes:

1. Order of magnitude estimates

2. Study estimate (Estimate of the factorial)
3. Preliminary estimates (Estimated Spending Authorization)
4. Definitive estimate (Estimate for project management)
5. Detailed estimate (Estimate from the contractor)

Cost Indexes:

A cost is similar to an index value at a given point in time that shows the cost at that point in time in relation to a base time. As a result, the current cost is calculated using the cost index as follows:

$$\frac{\text{Present cost}}{\text{index at present time}} = \frac{(\text{Original cost})}{\text{index value at time of original cost}}$$

Various types of cost indexes are issued on a daily basis. Others may be used to estimate the cost of machinery, while others are more applicable to labour, manufacturing, supplies, or other specialized areas.

The most common of these indices are:

1. Marshal-and-Swift all-industry and process-industry equipment index
2. Engineering News-record construction index
3. Nelson-Farrar rebery construction index
4. Chemical Engineering Plant Cost Index

8.2 Purchased costs of Equipment's in 2022:

8.2.1 Furnace

8.2.1.1 Purchased Cost of Furnace (H-101):

Box type horizontal tube furnace

Required Heat Duty = 20.5 MM Btu/h

Required Heat Duty = 5998 kW

Table 4-3:Shows Required Data for Design Calculation of (H-101)

FACTORS	VALUES	UNITS
TOTAL REQUIRE HEAT DUTY	20,467,326	Btu/hr
FUEL NAME	Furnace Oil	
EFFICIENCY	75	%
TEMPERATURE OF INLET AIR	400	˚F
AVERAGE TUBE TEMPERATURE IN RADIANT SECTION, T_S	720	˚F
AIR TO FUEL RATIO	17.44	lb air/ lb fuel
HEATING VALUE OF AIR	82	Btu/lb
LOWER HEATING VALUE OF FLUE GAS	476	Btu/lb
LOWER HEATING VALUE OF FUEL	17130	Btu/lb
STEAM FOR ATOMIZATION	0.3	lb steam /lb oil
OUTSIDE DIAMETER OF TUBE	5	inches
EXPOSED LENGTH OF TUBE	38.5	ft
CENTER TO CENTER DISTANCE	8.5	inches

Bare cost of furnace = $64,000

$Ce=CS^n$

Where

Purchased equipment cost (Ce) will be

Characteristic size parameter (S) = 5998 kW

Cost Constant (C) = 560

index for that type of equipment (n) = 0.77

Material: Carbon Steel

Material Factor CS = 1

Purchased Cost of Equipment (2004) = $2 \times 560 \times (5998)^{0.77}$

Purchased Cost of Equipment in 2004 = $908,454

Cost Index (2004) = 444.2

From Appendix , Table ;

Cost index in 2022 = 808.7

$$\text{Purchased } Cost\ of\ furnace\ in\ 2022 = Cost\ in\ 2004 \left(\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2004}\right)$$

$$\text{Purchased } Cost\ of\ furnace\ in\ 2022 = \$908{,}454 \left(\frac{808.7}{444.2}\right)$$

Purchased Cost of furnace in 2022 = $1,653,910

8.2.2 Reactor

8.2.2.1 Purchased Cost of Reactor (R-101):

Table 8-1 Specification sheet of Reactor R-101

SPECIFICATION SHEET	
Identification	
Item	Reactor
Item No	R-101
Operation	Continuous
Type	Isothermal Packed Bed Reactor
Function	
Palmitic acid to 1-Tetradecene	

Chemical Reaction	
$C_{15}H_{31}COOH_{(l)} \overset{k_1}{\rightarrow} CH_3COOH_{(g)} + C_{14}H_{28}{}_{(l)}$ Palmitic acid Acetic acid 1-Tetradecene $C_{14}H_{28}{}_{(l)} \overset{k_2}{\rightarrow} C_{28}H_{56}{}_{(s)}$ 1-Tetradecene Gum	
Catalyst	Ni-Sn
Weight of Catalyst	104 kg
Volume of Catalyst	0.11m^3
Volume of Reactor	0.52m^3
Diameter of Reactor	0.5m
Length of Reactor	2.5m
Height of Bed	m^3
Space Time τ	41s
Pressure drop ΔP	7 kPa

Isothermal Packed bed reactor

Volume of reactor = 0.52 m^3

Diameter = 0.5m

Length = 2.4m

From Fig 6.5 (b) Vertical pressure vessel time mid-2004 (Richardson Coulson volume 6)

Material: Stainless Steel

Factor for Pressure 1-5 bar = 1

Material Factor SS = 1

Purchased Cost of Equipment (2004) = Bare cost from figure × Pressure Factor × Material Factor

Purchased Cost of Equipment in 2004 = $5,000 × 1 × 2

Purchased Cost of Equipment in 2004 = $10,000

Cost Index (2004) = 444.2

From Appendix , Table ;

Cost index in 2022 = 808.7

Purchased $Cost\ of\ reactor\ in\ 2022 = Cost\ in\ 2004\left(\frac{Cost\ index\ in\ 2022}{Cost\ index\ in\ 2004}\right)$

Purchased $Cost\ of\ reactor\ in\ 2022 = \$10{,}000\left(\frac{808.7}{444.2}\right)$

Purchased Cost of reactor in 2022 = $18,206

8.2.3 Separator

8.2.3.1 Purchased Cost of Filter (F-101):

Cost Estimation For Filter:

Operating pressure = 148 kPa

Average density = 980.76 kg/m^3

= 981 kg/m^3

Total flowrate = 38247 kg/hr

Capacity = 38247/981

= 38m^3 /hr

Volume for 1 hr time = 38 m^3

Material = Stainless steel

Purchased cost = $ 2100

CEPCI in 2002 = 395.6

CEPCI in 2022 = 808.7

Index Ratio = 2.044

Cost in 2022 = (2.044) * ($2100)

= $4292.4

8.2.4 Columns

8.2.4.1 Purchased Cost of Distillation column (T-101):

Cost of Distillation Column

Column Diameter = 2.5 m

Column Height = 11 m

Column Pressure = 1.25 bar

From Figure (With Pressure and material factor)

Equipment Cost in 2004 = 17000 $

Cost index in 2004 = 444.2

Cost index in 2022 = 808.7

$$Cost\ in\ 2022 = Cost\ in\ 2004\ \times \left(\frac{cost\ index\ in\ 2022}{cost\ index\ in\ 2004}\right)$$

Cost in 2022 = 30949 $

8.2.4.2 Purchased Cost of Distillation column (T-102):

Cost of Plate = 380 $

Material Factor = 1

No of Plates = 35

Total Cost of plates = 13,300 $

Cost of plates in 2022 = 24,213 $

Total cost of column = plates + column cost

Total cost of column-101 = 55,163 $

Total Cost of column-102 = 34,590 $

8.2.5 Heat Exchangers

8.2.5.1 Cost of Heat Exchanger (HX-101)

Shell and Tube Heat Exchanger

Heat transfer surface Area = 2526 ft^2 = 236 m^2

Material of Construction = Carbon Steel from Appendix C, Figure C-4;

Cost of Heat Exchanger in 2004 = $ 60,000

Pressure Factor 1-10 = 1 bar

Type Factor U-tube = 0.85

Cost of Equipment in 2004 = $60000 * Pressure Factor * Type Factor Cost of Equipment in 2004 = **$51000**

From Appendix C Table C.5

2004 Cost Index = 444.2

2022 Cost Index = 806.3

$Cost\ of$ exchanger in 2022 =Factor $Cost\ in$ 2004 $\times \frac{\text{Cost index in 2022}}{\text{Cost index in 2004}}$

Equipment Cost in 2022 = **$92573**

8.2.5.2 Cost of Heat Exchanger (HX-102)

Shell and Tube Heat Exchanger

Exchanger Area = 1556 ft2 = 144 m2

Material of Construction = Carbon Steel from Appendix C, Figure C-4;

Cost of Heat Exchanger in 2004 = 39000

Type Factor U-tube = 0.85

Cost of Equipment in 2004 = 39000 $ * Type Factor Cost of Equipment in 2004 = 3150 $

2004 Cost Index = 444.2

From Appendix C Table C5

2022 Cost Index = 806.3

$Cost\ of$ exchanger in 2022 =Factor $Cost\ in$ 2004 × {($Cost\ index\ in$ 2022)/($Cost\ index\ in$ 2004)}

Equipment Cost in 2022 = 60001 $

8.2.5.3 Cost of Heat Exchanger (HX-103)

Hot fluid = heavy organics

Cold fluid = lube oil

Heat transfer area = 64.2 ft2 = 5.96 m2

From Appendix C, Figure C-5;

Bare cost of Double pipe heat exchanger in 2004 = $ 3200

2004 Cost index = 444.2

From Appendix C, Table C-5;

Cost index in 2022 = 806.3

$Cost\ of$ exchanger in 2022 = $Cost\ in$ 2004 × {($Cost\ index\ in$ 2022)/($Cost\ index\ in$ 2004)}

Cost of exchanger in 2022 = $5808

8.2.5.4 Cost of Heat Exchanger (HX-104)

Shell and Tube Heat Exchanger

Exchanger Area = 318 ft2 = 29.5 m2

Material of Construction = Carbon Steel From Appendix C, Figure C-4;

Cost of Heat Exchanger in 2004 = 25000

$Pressure Factor 1-10 = 1

Type Factor U-tube = 0.85

Cost of Equipment in 2004 = 25000 $ * Pressure Factor * Type Factor Cost of Equipment in 2004 = 21250 $

2004 Cost Index = 444.2

From Appendix C Table C5

2022 Cost Index = 806.3

$Cost\ of$ exchanger in 2022 =Factor $Cost\ in$ 2004 × {($Cost\ index\ in$ 2022)/($Cost\ index\ in$ 2004)}

Equipment Cost in 2022 = 38462 $

8.2.5.5 Cost of Heat Exchanger (HX-105)

Shell and Tube Heat Exchanger

Exchanger Area = 1618 ft2 = 150 m2

Material of Construction = Carbon Steel From Appendix C, Figure C-4;

Cost of Heat Exchanger in 2004 = 40000

$Pressure Factor 1-10 = 1.3

Type Factor U-tube = 0.85

Cost of Equipment in 2004 = 40000 $ * Pressure Factor * Type Factor Cost of Equipment in 2004 = 44200 $

2004 Cost Index = 444.2

From Appendix C Table C5

2022 Cost Index = 806.3

$Cost\ of$ exchanger in 2022 =Factor $Cost\ in$ 2004 × {($Cost\ index\ in$ 2022)/($Cost\ index\ in$ 2004)}

Equipment Cost in 2022 = 80002 $

8.2.6 Pump

8.2.6.1 Purchased Cost of Pump (p-100):

Cost of pump in 2002 Appendix 1 Pumps, Centrifugal

Cost Factors:

Cost in 2002 = $ 2700

Total Cost of pump in 2002 = $2700

Cost index in 2002 = 128.7

Cost index in 2022 = 298.8

Cost of pump in 2022: Cost of pump in 2002*$(\frac{Cost\ index\ 2022}{Cost\ index\ 2002})$

$$=\$2700*(\frac{298.8}{128.7})$$

Cost of pump in 2022: $6281

Table 8-2 Purchased costs of equipments in 2022

Equipment	Cost ($)	Total Costs ($)
Reactor		**18,206**
Reactor (R-100)	$18,206	
Furnace		**1,653,910**
Furnace (F-101)	$1,653,910	
Distillation Columns		**450,775**
(T-101)	$55,163	
Re-boiler (E-101)	$239,042	
Condenser (E- 102)	$27,309	
(T-102)	$34,591	
Re-boiler (E-103)	$71,002	
Condenser (E- 104)	$23,667	
Filter		**4,293**
F-101	$4,293	
Pump		**6,281**
(P-101)	$6,281	
Heat Exchangers		**263,144**
HX-101	$92,573	
HX-102	$60,001	
HX-103	$5,808	
HX-104	$24,760	
HX-105	$80,002	
Total	**$2,396,608**	

8.3 Estimation of project total capital investment

Table 8-3 ,Estimation of project total capital investment

Estimation of project total capital investment				
Item		Process type		
		Fluids-solids		Cost ($)
Major equipment, total purchase		PCE		$2,396,608
f_1	Equipment erection	45%	0.45	$1,078,474
f_2	Piping	45%	0.45	$1,078,474
f_3	Instrumentation	15%	0.15	$359,491
f_4	Electrical	10%	0.1	$239,661
f_5	Buildings, process	10%	0.1	$239,661
f_6	Utilities	45%	0.45	$1,078,474
f_7	Storages	20%	0.2	$479,322
f_8	Site development	5%	0.05	$119,830
f_9	Ancillary buildings	20%	0.2	$479,322
Total physical plant cost (PPC), PPC= PCE (1 + f_1 +…+ f_9)			**3.15**	**$7,549,316**
f_{10}	Design and Engineering	25%	0.25	$1,887,329
f_{11}	Contractor's fee	5%	0.05	$377,466
f_{12}	Contingency	10%	0.1	$754,932
Fixed capital (FC)= PPC (1 + f_{10}+f_{11}+f_{12})			**1.4**	**$10,569,043**
Working capital (WC)		5%	0.05	**$528,452**
Total Capital investment (TCI)				**$11,097,495**

8.4 Annual Production Cost

Table 8-4 Raw materials costs

Raw materials Costs				
Item	Flow rate, weight	Price per kg	Total price	
	kg/hr ,kg	$/kg	$/hr ,$	$/year
Palmitic acid	5,820	$1.043	$6,070	$48,073,097
Fuel oil	762	$0.18	$138	$1,096,041
Catalyst Ni-Sn	104	$3	$313	$313
	Total		**6,521**	**49,169,450**

Table 8-5 Utilities costs

Utilities Costs				
Item	Flow rate	Price per kg	Total price	
	kg/hr	$/kg	$/hr	$/year
Steam	18,147	0.02	$395	$3,130,695
Cooling water	24513	0.00002	$0.4	$3,524
Lube oil	84,189	2.89	$243,278	$243,278
	Total		**243,673**	**3,377,496**

Table 8-6 Variable costs

Variable Costs				
1	Raw materials			$49,169,450
2	Miscellaneous materials	10% of item 5	0.10	$79,268
3	Utilities			3,377,496
4	Shipping & packaging			-
	Sub-total A			**$52,626,215**
Fixed costs				
5	Maintenance	5-10% FC	0.08	$792,678
6	Operating labour	5-10% FC	0.08	$792,678
7	Laboratory costs	20-23% of 6	0.21	$166,462

8	Supervision	20% of item 6	0.20	$158,536
9	Plant overheads	50% of item 6	0.50	$396,339
10	Capital charges	10% of FC	0.10	$1,056,904
11	Insurance	1% of FC	0.01	$105,690
12	Local taxes	2% of FC	0.02	$211,381
13	Royalties	1% of FC	0.01	$105,690
	Sub-total B			**$3,786,360**
	Direct Production costs,(DPC) = A+B			**$56,412,574**
14	Sales expense	2% of DPC	0.02	$1,128,251
15	iGeneral overheads	20-30% of DPC	0.25	$14,103,144
16	iResearch & development	2% of DPC	0.05	$2,820,629
	Sub-total C			**$18,052,024**
	Annual production cost = A+B+C			**$74,464,598**
	Production rate of Plant (ton/year)			**35,000**

Production Cost ($/ton) = $\frac{Annual\ production\ cost}{Annual\ production\ rate}$ **$2,128**

8.5 Profitability Analysis:

8.5.1 Selling Price:

Selling Price of Product = $2300/ton

8.5.2 Profit:

Profit = Selling Price – Production cost

Profit = 172 $/ton

Total Production per year = 35000 ton/year

Profit Per year = 6,035,402 $/year

8.5.3 Total income:

Selling Price = 2300 $/ton

Total Production per year = 35000 ton/year

Total income = $80,500,000 /year

8.5.4 Depreciation:

Depreciation = D = $[(V-V_s)/N]$

FCI = V = $10,569,043

Salvage Value = Vs = 5% of FCI = $528,452

Number of Years = N = 20 yr

D = $ 502,030

8.5.5 Gross Income:

Gross Income = Total Income – Total Production Cost – Depreciation

Gross Income = 80,500,000– $74,464,598 – 502,030

Gross Income = 5,533,372

8.5.6 Net Income:

Taxes = 35%

Income Taxes =$1,936,680/yr

Net Income = Gross Income – Taxes = $3,596,692/yr

8.5.7 Rate of Return (ROR):

Rate of return = (Net income/ Total capital investment) *100%

Rate of return = (3,596,692/$11,097,495) *100

ROR = 32.4 %

8.5.8 Payback Period:

Payback period = 1/ROR = 1/0.324

Payback period =3.1 years

CHAPTER 9

INSTRUMENTATION & PROCESS CONTROL

9.1 Instrumentation and process control

Production cycles are in a constant state of flux, making it challenging to maintain them there for an extended period of time. The cycles have a tendency to deviate from this equilibrium, which might result in issues that degrade the final product's quality. To avoid this, we need a process control system that can identify any problems and address them before they have a big impact. To address these problems, we can either totally eradicate them or significantly reduce their occurrence.

Even though the majority of problems have unpredictable timing, we can foresee their possibility and take action to lessen their negative effects on the manufacturing process. We can improve our production process' efficiency by removing or managing these problems. Each cycle has variables that are subject to sudden changes that may have an impact on how the process turns out. As a result, we must keep an eye on these variables and use them as a signal to regulate the process.

We can modify the process's outcome to get better outcomes by adjusting the input variable. This control method enhances the effectiveness of our production process by enabling us to consistently produce higher yields. It also functions effectively in routine, risky, and remote tasks where human interaction is not always desirable or safe.

Complex systems like production processes must be managed carefully to produce the best results. We are able to increase efficiency and provide better yields by putting in place a process control system that can identify problems and fix them fast.[1]

The three causes are under maker control.

- Reduce variability,
- Increase effectiveness,
- Ensure safety/security

9.2 Instrumentation's primary goals:

- Secure plant operation
- Reach desired output or production
- Uphold requirements for product quality
- Work with minimal production costs.

9.3 Controller:

The controller responds to the error that a fault-detection system has found. This system mainly contrasts the supplied desired value to the controller with the actual value. [1]

9.3.1 Control elements

The last control aspect entails modifying the process's energy input in accordance with data from the controller and the desired input.

Defining the controller's category

The various regulators consist of:

- Pneumatic regulators, or regulators powered by air pressure
- Electricity-powered regulators (also known as electronic regulators)
- Hydraulic regulators, often known as hydraulic regulators [1]

9.4 Controlling plant species

Two categories of control strategies exist:

- Controls for input
- Feed forward

9.5 Heat exchanger Control

9.5.1 The usual route:

To keep the liquid on the left at the desired temperature, someone measures its temperature and modifies the input of hot and cold mediums.

9.5.2 Managing Overflow:

It is also advised to take fluctuations in the incoming stream's flow rate into account when determining the preferred temperature for a subsequent process.

9.5.3 Control Plan:

The heated liquid's temperature is measured by the temperature transmitter.

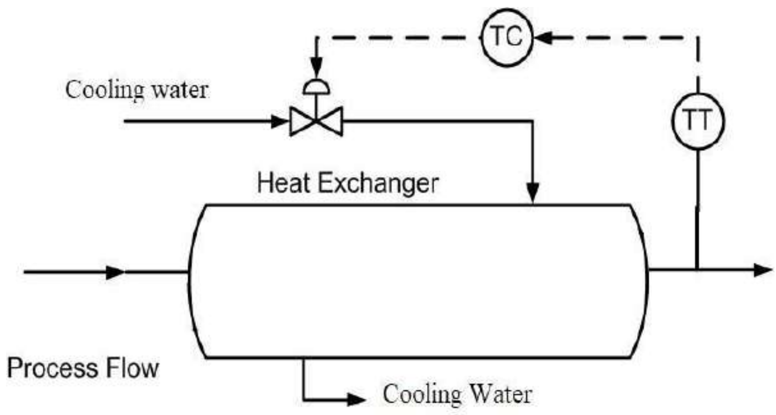


Figure 9-1 Control Schematic of Heat Exchanger

9.6 Control of Fixed-Bed Reactors

The primary goals are:

- The temperature is controlled by the furnace using a temperature controller.
- A pressure gauge measures the pressure to check for blockages within the reactor.

Additionally, display displays are put together to achieve the best possible parameter management.[1]

9.6.1 Disturbances include

- Changes in feed flowrate
- Concentration.
- Nutrient temperature

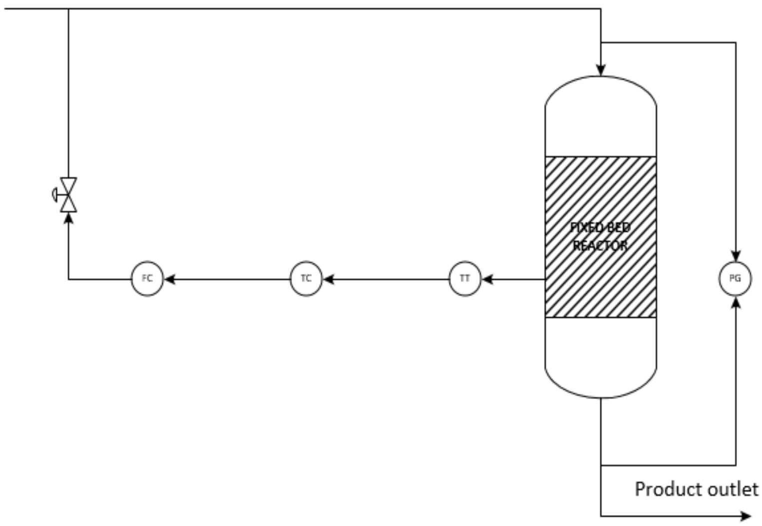


Figure-2: Control Schematic of Fixed Bed Reactor

Reference

[1] G. Stephanopoulos, Chemical Process Control; An introduction to Theory and Practice.

CHAPTER 10

HAZARD & OPERABILITY ANALYSIS

10.1 HAZOP:

A HAZOP survey is one of the most prevalent and well-acknowledged methods of systematic qualitative hazard assessments. It may be applied to an entire plant, a manufacturing unit, or a piece of equipment and it can be utilized for both new and existing facilities. It depends on the judgement of engineering and safety professionals in the areas with which they are most knowledgeable as a database and relies on the typical type of plant and process information. The ultimate result is thus trustworthy in terms of technical and operational expectations, but it is not quantitative and may not take into account the effects of complicated human mistake sequences.

10.2 Objectives of HAZOP study:

A HAZOP study's aims can be described as follows:

- To locate (areas in the design that might provide a substantial threat).
- To discover and investigate design aspects that impact the likelihood of a failure.
- There is a dangerous situation taking place.
- To acquaint the research team with the available design information.
- To guarantee that the regions of substantial hazard are studied in a methodical manner
- To find important design information that the team doesn't have access to right now.

10.3 Hazard & Operability Study:

The hazard & operability study, commonly referred to as the HAZOP study, is a systematic technique for identifying all plant or equipment hazards & operability problems. In this technique, each segment (pipeline, piece of equipment, instrument, etc.) is carefully examined, and all possible deviations from normal operating conditions are identified. This is accomplished by fully defining the intent of each segment and then applying guide words to each segment as follow:

- ❖ No or not------no part of intent is achieved, nothing else occurs (e.g., no flow)
- ❖ More------quantitative increase (e.g., higher temperature)
- ❖ Less-------quantitative decrease (e.g., lower pressure)
- ❖ As well as------qualitative increase (e.g., an impurity)
- ❖ Part of-------qualitative decrease (e.g., only one of those components in a mixture)

- ❖ Reverse------opposite (e.g., back flow)
- ❖ Other than------No part of the intent is achieved, and something completely different occurs (e.g., flow of wrong material)

These guide words are applied to flow, temperature, pressure, liquid level, composition, and any other variable affecting the process. The consequences of these deviations on the process are then assessed, and the measures needed to detect and correct the deviations are established. Since the majority of chemical process industry now uses some version of HAZOP for all new facilities and selectively uses it on existing ones.

10.4 Hazard assessment:

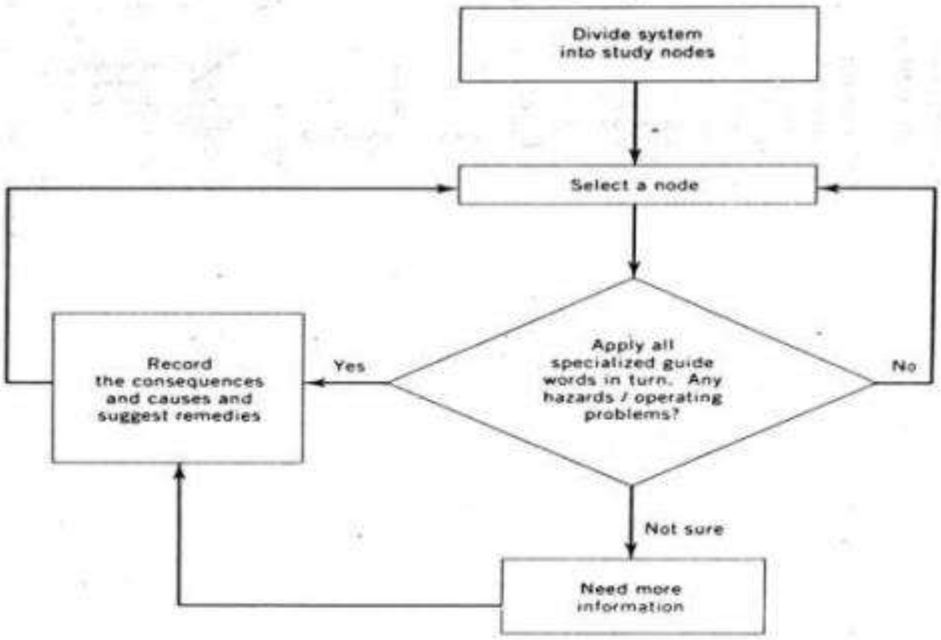
Hazard assessment is a vital tool in loss prevention throughout the life of the facility. Ideally, the assessment should be conducted during the conceptual design phase, final design stage, and prestartup period as well as when the plant is in full operation. In the conceptual design phase, many potential hazards can be identified and significant changes or corrections made at minimal cost. Results of these assessments are key inputs to both site selection and plant layout decisions. The major hazards usually include toxicity, fire and explosions; however, thermal radiation, noise, asphyxiation, and various environmental concerns also needed to be considered. A throughout hazard and risk assessment of a new facility is essential during the final design stage. At this stage, the piping and instrument diagrams, equipment details, and maintenance procedure are finalized. However, since equipment often has not been ordered, it is possible to make changes without incurring major penalties or delays.

A hazard assessment during the pre-startup period should be a final check rather than an initial assessment. This review should include the status of recommended changes from previous hazard studies and any significant design changes made after the final design. If serious hazards are identified at this time, it is unlikely that they can be eliminated without significant cost or start-up delay. Since process and operating procedure changes are often made during or shortly after plant startup, it is strongly advised that hazard assessment not stop after start-up. Rather, periodic hazard assessment studies should be used to define the hazard potential of such changes throughout the life of the facility. The average time between reviews is about 3 years; more hazardous facilities are reviewed more frequently.

10.5 Steps to conduct HAZOP study:

The steps of a HAZOP investigation are as follows:

1. Describe the study's aim, goal, and scope. The goal might be to evaluate a plant that has not yet been built or to assess the risk of an existing unit. The objectives described above can be made more detailed depending on the study's aim and conditions. The physical unit's limits, as well as the range of events and variables studied, define the study's scope. For example, HAZOPs used to be solely focused on fire and explosion endpoints, but now they often contain toxic release, disagreeable odor, and environmental endpoints as well.
2. Choose the HAZOP research team. To enable good group interaction, the team leader should be knowledgeable in HAZOP and interpersonal methods. The team should include as many different specialists as possible to cover all elements of design, operation, process chemistry, and safety. The team leader should go over the HAZOP method with the team and highlight that the final goal of a HAZOP survey is to identify hazards; finding solutions to issues is a distinct task.
3. The following items are frequently required, :
    - Gather Information
    - Description of the procedure
    - Flowcharts for processes
    - All raw materials, intermediates, and products have chemical, physical, and toxicological qualities.
    - Diagrams of piping and instruments (P&IDs)
    - Specifications for equipment, pipelines, and instruments
    - Logic diagrams for process control
    - Drawings for the layout
    - Operating procedures are a set of rules that govern how things are done.
    - Procedures for routine maintenance
    - Procedures for dealing with emergencies



4. Carry out the research. The unit is split into study "nodes" using the data obtained, and the procedure shown in Figure 1 is followed for each node. Process nodes are places in the process where known and desired values for process parameters (pressure, temperature, composition, and so on) exist. The functioning of various pieces of equipment, such as distillation columns, heat exchanges, and pumps, causes these values to fluctuate between nodes. To assist arrange the node process parameters and control logic information, several forms and work sheets have been designed.
5. The essence of the HAZOP research is repeated cycling through this process, which evaluates how and why each parameter could differ from the planned and the consequences.
6. Prepare a report. The study should reveal as much information as possible concerning events and their consequences. Clearly, if the HAZOP detects a not-too-improbable sequence of circumstances that might lead to a disaster, suitable follow-up action is required. Although risk reduction activity is not part of the HAZOP, it may be required as a result of the HAZOP.
7. HAZOP studies take a long time and are costly. Bringing an older plant's P&IDs up to date might be a big technical undertaking. Even yet, when weighed against the possible loss of life, property, business, and even the survival of the company that a catastrophic spill may cause, they are cost effective

10.6 HAZOP Analysis on Equipment:

Now, we will perform HAZOP analysis of each equipment designed and we will see what can be possible hazards occur due to change in operating conditions and how can we manage these things so that we can minimize or eliminate hazardous situations.

10.6.1 HAZOP study on Reactor:

Guide word and Deviation from operating Conditions	Event that could cause this deviation	Consequence of this deviation on item of equipment under consideration	Additional implication of this consequence	Process indication
Less level	Reactor vessel run dry Product valve open or broken	Pump cavities Reagent released	Damage to pump	Level controller installed at mid-way up of reactor
More level	Feed reactant valve open or broken Product valve close	Error in flow controller at inlet feed	Over flow and release of toxic chemicals	Level controller installed at mid-way up of reactor
Less pressure	Relief valve open or broken Pressure controller failure	No reaction	Phase change of components	Pressure controller installed over Reactor
More pressure	Relief valve closed Pressure controller failure		Explosion	Pressure controller installed over Reactor

Less temperature	Temperature controller failure	No reaction would take place	Low temperature alarm activities would start	Temperature controller installed over Reactor

10.6.2 HAZOP study on Heat Exchanger:

Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
High	Pipe side Temperature	Pipe side outlet valve closes	Pipe damage or rupture	Install high temperature security alarm
Less	Pipe side Temperature	Low flowrate of Cooling Lube oil	Process Fluid temperature too high	Install temperature indicator alarm
None	Cooling Lube oil Flow Rate	Failure of Cooling Lube oil inlet valve to open	Process fluid temperature not lowered accordingly	Install temperature indicator before and after the process fluid line
More	Cooling Lube oil Flow Rate	Failure of Cooling Lube oil inlet valve to close	Process fluid temperature too low	Install temperature indicator before and after the process fluid line
Less	Cooling Lube oil Flow Rate	Pipe leakages	Process fluid temperature not decreased accordingly	Installation of Flow Meter

High	Annulus Side Pressure	Annulus side discharge valve closes	Annulus side will be over pressurized	Install high pressure security alarm
Low	Annulus Side Pressure	Compressor Trips	No significant effect	Not Applicable
High	Pipe Side Pressure	Pipe Side discharge valve closed	Pipe may rupture	Install high pressure security alarm

10.6.3 HAZOP study on Furnace:

Parameter	**Deviation**	**Cause**	**Consequence**	**Safe guard**	**Action**
Temperature	Higher	Too much fuel supplied to the furnace Inlet flowrate decreases	Cannot get desired products Pressure build up lead to explosion	Install Flow controller & alarm when fuel flow rate is 20% more than set point	Check the flowrate Shut down if temperature is too high
Temperature	Lower	Not enough heat provided Inlet flowrate is too high	Effect the temperature of product process upset and capacity reduced	Flow controller alarm when fuel flow rate is 20% lower than set point	Check valves, set point, Increase fuel flow or decrease inlet flow

10.6.4 HAZOP study on Distillation Column:

Guide word and deviation from operating conditions	**Event that could cause this deviation**	**Consequence of this deviation on item of equipment under consideration**	**Additional implication of this consequence**	**Process indications**	**Process indications**
No Flow	Pipe blockage Valves fail open Tube leakages	Dry out in column Possible dangerous concentration No operation	No Production	Flow controller installed above condenser inlet	Set up low temperature alarm and Direct towards maintenance procedure
Less Flow	Blockage of pipeline Valves failure Tube leakages	Dry out in column Product quality variations	Equipment shutdown	Flow controller installed above condenser inlet.	Set up low temperature alarm and Direct towards maintenance schedule.
More Flow	Fully open valve Control valve failure	Flooding in the column Changes in product quality Temperature decrease	Chances of flooding and entrainment.	Flow controller installed above condenser inlet.	Install flow controller
High Level	Blockage at output	Over high pressure across plates Back flow of	Over flow to downstream unit operation	Installed Level controller	Set up high level alarm and direct towards

		bottom liquid to column		over reflux drum	maintenance schedule.
Low Level	Pipe partial clogged and leakage	Back flow can occur to fulfill the requirement	Damage to column	Installed Level controller over reflux drum	At how much low level can reboiler damage?
More Pressure	High Level	Failure of pressure relief valve	Column may explode	Pressure controller installed at top and bottom of column.	What can be the maximum operating pressure?
High Temperature	Less feed in the column	Pressure buildup in column Undesired components	Damage to reboiler and condenser	Temperature controller installed over condenser and reboiler	Install high temperature alarm. How much Install high temperature alarm. How much
Low temperature	Malfunctioning of reboiler	Desired components will not separate Undesired product	Damage to reboiler and condense	Damage to reboiler and condense	Set up low temperature alarm and Direct towards maintenance procedure and plan

CHAPTER 11

ENVIRONMENTAL IMPACT ASSESSMENT

11.1 Introduction

A comprehensive procedure called an environmental impact assessment (EIA) aids in determining the potential effects of a project proposal on the environment, society, culture, and public health. Before important decisions and commitments are made, it entails identifying, anticipating, assessing, and mitigating the project's biophysical, social, and other pertinent repercussions.

EIA is a useful tool for project planning and design since it enables early detection of potential environmental and social hazards and gives the chance to discover solutions to mitigate or avoid negative effects. EIA assists in structuring projects to be more compatible with the local environment and community by taking into account a wide range of elements, including ecological, social, cultural, and health considerations.

The fact that EIA can have positive effects on the environment and the economy is one of its main advantages. EIA, for instance, might assist avoid expensive cleanup and mitigation actions later on by identifying potential hazards and suggesting changes to project design. Additionally, adhering to laws and regulations through the EIA process might avoid legal repercussions and delays, saving money and time when a project is implemented.

Along with its technical components, EIA is essential for advancing sustainable development. It offers a chance to think about how a project might affect the environment, society, and economy in the long run and promotes the inclusion of environmental and social factors in decision-making processes. EIA encourages informed decision-making and aids in ensuring that projects are carried out in a responsible and sustainable manner by encouraging openness, public participation, and stakeholder interaction .[1]

The process of assessing a project's or development's anticipated environmental effects while taking into account related socioeconomic, cultural, and human health effects—both positive and negative is known as an environmental impact assessment (EIA) .[2]

11.2 Evolution of EIA

The fast industrialisation and urbanisation of Western nations prior to World War I caused the depletion of natural resources, which persisted after the Second World War and gave rise to worries about pollution, quality of life, and environmental stress. Investors and the general public first became aware of how their initiatives were affecting the environment, resources, raw materials, and people in the 1960s. The establishment of pressure organisations promoting a device to protect the environment during development resulted from this realisation. As a result, the US passed the National Environmental Policy Act in 1970, becoming the first nation to legalise the use of environmental impact assessments (EIA) as a formal method of environmental protection.

The concept of EIA was made official by the 1972 Stockholm United Nations Conference on the Environment and subsequent treaties. Since then, nearly 100 nations have ratified the EIA as a global standard regulatory method. It is now required in many wealthy nations. Early 1970s saw the introduction of EIA in nations including Canada, Australia, and New Zealand, as well as comparatively early adoption in emerging nations like Colombia (1974) and the Philippines (1978). EIA requirements have started to appear in the eligibility requirements set forth by multilateral and bilateral lenders.[3]

11.3 The objectives of EIA

11.3.1 EIA as a Tool for Decision-Making

By methodically analysing the environmental impacts of a proposed action, including alternatives, before reaching a decision, EIA serves as a tool for decision-makers, such as local authorities. Even while EIA is more comprehensive and less quantitative than methods like cost-benefit analysis (CBA), it aids in the clarification of trade-offs related to proposed developments, resulting in more informed decision-making. A balanced solution that takes into account the interests of both the development action and the environment can be reached through agreements between developers, public interest organisations, and planning regulators with the help of the EIA process.[4]

11.3.2 EIA as a Tool for Creating Development Action Plans

Developers may see the EIA process as an additional barrier to getting development clearance, but it can really be helpful because it offers a framework for taking location, design, and environmental concerns into account at the same time. By identifying areas where changes can reduce or eliminate environmental impacts, EIA can help in the formulation of development actions. Early planning stage consideration of environmental effects can lead to more environmentally responsible development, better relationships between developers, planning authorities, and local communities, a smoother application process for development permits, and possibly a profitable return on the investment in EIA. [4]

11.3.3 EIA as a Tool for Consultation and Participation with Stakeholders

Actions related to development may have a wide range of effects on the environment and different society groups. At many levels of government, there is a growing emphasis on the value of stakeholder input and involvement in the design and implementation of projects. EIA can be a useful tool for interacting with communities and stakeholders, giving individuals who could be impacted by a planned development the chance to learn more and take an active part in the planning and development process. [4]

11.4 The Use of EIA in Sustainable Development

Environmentally hazardous developments that are already operational might be difficult to manage and may even require shutdown or expensive mitigating measures. However, it is more efficient to eliminate or avoid such repercussions up front, during the planning stage. This is in line with the idea of sustainable development, which was emphasised in the ground-breaking EIA laws passed in the US and the EC. Although this role may not always be fully appreciated when evaluating the efficacy of EIA, it is possible that EIA might play a crucial role in fostering sustainable development. [4]

11.5 EIA procedures

There are precise procedures that must be followed in order to complete an Environmental Impact Assessment (EIA) for a particular project. These actions make it possible to recognise and lessen potential environmental effects. Stakeholder consultation and an extensive examination of the project's environmental impacts are both parts of the process. The negative effects of the project on the environment can be reduced by following the processes described in the EIA process. Regardless of the nature or magnitude of the project, it is imperative to follow these procedures for an efficient and thorough evaluation of the project's environmental impact.

Figure 11-1 Steps of EIA

11.6 EIA on our project

Table 11-1 Shows screening & environmental impacts of chemical involved

Chemicals Involved	Screening (Toxic or Not)	Environmental Impacts	Impacts on Health
Palmitic Acid [5]	Yes	Palmitic acid is expected to predominately be found in the particulate phase when discharged into the atmosphere. Any palmitic acid in the vapour phase is anticipated to decay through a 20-hour-long interaction with hydroxyl radicals generated by photochemical processes. Palmitic acid is probably stationary in soil, according to an estimated value of 189,000. Volatilization from damp soil is not anticipated, and it is not predicted to have a substantial impact on the surface of dry soil..	inflammation of the skin and eyes. can irritate the respiratory system as well. may cause digestive system discomfort, resulting in signs including nausea, vomiting, and diarrhoea.
Acetic Acid [6]	Yes	The molecule degrades after being released into the atmosphere by reacting with hydroxyl radicals, which are created by photochemical processes. This deterioration is thought to have a half-life of about 26.7 days. Acetate, a type of the chemical, is also found in atmospheric particulate matter. Wet and dry deposition processes can both be used to remove something from the air.	may cause damage to the lungs, bronchial system, throat, nose, and throat mucous membranes. It May result in severe burns. may cause blindness, vision loss, or eye injury. Long-term contact can seriously harm tissue.

		It has been demonstrated that the substance can harm aquatic species since it can change the pH (acidity) of the water.	
1-Tetradecene [7]	No	If ingested and enters the airways, it may be fatal.	Repeated or prolonged contact with the mixture may lead to removal of natural skin oils, resulting in dryness and dehydration of the skin.
Octacosene	No	This material is not anticipated to have adverse impacts on the environment, including aquatic organisms.	It has No serious impacts on the health

Personal Protective equipment (PPE's)

Personal Protective Equipment (PPE) refers to devices or appliances designed to be worn or held by individuals for protection against health and safety hazards. The following are essential PPE items required in a plant:

- Respiratory protection
- Safety vests
- Goggles
- Gloves
- Hearing protection
- Safety dress
- Face shields
- Other protective gears
- Special type of oxygen mask
- Resuscitation mask

These PPE items should be available in every process plant to handle emergencies without posing harm to the workforce. Regular monitoring of all activities, including maintenance and processing, is necessary to prevent leakage of dangerous gases and protect the physical environment and surrounding organisms from harm.[4]

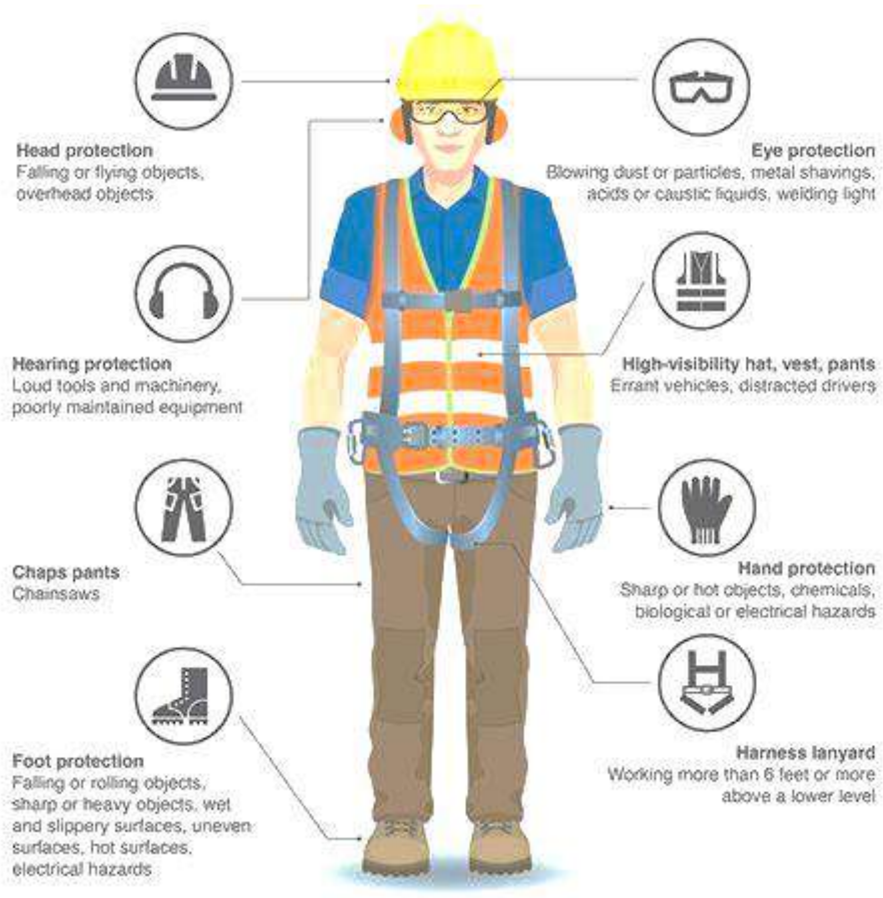
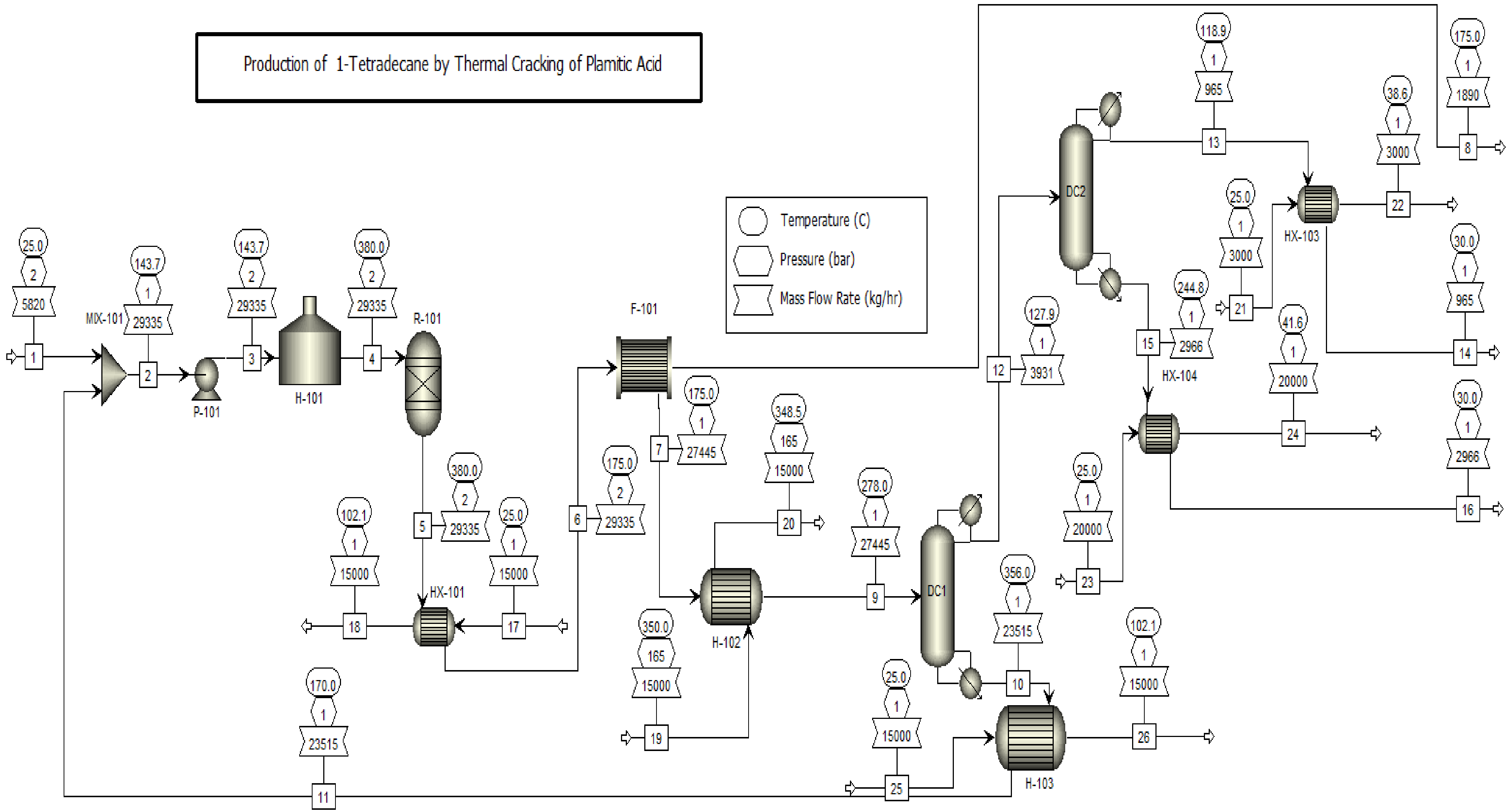


Figure 11-2 Personal Protective equipments

CHAPTER 12

PROCESS SIMULATION


Production of 1-Tetradecane by Thermal Cracking of Plamitic Acid
Temperature (C)
Pressure (bar)
Mass Flow Rate (kg/hr)
MIX-101
P-101
H-101
R-101
F-101
HX-101
H-102
H-103
DC1
DC2
HX-103
HX-104
25.0
2
5820
1
143.7
1
29335
2
143.7
2
29335
3
380.0
2
29335
4
380.0
2
29335
5
175.0
2
29335
6
175.0
1
27445
7
175.0
1
1890
8
278.0
1
27445
9
356.0
1
23515
10
170.0
1
23515
11
127.9
1
3931
12
118.9
1
965
13
30.0
1
965
14
244.8
1
2966
15
30.0
1
2966
16
25.0
1
15000
17
102.1
1
15000
18
350.0
165
15000
19
348.5
165
15000
20
25.0
1
3000
21
38.6
1
3000
22
25.0
1
20000
23
41.6
1
20000
24
25.0
1
15000
25
102.1
1
15000
26

```
 + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + +
+ + + + + +
 + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + +
+ + + + + +
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+ +
 + +                      ASPEN PLUS CALCULATION REPORT
+ +
 + +
+ +
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+ + + + + +

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 781/221-6400                           EUROPE (44) 1189-226555

 PLATFORM: WIN-X64                                       MAY 12, 2023
 VERSION: 37.0   Build 395                               FRIDAY
 INSTALLATION:                                           7:56:58 P.M.
```

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                              RUN CONTROL SECTION

 RUN CONTROL INFORMATION
 -----------------------

 THIS COPY OF ASPEN PLUS LICENSED TO

 TYPE OF RUN: NEW

 INPUT FILE NAME: _5553zyv.inm

 OUTPUT PROBLEM DATA FILE NAME: _5553zyv
 LOCATED IN:


 PDF SIZE USED FOR INPUT TRANSLATION:
   NUMBER OF FILE RECORDS (PSIZE) =     0
   NUMBER OF IN-CORE RECORDS      =   256
 PSIZE NEEDED FOR SIMULATION    =   256

 CALLING PROGRAM NAME:          apmain
 LOCATED IN:                    f:\New folder (4)\Aspen Plus
V11.0\Engine\\xeq

 SIMULATION REQUESTED FOR ENTIRE FLOWSHEET
```

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FLOWSHEET SECTION

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
1	----	MIX-101	17	----	HX-101
19	----	H-102	25	----	H-103
21	----	HX-103	23	----	HX-104
2	MIX-101	P-101	3	P-101	H-101
4	H-101	R-101	6	HX-101	F-101
18	HX-101	----	7	F-101	H-102
8	F-101	----	5	R-101	HX-101
20	H-102	----	9	H-102	DC1
13	DC2	HX-103	15	DC2	HX-104
11	H-103	MIX-101	26	H-103	----
14	HX-103	----	22	HX-103	----
16	HX-104	----	24	HX-104	----
12	DC1	DC2	10	DC1	H-103

FLOWSHEET CONNECTIVITY BY BLOCKS

BLOCK	INLETS	OUTLETS
MIX-101	1 11	2
P-101	2	3
H-101	3	4
HX-101	5 17	6 18
F-101	6	7 8
R-101	4	5
H-102	19 7	20 9
DC2	12	13 15
H-103	10 25	11 26
HX-103	13 21	14 22
HX-104	15 23	16 24
DC1	9	12 10

CONVERGENCE STATUS SUMMARY

TEAR STREAM SUMMARY
===================

STREAM ID	VARIABLE ID	MAXIMUM ERR/TOL	MAX. ERR. RELATIVE	ABSOLUTE ERROR	CONV STAT	BLOCK
11	1-OCT-01MOLEFLOW	0.31655E-04	-0.31655E-08	0.99832E-15	#	$OLVER01

\# = CONVERGED
* = NOT CONVERGED

```
 CONVERGENCE BLOCK:  $OLVER01
 ----------------------------
     Tear Stream  :  11
     Tolerance used:  0.100D-03
     Trace molefrac:  0.100D-05
     Trace substr-2:  0.100D-05


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                               FLOWSHEET SECTION

 CONVERGENCE BLOCK:  $OLVER01 (CONTINUED)
     MAXIT=   30 WAIT   1 ITERATIONS BEFORE ACCELERATING
     QMAX =   0.0     QMIN =  -5.0
     METHOD: WEGSTEIN      STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:     5

                          *** FINAL VALUES ***


     VAR#  TEAR STREAM VAR   STREAM    SUBSTREA COMPONEN ATTRIBUT
ELEMENT  UNIT         VALUE        PREV VALUE   ERR/TOL
     ----  ----------------  ------    -------- -------- -------- -----
--  ----         -----        ----------   -------
        1  TOTAL MOLEFLOW    11        MIXED
KMOL/HR         91.7338      91.7338   -2.1971-07
        2  TOTAL MOLEFLOW    11        CIPSD
KMOL/HR       1.1354-03    1.1354-03   -3.1655-05
        3  SUBS-ATTR-VA      11        CIPSD             PSD      FRAC1
1.0000       1.0000       0.0
        4  SUBS-ATTR-VA      11        CIPSD             PSD      FRAC2
0.0          0.0          0.0
        5  SUBS-ATTR-VA      11        CIPSD             PSD      FRAC3
0.0          0.0          0.0
        6  SUBS-ATTR-VA      11        CIPSD             PSD      FRAC4
0.0          0.0          0.0
        7  SUBS-ATTR-VA      11        CIPSD             PSD      FRAC5
0.0          0.0          0.0
        8  SUBS-ATTR-VA      11        CIPSD             PSD      FRAC6
0.0          0.0          0.0
        9  SUBS-ATTR-VA      11        CIPSD             PSD      FRAC7
0.0          0.0          0.0
       10  SUBS-ATTR-VA      11        CIPSD             PSD      FRAC8
0.0          0.0          0.0
       11  SUBS-ATTR-VA      11        CIPSD             PSD      FRAC9
0.0          0.0          0.0
       12  SUBS-ATTR-VA      11        CIPSD             PSD
FRAC10                    0.0          0.0         0.0
       13  MOLE-FLOW         11        MIXED    N-HEX-01
KMOL/HR         91.5828      91.5828   -2.1971-07
       14  MOLE-FLOW         11        MIXED    ACETI-01
KMOL/HR       7.4685-07    7.4685-07   -2.2171-07
       15  MOLE-FLOW         11        MIXED    1-TET-01
KMOL/HR          0.1510       0.1510   -2.1983-07
```

```
       16  MOLE-FLOW         11         MIXED    1-OCT-01
KMOL/HR          0.0          0.0          0.0
       17  MOLE-FLOW         11         MIXED    WATER
KMOL/HR          0.0          0.0          0.0
       18  PRESSURE          11         MIXED
BAR                1.2000       1.2000       0.0
       19  MASS ENTHALPY     11         MIXED
CAL/GM        -695.0924    -695.0924   -4.7687-12
       20  MOLE-FLOW         11         CIPSD    N-HEX-01
KMOL/HR          0.0          0.0          0.0
       21  MOLE-FLOW         11         CIPSD    ACETI-01
KMOL/HR          0.0          0.0          0.0
       22  MOLE-FLOW         11         CIPSD    1-TET-01
KMOL/HR          0.0          0.0          0.0
       23  MOLE-FLOW         11         CIPSD    1-OCT-01
KMOL/HR       1.1354-03    1.1354-03   -3.1655-05
       24  MOLE-FLOW         11         CIPSD    WATER
KMOL/HR          0.0          0.0          0.0
       25  PRESSURE          11         CIPSD
BAR                1.2000       1.2000       0.0
       26  MASS ENTHALPY     11         CIPSD
CAL/GM        -333.5393    -333.5393       0.0

                    *** ITERATION HISTORY ***

     TEAR STREAMS AND TEAR VARIABLES:

     ITERATION MAX-ERR/TOL  VAR# STREAM ID VAR DESCRIPTION  SUBSTREA
COMPONEN ATTRIBUT ELEMENT
     --------- ----------  ---- --------- ---------------  -------- --
------ -------- -------
         1      0.1000E+07    3 11        SUBS-ATT         CIPSD
PSD      FRAC1
         2       8017.        2 11        TOTAL MO         CIPSD
         3      -5.303        2 11        TOTAL MO         CIPSD
         4       21.41        2 11        TOTAL MO         CIPSD
         5     -0.3165E-04    2 11        TOTAL MO         CIPSD
```

```
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                               FLOWSHEET SECTION

 COMPUTATIONAL SEQUENCE
 ----------------------

 SEQUENCE USED WAS:
    $OLVER01 MIX-101 P-101 H-101 *R-101 HX-101 F-101 H-102 DC1 H-103
    (RETURN $OLVER01)
    DC2 HX-103 HX-104

 OVERALL FLOWSHEET BALANCE
 -------------------------

                      ***  MASS AND ENERGY BALANCE  ***
                                IN               OUT        RELATIVE
DIFF.
    CONVENTIONAL COMPONENTS (KMOL/HR )
       N-HEX-01                  22.6980        4.91665
0.783389
       ACETI-01                  0.00000        17.0293        -
1.00000
       1-TET-01                  0.00000        15.7430        -
1.00000
       1-OCT-01                  0.00000        1.13415        -
1.00000
       WATER                     3774.57        3774.57       -
0.240953E-15
    TOTAL BALANCE
       MOLE(KMOL/HR )            3797.27        3813.40       -
0.422855E-02
       MASS(KG/HR   )            73820.4        73820.4       -
0.701768E-11
       ENTHALPY(CAL/SEC )      -0.708167E+08   -0.686830E+08   -
0.301310E-01

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR
```

```
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                          PHYSICAL PROPERTIES SECTION

 COMPONENTS
 ----------

  ID       TYPE  ALIAS          NAME
   N-HEX-01 C     C16H32O2       N-HEXADECANOIC-ACID
   ACETI-01 C     C2H4O2-1       ACETIC-ACID
   1-TET-01 C     C14H28-2       1-TETRADECENE
   1-OCT-01 C     C28H56-N2      1-OCTACOSENE
   WATER    C     H2O            WATER


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                              U-O-S BLOCK SECTION

 BLOCK:  DC1      MODEL: DSTWU
 -----------------------------
   INLET STREAM:           9
   CONDENSER OUTLET:       12
   REBOILER OUTLET:        10
   PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                       ***  MASS AND ENERGY BALANCE  ***
                                  IN                OUT         RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           122.953         122.953
0.00000
       MASS(KG/HR   )           27445.1         27445.1
0.00000
       ENTHALPY(CAL/SEC )     -0.465335E+07   -0.444147E+07   -
0.455345E-01

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                           ***  INPUT DATA  ***
    HEAVY KEY COMPONENT                                            N-HEX-
01
    RECOVERY FOR HEAVY KEY                                      0.00100000
    LIGHT KEY COMPONENT                                            1-TET-
01
    RECOVERY FOR LIGHT KEY                                      0.99000
    TOP STAGE PRESSURE (BAR     )                               1.00000
    BOTTOM STAGE PRESSURE (BAR     )                            1.20000
    NO. OF EQUILIBRIUM STAGES                                  43.0000
    DISTILLATE VAPOR FRACTION                                   0.0
```

```
                         ***  RESULTS  ***
    DISTILLATE TEMP.  (C        )                          127.912
    BOTTOM TEMP.  (C        )                              355.965
    MINIMUM REFLUX RATIO                                     0.15042
    ACTUAL REFLUX RATIO                                      0.16700
    MINIMUM STAGES                                           5.70575
    ACTUAL EQUILIBRIUM STAGES                               43.0000
    NUMBER OF ACTUAL STAGES ABOVE FEED                      23.0934
    DIST. VS FEED                                            0.25390
    CONDENSER COOLING REQUIRED (CAL/SEC )               115,269.
    NET CONDENSER DUTY (CAL/SEC )                      -115,269.
    REBOILER HEATING REQUIRED (CAL/SEC )                327,150.
    NET REBOILER DUTY (CAL/SEC )                        327,150.


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                            U-O-S BLOCK SECTION

 BLOCK:  DC2      MODEL: DSTWU
 -----------------------------
   INLET STREAM:           12
   CONDENSER OUTLET:       13
   REBOILER OUTLET:        15
   PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )          31.2178         31.2178
0.00000
       MASS(KG/HR   )          3930.53         3930.53
0.231393E-15
       ENTHALPY(CAL/SEC )     -726776.        -672023.        -
0.753362E-01

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                        ***  INPUT DATA  ***
    HEAVY KEY COMPONENT                                        1-TET-
01
    RECOVERY FOR HEAVY KEY                                   0.00100000
    LIGHT KEY COMPONENT                                        ACETI-
01
    RECOVERY FOR LIGHT KEY                                   0.99000
    TOP STAGE PRESSURE (BAR     )                            1.00000
    BOTTOM STAGE PRESSURE (BAR     )                         1.05000
    NO. OF EQUILIBRIUM STAGES                               40.0000
    DISTILLATE VAPOR FRACTION                                0.0
```

```
                         ***  RESULTS  ***
    DISTILLATE TEMP.  (C        )                          118.932
    BOTTOM TEMP.  (C        )                              244.835
    MINIMUM REFLUX RATIO                                     0.25741
    ACTUAL REFLUX RATIO                                      0.28070
    MINIMUM STAGES                                           6.52752
    ACTUAL EQUILIBRIUM STAGES                               40.0000
    NUMBER OF ACTUAL STAGES ABOVE FEED                      29.0446
    DIST. VS FEED                                            0.51352
    CONDENSER COOLING REQUIRED (CAL/SEC )                55,809.6
    NET CONDENSER DUTY (CAL/SEC )                       -55,809.6
    REBOILER HEATING REQUIRED (CAL/SEC )                110,562.
    NET REBOILER DUTY (CAL/SEC )                        110,562.


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                              U-O-S BLOCK SECTION

 BLOCK:  F-101    MODEL: CFFILTER
 --------------------------------
   INLET STREAM:          6
   OUTLET STREAMS:        7           8
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN                OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           130.558         130.558
0.00000
       MASS(KG/HR   )           29335.0         29335.0
0.248030E-15
       ENTHALPY(CAL/SEC )      -0.553168E+07   -0.553168E+07   -
0.458503E-08

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                          ***  INPUT DATA  ***
   CALCULATION METHOD                                        SIMULATION
   SELECTED MODEL                                            SOLIDS
SEPARATOR
   CLASSIFICATION CHARACTERISTIC                           PARTICLE SIZE
   FRACTION OF FLUID TO FLUID OUTLET                          0.95000
   FRACTION OF SOLIDS TO SOLID OUTLET                         0.99900
   SEPARATION SHARPNESS                                       1.00000
   OFFSET OF FINES                                            0.0
   ONE    PHASE  PQ  FLASH   SPECIFIED PHASE IS  LIQUID
   SPECIFIED PRESSURE    BAR                                  1.00000
   SPECIFIED HEAT DUTY   CAL/SEC                              0.0
```

```
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE
0.000100000


                           ***  RESULTS  ***
   FRACTION OF FLUID TO FLUID OUTLET                          0.95000
   FRACTION OF SOLIDS TO SOLID OUTLET                         0.99900
   SOLID LOAD OF FLUID OUTLET (KG/KG)                         0.162477-
04
   FLUID LOAD OF SOLID OUTLET (KG/KG)                         3.24275
   D50 OF SEPARATION CURVE METER                              0.200012-
07
   HEAT DUTY  CAL/SEC                                       0.25363E-01


 BLOCK:  H-101    MODEL: HEATER
 ------------------------------
   INLET STREAM:          3
   OUTLET STREAM:         4
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                       ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT        RELATIVE
DIFF.


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                              U-O-S BLOCK SECTION

 BLOCK:  H-101    MODEL: HEATER (CONTINUED)
    TOTAL BALANCE
       MOLE(KMOL/HR )            114.433         114.433
0.00000
       MASS(KG/HR   )            29335.0         29335.0
0.00000
       ENTHALPY(CAL/SEC )      -0.579153E+07   -0.402370E+07   -
0.305244

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                           ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE                C                    380.000
   PRESSURE DROP                        BAR
0.80000
   MAXIMUM NO. ITERATIONS                                        30
   CONVERGENCE TOLERANCE
0.000100000
```

```
                         ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                      380.00
   OUTLET PRESSURE       BAR                                    1.5000
   HEAT DUTY             CAL/SEC
0.17678E+07
   OUTLET VAPOR FRACTION                                        1.0000


   V-L PHASE EQUILIBRIUM :

      COMP              F(I)           X(I)           Y(I)
K(I)
      N-HEX-01         0.99868        0.99969        0.99868
1.2597
      ACETI-01         0.65266E-08    0.28527E-09    0.65266E-08
28.850
      1-TET-01         0.13195E-02    0.31487E-03    0.13195E-02
5.2844


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                              U-O-S BLOCK SECTION

 BLOCK:  H-102    MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             19
   OUTLET STREAM:            20
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
   COLD SIDE:
   ----------
   INLET STREAM:             7
   OUTLET STREAM:            9
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                   IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           955.579         955.579
0.00000
       MASS(KG/HR   )           42445.1         42445.1
0.00000
       ENTHALPY(CAL/SEC )     -0.183994E+08   -0.183994E+08
0.430311E-07

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
```

```
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                         ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED COLD OUTLET TEMP
     SPECIFIED VALUE                C                        278.0000
     LMTD CORRECTION FACTOR                                    1.00000


ASPEN PLUS   PLAT: WIN-X64   VER: 37.0                     05/12/2023
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                              U-O-S BLOCK SECTION

 BLOCK:  H-102    MODEL: HEATX (CONTINUED)

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                        0.0000
     COLD SIDE PRESSURE DROP        BAR                        0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K             0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K             0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K             0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K             0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K             0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K             0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K             0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K             0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K             0.0203

                       ***  OVERALL RESULTS  ***

   STREAMS:
                 --------------------------------------
                 |                                    |
   19       ----->|                HOT                 |-----> 20
   T=  3.5000D+02  |                                    |       T=
3.4851D+02
   P=  1.6500D+02  |                                    |       P=
1.6500D+02
   V=  1.0000D+00  |                                    |       V=
3.6843D-01
```

```
                |                                     |
   9        <-----|              COLD                  |<----- 7
   T=  2.7800D+02  |                                     |       T=
1.7504D+02
   P=  1.0000D+00  |                                     |       P=
1.0000D+00
   V=  1.6555D-01  |                                     |       V=
0.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY            CAL/SEC            562907.8600
     CALCULATED (REQUIRED) AREA      SQM                    24.4766
     ACTUAL EXCHANGER AREA           SQM                    24.4766
     PER CENT OVER-DESIGN                                    0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)     CAL/SEC-SQCM-K          0.0203
     UA (DIRTY)                      CAL/SEC-K            4969.2137

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                  1.0000
     LMTD (CORRECTED)                C                     113.2791
     NUMBER OF SHELLS IN SERIES                              1

   PRESSURE DROP:
     HOTSIDE, TOTAL                  BAR                     0.0000
     COLDSIDE, TOTAL                 BAR                     0.0000


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                              U-O-S BLOCK SECTION

 BLOCK:  H-102    MODEL: HEATX (CONTINUED)

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                           HOT
         -------------------------------------------------------------
         |                   |                   |                   |
 HOT IN  |        VAP        |       COND        |       COND        |
HOT OUT
 ------> |                   |                   |                   |-
----->
  350.0  |              348.5|              348.5|                   |
348.5
         |                   |                   |                   |
 COLDOUT |        BOIL       |       BOIL        |        LIQ        |
COLDIN
 <------ |                   |                   |
|<------
  278.0  |              276.2|              192.8|                   |
175.0
         |                   |                   |                   |
```

```
     -------------------------------------------------------------
                                        COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY        AREA       LMTD       AVERAGE U       UA
              CAL/SEC          SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1      11377.275         0.7767      72.1537     0.0203
157.6812
     2     467932.703        21.1959     108.7413     0.0203
4303.1743
     3      83597.883         2.5040     164.4468     0.0203
508.3583


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                                U-O-S BLOCK SECTION

 HEATX COLD-TQCU H-102    TQCURV INLET
 ------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
```

DUTY CAL/SEC	PRES BAR	TEMP C	VFRAC
0.0	1.0000	278.0000	0.1656
1.1383+04	1.0000	276.2052	0.1609
2.6805+04	1.0000	273.7414	0.1548
5.3610+04	1.0000	269.3758	0.1447
8.0415+04	1.0000	264.9132	0.1354
1.0722+05	1.0000	260.3629	0.1267
1.3403+05	1.0000	255.7338	0.1183
1.6083+05	1.0000	251.0344	0.1104
1.8764+05	1.0000	246.2729	0.1026
2.1444+05	1.0000	241.4572	9.4995-02
2.4125+05	1.0000	236.5951	8.7388-02
2.6805+05	1.0000	231.6944	7.9684-02
2.9486+05	1.0000	226.7631	7.1764-02
3.2166+05	1.0000	221.8097	6.3505-02
3.4847+05	1.0000	216.8432	5.4772-02
3.7527+05	1.0000	211.8734	4.5419-02
4.0208+05	1.0000	206.9110	3.5285-02
4.2888+05	1.0000	201.9684	2.4191-02
4.5569+05	1.0000	197.0590	1.1937-02

```
 !  4.7931+05 !     1.0000 !   192.7723 ! BUB>0.0    !
 !------------+------------+------------+------------!
 !  4.8249+05 !     1.0000 !   192.1052 !     0.0    !
 !  5.0930+05 !     1.0000 !   186.4617 !     0.0    !
 !  5.3610+05 !     1.0000 !   180.7744 !     0.0    !
 !  5.6291+05 !     1.0000 !   175.0421 !     0.0    !
 -----------------------------------------------------
```

```
ASPEN PLUS   PLAT: WIN-X64   VER: 37.0                   05/12/2023
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                              U-O-S BLOCK SECTION

 HEATX HOT-TQCUR H-102    TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:       CONSTANT2
   PRESSURE DROP:          0.0         BAR
   PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !   165.0000 !   350.0000 !     1.0000 !
 !  1.1383+04 !   165.0000 !   348.5133 ! DEW>1.0000 !
 !  2.6805+04 !   165.0000 !   348.5133 !     0.9823 !
 !  5.3610+04 !   165.0000 !   348.5133 !     0.9516 !
 !  8.0415+04 !   165.0000 !   348.5133 !     0.9209 !
 !------------+------------+------------+------------!
 !  1.0722+05 !   165.0000 !   348.5133 !     0.8903 !
 !  1.3403+05 !   165.0000 !   348.5133 !     0.8596 !
 !  1.6083+05 !   165.0000 !   348.5133 !     0.8289 !
 !  1.8764+05 !   165.0000 !   348.5133 !     0.7982 !
 !  2.1444+05 !   165.0000 !   348.5133 !     0.7675 !
 !------------+------------+------------+------------!
 !  2.4125+05 !   165.0000 !   348.5133 !     0.7368 !
 !  2.6805+05 !   165.0000 !   348.5133 !     0.7061 !
 !  2.9486+05 !   165.0000 !   348.5133 !     0.6754 !
 !  3.2166+05 !   165.0000 !   348.5133 !     0.6447 !
 !  3.4847+05 !   165.0000 !   348.5133 !     0.6140 !
 !------------+------------+------------+------------!
 !  3.7527+05 !   165.0000 !   348.5133 !     0.5833 !
 !  4.0208+05 !   165.0000 !   348.5133 !     0.5526 !
 !  4.2888+05 !   165.0000 !   348.5133 !     0.5219 !
 !  4.5569+05 !   165.0000 !   348.5133 !     0.4912 !
 !  4.7931+05 !   165.0000 !   348.5133 !     0.4642 !
 !------------+------------+------------+------------!
 !  4.8249+05 !   165.0000 !   348.5133 !     0.4605 !
 !  5.0930+05 !   165.0000 !   348.5133 !     0.4298 !
 !  5.3610+05 !   165.0000 !   348.5133 !     0.3991 !
 !  5.6291+05 !   165.0000 !   348.5133 !     0.3684 !
 -----------------------------------------------------
```

```
 ASPEN PLUS   PLAT: WIN-X64   VER: 37.0                   05/12/2023
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                              U-O-S BLOCK SECTION

 BLOCK:  H-103    MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             10
   OUTLET STREAM:            11
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
   COLD SIDE:
   ----------
   INLET STREAM:             25
   OUTLET STREAM:            26
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                 IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           924.361         924.361
0.00000
       MASS(KG/HR   )           38514.6         38514.6
0.00000
       ENTHALPY(CAL/SEC )      -0.196718E+08   -0.196718E+08   -
0.127631E-08

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED HOT OUTLET TEMP
     SPECIFIED VALUE                C                        170.0000
     LMTD CORRECTION FACTOR                                    1.00000
```

```
 ASPEN PLUS   PLAT: WIN-X64   VER: 37.0                   05/12/2023
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                              U-O-S BLOCK SECTION

 BLOCK:  H-103    MODEL: HEATX (CONTINUED)

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP         BAR                         0.0000
     COLD SIDE PRESSURE DROP         BAR                         0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID       CAL/SEC-SQCM-K              0.0203
     HOT 2-PHASE   COLD LIQUID       CAL/SEC-SQCM-K              0.0203
     HOT VAPOR     COLD LIQUID       CAL/SEC-SQCM-K              0.0203
     HOT LIQUID    COLD 2-PHASE      CAL/SEC-SQCM-K              0.0203
     HOT 2-PHASE   COLD 2-PHASE      CAL/SEC-SQCM-K              0.0203
     HOT VAPOR     COLD 2-PHASE      CAL/SEC-SQCM-K              0.0203
     HOT LIQUID    COLD VAPOR        CAL/SEC-SQCM-K              0.0203
     HOT 2-PHASE   COLD VAPOR        CAL/SEC-SQCM-K              0.0203
     HOT VAPOR     COLD VAPOR        CAL/SEC-SQCM-K              0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   10       ----->|                HOT                 |-----> 11
   T=  3.5596D+02  |                                    |       T=
1.7000D+02
   P=  1.2000D+00  |                                    |       P=
1.2000D+00
   V=  0.0000D+00  |                                    |       V=
0.0000D+00
                   |                                    |
   26       <-----|                COLD                |<----- 25
   T=  1.0208D+02  |                                    |       T=
2.5000D+01
   P=  1.0000D+00  |                                    |       P=
1.0000D+00
   V=  1.9222D-01  |                                    |       V=
0.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY            CAL/SEC                825486.5188
     CALCULATED (REQUIRED) AREA      SQM                        23.2490
     ACTUAL EXCHANGER AREA           SQM                        23.2490
     PER CENT OVER-DESIGN                                        0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)     CAL/SEC-SQCM-K              0.0203
     UA (DIRTY)                      CAL/SEC-K                4719.9912

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                      1.0000
     LMTD (CORRECTED)                C                         174.8915
     NUMBER OF SHELLS IN SERIES                                  1
```

```
   PRESSURE DROP:
     HOTSIDE, TOTAL                    BAR                         0.0000
     COLDSIDE, TOTAL                   BAR                         0.0000


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                                        U-O-S BLOCK SECTION

 BLOCK:  H-103    MODEL: HEATX (CONTINUED)

                              ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                            HOT
         -------------------------------------------------------------
         |                              |                            |
 HOT IN  |             LIQ              |            LIQ             |
HOT OUT
 ------> |                              |                            |-
----->
  356.0  |                         258.5|                            |
170.0
         |                              |                            |
 COLDOUT |             BOIL             |            LIQ             |
COLDIN
 <------ |                              |
|<------
  102.1  |                         102.1|                            |
25.0
         |                              |                            |
         -------------------------------------------------------------
                                            COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1     455289.366       11.1442     201.2342     0.0203
2262.4849
     2     370197.152       12.1048     150.6394     0.0203
2457.5062


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                                        U-O-S BLOCK SECTION

 HEATX COLD-TQCU H-103    TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
```

PROPERTY OPTION SET: SRK SOAVE-REDLICH-KWONG EQUATION OF STATE

DUTY CAL/SEC	PRES BAR	TEMP C	VFRAC
0.0	1.0000	102.0834	0.1922
3.9309+04	1.0000	102.0834	0.1756
7.8618+04	1.0000	102.0834	0.1590
1.1793+05	1.0000	102.0834	0.1424
1.5724+05	1.0000	102.0834	0.1258
1.9654+05	1.0000	102.0834	0.1092
2.3585+05	1.0000	102.0834	9.2646-02
2.7516+05	1.0000	102.0834	7.6050-02
3.1447+05	1.0000	102.0834	5.9454-02
3.5378+05	1.0000	102.0834	4.2857-02
3.9309+05	1.0000	102.0834	2.6261-02
4.3240+05	1.0000	102.0834	9.6649-03
4.5529+05	1.0000	102.0834	BUB>0.0
4.7171+05	1.0000	98.6944	0.0
5.1102+05	1.0000	90.5606	0.0
5.5032+05	1.0000	82.4032	0.0
5.8963+05	1.0000	74.2264	0.0
6.2894+05	1.0000	66.0346	0.0
6.6825+05	1.0000	57.8322	0.0
7.0756+05	1.0000	49.6233	0.0
7.4687+05	1.0000	41.4122	0.0
7.8618+05	1.0000	33.2030	0.0
8.2549+05	1.0000	25.0000	0.0

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U-O-S BLOCK SECTION

HEATX HOT-TQCUR H-103 TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 BAR
PROPERTY OPTION SET: SRK SOAVE-REDLICH-KWONG EQUATION OF STATE

DUTY CAL/SEC	PRES BAR	TEMP C	VFRAC
0.0	1.2000	355.9647	0.0
3.9309+04	1.2000	347.9722	0.0
7.8618+04	1.2000	339.9022	0.0
1.1793+05	1.2000	331.7546	0.0
1.5724+05	1.2000	323.5292	0.0
1.9654+05	1.2000	315.2252	0.0
2.3585+05	1.2000	306.8416	0.0
2.7516+05	1.2000	298.3772	0.0
3.1447+05	1.2000	289.8304	0.0
3.5378+05	1.2000	281.1995	0.0
3.9309+05	1.2000	272.4823	0.0
4.3240+05	1.2000	263.6764	0.0
4.5529+05	1.2000	258.5065	0.0
4.7171+05	1.2000	254.7793	0.0
5.1102+05	1.2000	245.7880	0.0
5.5032+05	1.2000	236.6993	0.0
5.8963+05	1.2000	227.5094	0.0
6.2894+05	1.2000	218.2146	0.0
6.6825+05	1.2000	208.8106	0.0
7.0756+05	1.2000	199.2924	0.0
7.4687+05	1.2000	189.6551	0.0
7.8618+05	1.2000	179.8930	0.0
8.2549+05	1.2000	170.0000	0.0

```
 ASPEN PLUS   PLAT: WIN-X64   VER: 37.0                   05/12/2023
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                              U-O-S BLOCK SECTION

 BLOCK:  HX-101   MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             5
   OUTLET STREAM:            6
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
   COLD SIDE:
   ----------
   INLET STREAM:             17
   OUTLET STREAM:            18
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                       ***  MASS AND ENERGY BALANCE  ***
                                    IN                OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           963.185         963.185
0.00000
       MASS(KG/HR   )           44335.0         44335.0
0.00000
       ENTHALPY(CAL/SEC )     -0.198819E+08   -0.198819E+08   -
0.197944E-08

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                           ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE
0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE
0.000100000

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED HOT OUTLET TEMP
     SPECIFIED VALUE                C                         175.0000
     LMTD CORRECTION FACTOR                                    1.00000
```

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 ASPEN PLUS   PLAT: WIN-X64   VER: 37.0                  05/12/2023
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                              U-O-S BLOCK SECTION

 BLOCK:  HX-101   MODEL: HEATX (CONTINUED)

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                        0.0000
     COLD SIDE PRESSURE DROP        BAR                        0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K             0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K             0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K             0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K             0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K             0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K             0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K             0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K             0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K             0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   5         ----->|                HOT                 |-----> 6
   T=  3.8000D+02  |                                    |       T=
1.7500D+02
   P=  1.9500D+00  |                                    |       P=
1.9500D+00
   V=  1.0000D+00  |                                    |       V=
0.0000D+00
                   |                                    |
   18        <-----|                COLD                |<----- 17
   T=  1.0208D+02  |                                    |       T=
2.5000D+01
   P=  1.0000D+00  |                                    |       P=
1.0000D+00
   V=  5.2216D-01  |                                    |       V=
0.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           CAL/SEC              1606958.7005
     CALCULATED (REQUIRED) AREA     SQM                       42.8169
     ACTUAL EXCHANGER AREA          SQM                       42.8169
     PER CENT OVER-DESIGN                                      0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K             0.0203
     UA (DIRTY)                     CAL/SEC-K               8692.6506

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                    1.0000
     LMTD (CORRECTED)               C                        184.8641
     NUMBER OF SHELLS IN SERIES                                 1
```

```
   PRESSURE DROP:
     HOTSIDE, TOTAL                  BAR                         0.0000
     COLDSIDE, TOTAL                 BAR                         0.0000


ASPEN PLUS   PLAT: WIN-X64   VER: 37.0                       05/12/2023
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                              U-O-S BLOCK SECTION

 BLOCK:  HX-101   MODEL: HEATX (CONTINUED)

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                            HOT
         -------------------------------------------------------------
         |              |              |              |              |
 HOT IN  |     VAP      |     COND     |     COND     |     LIQ      |
HOT OUT
 ------> |              |              |              |              |-
----->
  380.0  |         366.0|         244.7|         234.1|              |
175.0
         |              |              |              |              |
 COLDOUT |     BOIL     |     BOIL     |     LIQ      |     LIQ      |
COLDIN
 <------ |              |              |              |
|<------
  102.1  |         102.1|         102.1|          88.9|              |
25.0
         |              |              |              |              |
         -------------------------------------------------------------
                                            COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA        LMTD        AVERAGE U        UA
              CAL/SEC         SQM          C          CAL/SEC-SQCM-K
CAL/SEC-K
     1      73397.582        1.3348     270.8547     0.0203
270.9850
     2    1163363.966       29.0734     197.0987     0.0203
5902.4434
     3      63915.654        2.1874     143.9261     0.0203
444.0868
     4     306281.498       10.2214     147.5959     0.0203
2075.1355
```

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U-O-S BLOCK SECTION

HEATX COLD-TQCU HX-101 TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 BAR
PROPERTY OPTION SET: SRK SOAVE-REDLICH-KWONG EQUATION OF STATE

DUTY CAL/SEC	PRES BAR	TEMP C	VFRAC
0.0	1.0000	102.0834	0.5222
7.3398+04	1.0000	102.0834	0.4912
7.6522+04	1.0000	102.0834	0.4899
1.5304+05	1.0000	102.0834	0.4575
2.2957+05	1.0000	102.0834	0.4252
3.0609+05	1.0000	102.0834	0.3929
3.8261+05	1.0000	102.0834	0.3606
4.5913+05	1.0000	102.0834	0.3283
5.3565+05	1.0000	102.0834	0.2960
6.1217+05	1.0000	102.0834	0.2637
6.8870+05	1.0000	102.0834	0.2314
7.6522+05	1.0000	102.0834	0.1991
8.4174+05	1.0000	102.0834	0.1668
9.1826+05	1.0000	102.0834	0.1345
9.9478+05	1.0000	102.0834	0.1022
1.0713+06	1.0000	102.0834	6.9856-02
1.1478+06	1.0000	102.0834	3.7548-02
1.2243+06	1.0000	102.0834	5.2404-03
1.2368+06	1.0000	102.0834	BUB>0.0
1.3007+06	1.0000	88.8629	0.0
1.3009+06	1.0000	88.8227	0.0
1.3774+06	1.0000	72.9169	0.0
1.4539+06	1.0000	56.9570	0.0
1.5304+06	1.0000	40.9744	0.0
1.6070+06	1.0000	25.0000	0.0

ASPEN PLUS PLAT: WIN-X64 VER: 37.0 05/12/2023
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U-O-S BLOCK SECTION

HEATX HOT-TQCUR HX-101 TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 BAR
PROPERTY OPTION SET: SRK SOAVE-REDLICH-KWONG EQUATION OF STATE

DUTY CAL/SEC	PRES BAR	TEMP C	VFRAC
0.0	1.9500	380.0000	1.0000
7.3398+04	1.9500	365.9969	DEW>1.0000
7.6522+04	1.9500	365.9261	0.9947
1.5304+05	1.9500	363.9814	0.8683
2.2957+05	1.9500	361.5476	0.7473
3.0609+05	1.9500	358.4750	0.6333
3.8261+05	1.9500	354.5838	0.5282
4.5913+05	1.9500	349.6834	0.4342
5.3565+05	1.9500	343.6118	0.3528
6.1217+05	1.9500	336.2867	0.2848
6.8870+05	1.9500	327.7358	0.2297
7.6522+05	1.9500	318.0855	0.1858
8.4174+05	1.9500	307.5162	0.1509
9.1826+05	1.9500	296.2167	0.1223
9.9478+05	1.9500	284.3567	9.7740-02
1.0713+06	1.9500	272.0817	7.5230-02
1.1478+06	1.9500	259.5197	5.2787-02
1.2243+06	1.9500	246.7957	2.8434-02
1.2368+06	1.9500	244.7256	2.4157-02
1.3007+06	1.9500	234.0804	BUB>0.0
1.3009+06	1.9500	234.0444	0.0
1.3774+06	1.9500	219.7080	0.0
1.4539+06	1.9500	205.1005	0.0
1.5304+06	1.9500	190.2045	0.0
1.6070+06	1.9500	175.0000	0.0

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 ASPEN PLUS   PLAT: WIN-X64   VER: 37.0                  05/12/2023
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                                  U-O-S BLOCK SECTION

 BLOCK:  HX-103   MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             13
   OUTLET STREAM:            14
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
   COLD SIDE:
   ----------
   INLET STREAM:             21
   OUTLET STREAM:            22
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )          182.556         182.556
0.00000
       MASS(KG/HR   )          3964.74         3964.74
0.00000
       ENTHALPY(CAL/SEC )     -0.368794E+07   -0.368794E+07
0.250545E-10

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                          ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE
0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE
0.000100000

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED HOT OUTLET TEMP
     SPECIFIED VALUE              C                          30.0000
     LMTD CORRECTION FACTOR                                   1.00000
```

```
 ASPEN PLUS   PLAT: WIN-X64   VER: 37.0                  05/12/2023
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                              U-O-S BLOCK SECTION

 BLOCK:  HX-103   MODEL: HEATX (CONTINUED)

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                        0.0000
     COLD SIDE PRESSURE DROP        BAR                        0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K             0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K             0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K             0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K             0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K             0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K             0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K             0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K             0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K             0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                 --------------------------------------
                 |                                    |
   13      ----->|               HOT                  |-----> 14
   T=  1.1893D+02  |                                  |       T=
3.0000D+01
   P=  1.0000D+00  |                                  |       P=
1.0000D+00
   V=  0.0000D+00  |                                  |       V=
0.0000D+00
                 |                                    |
   22      <-----|               COLD                 |<----- 21
   T=  3.8595D+01  |                                  |       T=
2.5000D+01
   P=  1.0000D+00  |                                  |       P=
1.0000D+00
   V=  0.0000D+00  |                                  |       V=
0.0000D+00
                 --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           CAL/SEC                13026.4052
     CALCULATED (REQUIRED) AREA     SQM                        2.3650
     ACTUAL EXCHANGER AREA          SQM                        2.3650
     PER CENT OVER-DESIGN                                      0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K             0.0203
     UA (DIRTY)                     CAL/SEC-K                480.1316

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                    1.0000
     LMTD (CORRECTED)               C                         27.1309
     NUMBER OF SHELLS IN SERIES                                 1
```

```
   PRESSURE DROP:
     HOTSIDE, TOTAL                  BAR                        0.0000
     COLDSIDE, TOTAL                 BAR                        0.0000


ASPEN PLUS   PLAT: WIN-X64   VER: 37.0                    05/12/2023
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                              U-O-S BLOCK SECTION

 BLOCK:  HX-103   MODEL: HEATX (CONTINUED)

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                     HOT
         -------------------------------------------------------------
         |                                                           |
 HOT IN  |                           LIQ                             |
HOT OUT
 ------> |                                                           |-
----->
  118.9  |                                                           |
30.0
         |                                                           |
 COLDOUT |                           LIQ                             |
COLDIN
 <------ |
|<------
   38.6  |                                                           |
25.0
         |                                                           |
         -------------------------------------------------------------
                                     COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1     13026.405         2.3650      27.1309     0.0203
480.1316


ASPEN PLUS   PLAT: WIN-X64   VER: 37.0                    05/12/2023
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                              U-O-S BLOCK SECTION

 HEATX COLD-TQCU HX-103   TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
```

DUTY CAL/SEC	PRES BAR	TEMP C	VFRAC
0.0	1.0000	38.5954	0.0
620.3050	1.0000	37.9476	0.0
1240.6100	1.0000	37.9476	0.0
1860.9150	1.0000	37.2999	0.0
2481.2200	1.0000	36.6522	0.0
3101.5250	1.0000	36.0045	0.0
3721.8300	1.0000	35.3568	0.0
4342.1351	1.0000	34.7092	0.0
4962.4401	1.0000	34.0616	0.0
5582.7451	1.0000	33.4141	0.0
6203.0501	1.0000	32.7666	0.0
6823.3551	1.0000	32.1191	0.0
7443.6601	1.0000	31.4716	0.0
8063.9651	1.0000	30.8242	0.0
8684.2701	1.0000	30.1769	0.0
9304.5751	1.0000	29.5296	0.0
9924.8801	1.0000	28.8823	0.0
1.0545+04	1.0000	28.2351	0.0
1.1165+04	1.0000	27.5880	0.0
1.1786+04	1.0000	26.9409	0.0
1.2406+04	1.0000	26.2939	0.0
1.3026+04	1.0000	25.6469	0.0

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U-O-S BLOCK SECTION

HEATX HOT-TQCUR HX-103 TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 BAR
PROPERTY OPTION SET: SRK SOAVE-REDLICH-KWONG EQUATION OF STATE

DUTY CAL/SEC	PRES BAR	TEMP C	VFRAC
0.0	1.0000	118.9322	1.0669-07
620.3050	1.0000	114.9474	0.0
1240.6100	1.0000	110.9371	0.0
1860.9150	1.0000	106.9013	0.0
2481.2200	1.0000	102.8402	0.0
3101.5250	1.0000	98.7539	0.0
3721.8300	1.0000	94.6425	0.0
4342.1351	1.0000	90.5060	0.0
4962.4401	1.0000	86.3446	0.0
5582.7451	1.0000	82.1582	0.0
6203.0501	1.0000	77.9471	0.0
6823.3551	1.0000	73.7111	0.0
7443.6601	1.0000	69.4504	0.0
8063.9651	1.0000	65.1650	0.0
8684.2701	1.0000	60.8550	0.0
9304.5751	1.0000	56.5204	0.0
9924.8801	1.0000	52.1613	0.0
1.0545+04	1.0000	47.7777	0.0
1.1165+04	1.0000	43.3697	0.0
1.1786+04	1.0000	38.9374	0.0
1.2406+04	1.0000	34.4808	0.0
1.3026+04	1.0000	30.0000	0.0

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 ASPEN PLUS   PLAT: WIN-X64   VER: 37.0                  05/12/2023
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                              U-O-S BLOCK SECTION

 BLOCK:  HX-104   MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:            15
   OUTLET STREAM:           16
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
   COLD SIDE:
   ----------
   INLET STREAM:            23
   OUTLET STREAM:           24
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           1125.36         1125.36
0.00000
       MASS(KG/HR   )           22965.8         22965.8
0.00000
       ENTHALPY(CAL/SEC )     -0.214517E+08   -0.214517E+08   -
0.794239E-09

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                          ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED HOT OUTLET TEMP
     SPECIFIED VALUE                C                          30.0000
     LMTD CORRECTION FACTOR                                     1.00000
```

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 ASPEN PLUS   PLAT: WIN-X64   VER: 37.0                    05/12/2023
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                                  U-O-S BLOCK SECTION

 BLOCK:  HX-104   MODEL: HEATX (CONTINUED)

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                        0.0000
     COLD SIDE PRESSURE DROP        BAR                        0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K             0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K             0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K             0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K             0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K             0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K             0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K             0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K             0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K             0.0203

                            ***  OVERALL RESULTS  ***

   STREAMS:
                 --------------------------------------
                 |                                    |
   15       ----->|                HOT                 |-----> 16
   T=  2.4484D+02 |                                    |       T=
3.0000D+01
   P=  1.0500D+00 |                                    |       P=
1.0500D+00
   V=  0.0000D+00 |                                    |       V=
0.0000D+00
                 |                                    |
   24       <-----|                COLD                |<----- 23
   T=  4.1605D+01 |                                    |       T=
2.5000D+01
   P=  1.0000D+00 |                                    |       P=
1.0000D+00
   V=  0.0000D+00 |                                    |       V=
0.0000D+00
                 --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           CAL/SEC               106051.8144
     CALCULATED (REQUIRED) AREA     SQM                        9.7631
     ACTUAL EXCHANGER AREA          SQM                        9.7631
     PER CENT OVER-DESIGN                                      0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K             0.0203
     UA (DIRTY)                     CAL/SEC-K               1982.0943

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                    1.0000
     LMTD (CORRECTED)               C                         53.5049
     NUMBER OF SHELLS IN SERIES                                  1
```

```
   PRESSURE DROP:
     HOTSIDE, TOTAL                    BAR                          0.0000
     COLDSIDE, TOTAL                   BAR                          0.0000


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                                          U-O-S BLOCK SECTION

 BLOCK:  HX-104   MODEL: HEATX (CONTINUED)

                                    ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                                HOT
         -------------------------------------------------------------
         |                                                           |
 HOT IN  |                                      LIQ                  |
HOT OUT
 ------> |                                                           |-
----->
  244.8  |                                                           |
30.0
         |                                                           |
 COLDOUT |                                      LIQ                  |
COLDIN
 <------ |
|<------
   41.6  |                                                           |
25.0
         |                                                           |
         -------------------------------------------------------------
                                                COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1     106051.814         9.7631      53.5049     0.0203
1982.0943


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                                          U-O-S BLOCK SECTION

 HEATX COLD-TQCU HX-104   TQCURV INLET
 ------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0        BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
```

DUTY CAL/SEC	PRES BAR	TEMP C	VFRAC
0.0	1.0000	41.6046	0.0
5050.0864	1.0000	40.8134	0.0
1.0100+04	1.0000	40.0223	0.0
1.5150+04	1.0000	39.2312	0.0
2.0200+04	1.0000	38.4401	0.0
2.5250+04	1.0000	37.6491	0.0
3.0301+04	1.0000	36.8581	0.0
3.5351+04	1.0000	36.0671	0.0
4.0401+04	1.0000	35.2762	0.0
4.5451+04	1.0000	34.4854	0.0
5.0501+04	1.0000	33.6946	0.0
5.5551+04	1.0000	32.9038	0.0
6.0601+04	1.0000	32.1131	0.0
6.5651+04	1.0000	31.3224	0.0
7.0701+04	1.0000	30.5319	0.0
7.5751+04	1.0000	29.7414	0.0
8.0801+04	1.0000	28.9509	0.0
8.5851+04	1.0000	28.1606	0.0
9.0902+04	1.0000	27.3703	0.0
9.5952+04	1.0000	26.5801	0.0
1.0100+05	1.0000	25.7900	0.0
1.0605+05	1.0000	25.0000	0.0

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U-O-S BLOCK SECTION

HEATX HOT-TQCUR HX-104 TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 BAR
PROPERTY OPTION SET: SRK SOAVE-REDLICH-KWONG EQUATION OF STATE

DUTY CAL/SEC	PRES BAR	TEMP C	VFRAC
0.0	1.0500	244.8351	0.0

```
 !  5050.0864 !     1.0500 !   236.1100 !     0.0    !
 !  1.0100+04 !     1.0500 !   227.2707 !     0.0    !
 !  1.5150+04 !     1.0500 !   218.3143 !     0.0    !
 !  2.0200+04 !     1.0500 !   209.2372 !     0.0    !
 !------------+------------+------------+------------!
 !  2.5250+04 !     1.0500 !   200.0354 !     0.0    !
 !  3.0301+04 !     1.0500 !   190.7042 !     0.0    !
 !  3.5351+04 !     1.0500 !   181.2383 !     0.0    !
 !  4.0401+04 !     1.0500 !   171.6318 !     0.0    !
 !  4.5451+04 !     1.0500 !   161.8783 !     0.0    !
 !------------+------------+------------+------------!
 !  5.0501+04 !     1.0500 !   151.9705 !     0.0    !
 !  5.5551+04 !     1.0500 !   141.9004 !     0.0    !
 !  6.0601+04 !     1.0500 !   131.6593 !     0.0    !
 !  6.5651+04 !     1.0500 !   121.2377 !     0.0    !
 !  7.0701+04 !     1.0500 !   110.6254 !     0.0    !
 !------------+------------+------------+------------!
 !  7.5751+04 !     1.0500 !    99.8112 !     0.0    !
 !  8.0801+04 !     1.0500 !    88.7834 !     0.0    !
 !  8.5851+04 !     1.0500 !    77.5295 !     0.0    !
 !  9.0902+04 !     1.0500 !    66.0368 !     0.0    !
 !  9.5952+04 !     1.0500 !    54.2924 !     0.0    !
 !------------+------------+------------+------------!
 !  1.0100+05 !     1.0500 !    42.2839 !     0.0    !
 !  1.0605+05 !     1.0500 !    30.0000 !     0.0    !
 -----------------------------------------------------

 BLOCK:  MIX-101  MODEL: MIXER
 -----------------------------
   INLET STREAMS:         1           11
   OUTLET STREAM:         2
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT        RELATIVE
DIFF.


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                              U-O-S BLOCK SECTION

 BLOCK:  MIX-101  MODEL: MIXER (CONTINUED)
    TOTAL BALANCE
       MOLE(KMOL/HR )            114.433         114.433       -
0.176441E-10
       MASS(KG/HR   )            29335.0         29335.0       -
0.176592E-10
       ENTHALPY(CAL/SEC )      -0.579186E+07   -0.579186E+07
0.339033E-08

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              0.00000      KG/HR
    PRODUCT STREAMS CO2E           0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION    0.00000      KG/HR
    UTILITIES CO2E PRODUCTION      0.00000      KG/HR
```

```
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                       ***  INPUT DATA  ***
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                        30
   CONVERGENCE TOLERANCE
0.000100000
   OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

 BLOCK:  P-101    MODEL: PUMP
 ----------------------------
   INLET STREAM:          2
   OUTLET STREAM:         3
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                 IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           114.433         114.433
0.00000
       MASS(KG/HR   )           29335.0         29335.0
0.00000
       ENTHALPY(CAL/SEC )     -0.579186E+07   -0.579153E+07   -
0.569563E-04

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR


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                              U-O-S BLOCK SECTION

 BLOCK:  P-101    MODEL: PUMP (CONTINUED)

                       ***  INPUT DATA  ***
    OUTLET PRESSURE  BAR                                       2.30000
    PUMP EFFICIENCY                                            0.80000
    DRIVER EFFICIENCY                                          0.80000

    FLASH SPECIFICATIONS:
    2 PHASE FLASH
    MAXIMUM NUMBER OF ITERATIONS                               70
    TOLERANCE                                                  0.000100000

                        ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  L/MIN                              602.685
    PRESSURE CHANGE  BAR                                       1.10000
    NPSH AVAILABLE   M-KGF/KG                                15.0836
    FLUID POWER  KW                                            1.10492
    BRAKE POWER  KW                                            1.38115
```

```
    ELECTRICITY  KW                                         1.72644
    PUMP EFFICIENCY USED                                    0.80000
    NET WORK REQUIRED  KW                                   1.72644
    HEAD DEVELOPED M-KGF/KG                                13.8272

 BLOCK:  R-101    MODEL: RYIELD
 ------------------------------
   INLET STREAM:          4
   OUTLET STREAM:         5
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE


***********************************************************************
     *
*
     *     SPECIFIED YIELDS HAVE BEEN NORMALIZED TO MAINTAIN MASS
BALANCE  *
     *
*

***********************************************************************


                      ***  MASS AND ENERGY BALANCE  ***
                             IN          OUT       GENERATION
RELATIVE DIFF.
   TOTAL BALANCE
   MOLE(KMOL/HR )         114.433       130.558       16.1251
0.00000
   MASS(KG/HR   )         29335.0       29335.0
0.00000
   ENTHALPY(CAL/SEC )   -0.402370E+07 -0.392472E+07              -
0.245998E-01


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                              U-O-S BLOCK SECTION

 BLOCK:  R-101    MODEL: RYIELD (CONTINUED)

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE C                                 380.000
   SPECIFIED PRESSURE    BAR                                 1.95000
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE
0.000100000
```

```
    MOLE-YIELD
     SUBSTREAM MIXED   :
     N-HEX-01  0.850        ACETI-01  0.150        1-TET-01  0.140
     SUBSTREAM CISOLID :
     1-OCT-01  0.100E-01

                           ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                    380.00
   OUTLET PRESSURE       BAR                                  1.9500
   HEAT DUTY             CAL/SEC                              98982.
   VAPOR FRACTION                                             1.0000


   ATOM BALANCE:
   -------------

      ATOM  MOLES IN    MOLES OUT   GENERATION  MASS IN     MASS OUT
GENERATION  ERROR/TOL
      UNIT  KMOL/HR     KMOL/HR     KMOL/HR     KG/HR       KG/HR
KG/HR
      C      1831.       1832.       1.716      0.2199E+05  0.2201E+05
20.61       9.372
      H      3661.       3665.       3.431       3690.       3694.
3.458       9.372
      O      228.6       227.1      -1.504       3657.       3633.
-24.06       66.24


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                          U-O-S BLOCK SECTION

 BLOCK:  R-101    MODEL: RYIELD (CONTINUED)

   V-L PHASE EQUILIBRIUM :

      COMP              F(I)           X(I)           Y(I)
K(I)
      N-HEX-01         0.74561        0.95452        0.74561
0.99509
      ACETI-01         0.13158        0.75221E-02    0.13158
22.283
      1-TET-01         0.12281        0.37962E-01    0.12281
4.1210
```

```
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                                  STREAM SECTION

 SUBSTREAM ATTR PSD TYPE: PSD
 ----------------------------

 INTERVAL     LOWER LIMIT          UPPER LIMIT
     1          0.0     METER      2.0000-05  METER
     2       2.0000-05  METER      4.0000-05  METER
     3       4.0000-05  METER      6.0000-05  METER
     4       6.0000-05  METER      8.0000-05  METER
     5       8.0000-05  METER      1.0000-04  METER
     6       1.0000-04  METER      1.2000-04  METER
     7       1.2000-04  METER      1.4000-04  METER
     8       1.4000-04  METER      1.6000-04  METER
     9       1.6000-04  METER      1.8000-04  METER
    10       1.8000-04  METER      2.0000-04  METER


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                                  STREAM SECTION

 1 10 11 12 13
 -------------

 STREAM ID                 1          10         11         12         13
 FROM :                    ----       DC1        H-103      DC1
DC2
 TO   :                    MIX-101    H-103      MIX-101    DC2
HX-103
 CLASS:                    MIXCIPSD   MIXCIPSD   MIXCIPSD   MIXCIPSD
MIXCIPSD

 CONV. MAX. REL. ERR:      0.0        0.0    -3.1655-09     0.0
0.0
 TOTAL STREAM:
   KG/HR                5820.4227  2.3515+04  2.3515+04  3930.5265
964.7413
   CAL/SEC             -1.2517+06 -3.7147+06 -4.5402+06 -7.2678+05 -
4.9651+05
 SUBSTREAM: MIXED
 PHASE:                    LIQUID     LIQUID     LIQUID     LIQUID
LIQUID
 COMPONENTS: KMOL/HR
   N-HEX-01                22.6980    91.5828    91.5828  9.1674-02
2.4863-07
   ACETI-01                 0.0     7.4685-07  7.4685-07    16.1778
16.0161
   1-TET-01                 0.0        0.1510     0.1510    14.9483
1.4948-02
   1-OCT-01                 0.0        0.0        0.0        0.0
0.0
```

```
   WATER                    0.0         0.0         0.0         0.0
0.0
 TOTAL FLOW:
   KMOL/HR                 22.6980     91.7338     91.7338     31.2178
16.0310
   KG/HR                 5820.4227  2.3514+04  2.3514+04  3930.5265
964.7413
   L/MIN                  111.7670    631.0606    492.8582     92.7956
18.2693
 STATE VARIABLES:
   TEMP   C                25.0000    355.9647    170.0000    127.9125
118.9322
   PRES   BAR               1.5000      1.2000      1.2000      1.0000
1.0000
   VFRAC                    0.0         0.0         0.0         0.0
0.0
   LFRAC                    1.0000      1.0000      1.0000      1.0000
1.0000
   SFRAC                    0.0         0.0         0.0         0.0
0.0
 ENTHALPY:
   CAL/MOL               -1.9852+05 -1.4578+05 -1.7817+05 -8.3811+04 -
1.1150+05
   CAL/GM                 -774.1819  -568.7134  -695.0924  -665.6597 -
1852.7485
   CAL/SEC               -1.2517+06 -3.7147+06 -4.5401+06 -7.2678+05 -
4.9651+05
 ENTROPY:
   CAL/MOL-K              -418.9051  -303.4679  -364.1148  -172.7178   -
67.0511
   CAL/GM-K                 -1.6336    -1.1839    -1.4205    -1.3718    -
1.1142
 DENSITY:
   MOL/CC                 3.3847-03  2.4227-03  3.1021-03  5.6069-03
1.4625-02
   GM/CC                    0.8679      0.6210      0.7952      0.7059
0.8801
 AVG MW                   256.4289    256.3300    256.3300    125.9064
60.1797

 SUBSTREAM: CIPSD         STRUCTURE: CONVENTIONAL
 COMPONENTS: KMOL/HR
   N-HEX-01                 0.0         0.0         0.0         0.0
0.0
   ACETI-01                 0.0         0.0         0.0         0.0
0.0
   1-TET-01                 0.0         0.0         0.0         0.0
0.0
   1-OCT-01                 0.0      1.1354-03  1.1354-03     0.0
0.0
   WATER                    0.0         0.0         0.0         0.0
0.0
 TOTAL FLOW:
   KMOL/HR                  0.0      1.1354-03  1.1354-03     0.0
0.0
   KG/HR                    0.0         0.4459      0.4459     0.0
0.0
```

```
   L/MIN                  0.0      9.6492-03  8.8343-03     0.0
0.0


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                                 STREAM SECTION

 1 10 11 12 13 (CONTINUED)

 STREAM ID               1           10          11          12          13

 STATE VARIABLES:
   TEMP   C             MISSING   355.9647   170.0000    MISSING
MISSING
   PRES   BAR            1.5000     1.2000     1.2000    MISSING
MISSING
   VFRAC                MISSING     0.0        0.0       MISSING
MISSING
   LFRAC                MISSING     0.0        0.0       MISSING
MISSING
   SFRAC                MISSING     1.0000     1.0000    MISSING
MISSING
 ENTHALPY:
   CAL/MOL              MISSING -7.7861+04 -1.3100+05    MISSING
MISSING
   CAL/GM               MISSING  -198.2433  -333.5393    MISSING
MISSING
   CAL/SEC              MISSING   -24.5554   -41.3138    MISSING
MISSING
 ENTROPY:
   CAL/MOL-K            MISSING  -564.2272  -663.5484    MISSING
MISSING
   CAL/GM-K             MISSING    -1.4366    -1.6895    MISSING
MISSING
 DENSITY:
   MOL/CC               MISSING  1.9610-03  2.1419-03    MISSING
MISSING
   GM/CC                MISSING     0.7702     0.8413    MISSING
MISSING
 AVG MW                 MISSING   392.7526   392.7526    MISSING
MISSING
 SUBSTREAM ATTRIBUTES:
 PSD
   FRAC1                MISSING     1.0000     1.0000    MISSING
MISSING
   FRAC2                MISSING     0.0        0.0       MISSING
MISSING
   FRAC3                MISSING     0.0        0.0       MISSING
MISSING
   FRAC4                MISSING     0.0        0.0       MISSING
MISSING
   FRAC5                MISSING     0.0        0.0       MISSING
MISSING
   FRAC6                MISSING     0.0        0.0       MISSING
MISSING
```

```
   FRAC7                   MISSING     0.0         0.0        MISSING
MISSING
   FRAC8                   MISSING     0.0         0.0        MISSING
MISSING
   FRAC9                   MISSING     0.0         0.0        MISSING
MISSING
   FRAC10                  MISSING     0.0         0.0        MISSING
MISSING


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                                 STREAM SECTION

 14 15 16 17 18
 --------------

 STREAM ID                 14          15          16          17          18
 FROM :                    HX-103      DC2         HX-104      ----
HX-101
 TO   :                    ----        HX-104      ----        HX-101      --
--
 CLASS:                    MIXCIPSD    MIXCIPSD    MIXCIPSD    MIXCIPSD
MIXCIPSD
 TOTAL STREAM:
   KG/HR                  964.7413  2965.7852  2965.7852  1.5000+04
1.5000+04
   CAL/SEC             -5.0953+05 -1.7552+05 -2.8157+05 -1.5957+07 -
1.4350+07
 SUBSTREAM: MIXED
 PHASE:                    LIQUID      LIQUID      LIQUID      LIQUID
MIXED
 COMPONENTS: KMOL/HR
   N-HEX-01              2.4863-07  9.1674-02  9.1674-02     0.0
0.0
   ACETI-01                16.0161     0.1618      0.1618      0.0
0.0
   1-TET-01              1.4948-02    14.9334     14.9334      0.0
0.0
   1-OCT-01                 0.0         0.0         0.0        0.0
0.0
   WATER                    0.0         0.0         0.0      832.6265
832.6265
 TOTAL FLOW:
   KMOL/HR                 16.0310     15.1868     15.1868   832.6265
832.6265
   KG/HR                  964.7413  2965.7852  2965.7852  1.5000+04
1.5000+04
   L/MIN                   16.0326     83.4917     65.0605   260.1252
2.2434+05
 STATE VARIABLES:
   TEMP   C                30.0000    244.8351     30.0000    25.0000
102.0834
   PRES   BAR               1.0000      1.0500      1.0500     1.0000
1.0000
   VFRAC                    0.0         0.0         0.0        0.0
0.5222
```

```
   LFRAC                  1.0000     1.0000     1.0000     1.0000
0.4778
   SFRAC                  0.0        0.0        0.0        0.0
0.0
 ENTHALPY:
   CAL/MOL            -1.1442+05 -4.1606+04 -6.6745+04 -6.8993+04 -
6.2045+04
   CAL/GM             -1901.3574  -213.0502  -341.7805 -3829.7161 -
3444.0460
   CAL/SEC            -5.0953+05 -1.7552+05 -2.8157+05 -1.5957+07 -
1.4350+07
 ENTROPY:
   CAL/MOL-K            -75.4905  -258.3265  -320.0186   -38.9675   -
21.2126
   CAL/GM-K              -1.2544    -1.3228    -1.6387    -2.1630    -
1.1775
 DENSITY:
   MOL/CC              1.6665-02  3.0316-03  3.8904-03  5.3348-02
6.1858-05
   GM/CC                  1.0029     0.5920     0.7598     0.9611
1.1144-03
 AVG MW                  60.1797   195.2866   195.2866    18.0153
18.0153


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                                  STREAM SECTION

 19 2 20 21 22
 -------------

 STREAM ID               19         2          20         21          22
 FROM :                  ----       MIX-101    H-102      ----
HX-103
 TO   :                  H-102      P-101      ----       HX-103      --
--
 CLASS:                  MIXCIPSD   MIXCIPSD   MIXCIPSD   MIXCIPSD
MIXCIPSD
 TOTAL STREAM:
   KG/HR               1.5000+04  2.9335+04  1.5000+04  3000.0000
3000.0000
   CAL/SEC            -1.3183+07 -5.7919+06 -1.3746+07 -3.1914+06 -
3.1784+06
 SUBSTREAM: MIXED
 PHASE:                  VAPOR      LIQUID     MIXED      LIQUID
LIQUID
 COMPONENTS: KMOL/HR
   N-HEX-01               0.0      114.2808     0.0        0.0
0.0
   ACETI-01               0.0     7.4685-07     0.0        0.0
0.0
   1-TET-01               0.0        0.1510     0.0        0.0
0.0
   1-OCT-01               0.0        0.0        0.0        0.0
0.0
```

```
   WATER                  832.6265     0.0       832.6265   166.5253
166.5253
 TOTAL FLOW:
   KMOL/HR                832.6265   114.4318   832.6265   166.5253
166.5253
   KG/HR                1.5000+04  2.9335+04  1.5000+04  3000.0000
3000.0000
   L/MIN                2511.4489   602.6852  1284.9935    52.0250
52.6756
 STATE VARIABLES:
   TEMP   C               350.0000   143.7273   348.5133    25.0000
38.5954
   PRES   BAR             165.0000     1.2000   165.0000     1.0000
1.0000
   VFRAC                    1.0000     0.0         0.3684     0.0
0.0
   LFRAC                    0.0        1.0000     0.6316     1.0000
1.0000
   SFRAC                    0.0        0.0        0.0        0.0
0.0
 ENTHALPY:
   CAL/MOL             -5.6999+04 -1.8221+05 -5.9433+04 -6.8993+04 -
6.8712+04
   CAL/GM              -3163.9509  -710.7847 -3299.0490 -3829.7161 -
3814.0844
   CAL/SEC             -1.3183+07 -5.7918+06 -1.3746+07 -3.1914+06 -
3.1784+06
 ENTROPY:
   CAL/MOL-K             -17.0775  -373.4364   -21.7263   -38.9675   -
38.1649
   CAL/GM-K               -0.9479    -1.4567    -1.2060    -2.1630    -
2.1185
 DENSITY:
   MOL/CC               5.5255-03  3.1645-03  1.0799-02  5.3348-02
5.2689-02
   GM/CC                9.9544-02     0.8112     0.1946     0.9611
0.9492
 AVG MW                   18.0153   256.3496    18.0153    18.0153
18.0153

 SUBSTREAM: CIPSD        STRUCTURE: CONVENTIONAL
 COMPONENTS: KMOL/HR
   N-HEX-01                0.0        0.0        0.0        0.0
0.0
   ACETI-01                0.0        0.0        0.0        0.0
0.0
   1-TET-01                0.0        0.0        0.0        0.0
0.0
   1-OCT-01                0.0     1.1354-03     0.0        0.0
0.0
   WATER                   0.0        0.0        0.0        0.0
0.0
 TOTAL FLOW:
   KMOL/HR                 0.0     1.1354-03     0.0        0.0
0.0
   KG/HR                   0.0        0.4459     0.0        0.0
0.0
```

```
   L/MIN                  0.0     8.7302-03     0.0         0.0
0.0


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                                 STREAM SECTION

 19 2 20 21 22 (CONTINUED)

 STREAM ID              19         2          20          21          22

 STATE VARIABLES:
   TEMP   C             MISSING   143.7273    MISSING    MISSING
MISSING
   PRES   BAR          165.0000     1.2000   165.0000     1.0000
1.0000
   VFRAC                MISSING     0.0       MISSING    MISSING
MISSING
   LFRAC                MISSING     0.0       MISSING    MISSING
MISSING
   SFRAC                MISSING     1.0000    MISSING    MISSING
MISSING
 ENTHALPY:
   CAL/MOL              MISSING -1.3731+05    MISSING    MISSING
MISSING
   CAL/GM               MISSING  -349.6005    MISSING    MISSING
MISSING
   CAL/SEC              MISSING   -43.3032    MISSING    MISSING
MISSING
 ENTROPY:
   CAL/MOL-K            MISSING  -678.2188    MISSING    MISSING
MISSING
   CAL/GM-K             MISSING    -1.7268    MISSING    MISSING
MISSING
 DENSITY:
   MOL/CC               MISSING  2.1675-03    MISSING    MISSING
MISSING
   GM/CC                MISSING     0.8513    MISSING    MISSING
MISSING
 AVG MW                 MISSING   392.7526    MISSING    MISSING
MISSING
 SUBSTREAM ATTRIBUTES:
 PSD
   FRAC1                MISSING     1.0000    MISSING    MISSING
MISSING
   FRAC2                MISSING     0.0       MISSING    MISSING
MISSING
   FRAC3                MISSING     0.0       MISSING    MISSING
MISSING
   FRAC4                MISSING     0.0       MISSING    MISSING
MISSING
   FRAC5                MISSING     0.0       MISSING    MISSING
MISSING
   FRAC6                MISSING     0.0       MISSING    MISSING
MISSING
```

```
   FRAC7                    MISSING     0.0       MISSING    MISSING
MISSING
   FRAC8                    MISSING     0.0       MISSING    MISSING
MISSING
   FRAC9                    MISSING     0.0       MISSING    MISSING
MISSING
   FRAC10                   MISSING     0.0       MISSING    MISSING
MISSING


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                                 STREAM SECTION

 23 24 25 26 3
 -------------

 STREAM ID                  23         24         25         26         3
 FROM :                     ----       HX-104     ----       H-103      P-
101
 TO   :                     HX-104     ----       H-103      ----       H-
101
 CLASS:                     MIXCIPSD   MIXCIPSD   MIXCIPSD   MIXCIPSD
MIXCIPSD
 TOTAL STREAM:
   KG/HR                  2.0000+04  2.0000+04  1.5000+04  1.5000+04
2.9335+04
   CAL/SEC               -2.1276+07 -2.1170+07 -1.5957+07 -1.5132+07 -
5.7915+06
 SUBSTREAM: MIXED
 PHASE:                     LIQUID     LIQUID     LIQUID     MIXED
LIQUID
 COMPONENTS: KMOL/HR
   N-HEX-01                  0.0        0.0        0.0        0.0
114.2808
   ACETI-01                  0.0        0.0        0.0        0.0
7.4685-07
   1-TET-01                  0.0        0.0        0.0        0.0
0.1510
   1-OCT-01                  0.0        0.0        0.0        0.0
0.0
   WATER                  1110.1687  1110.1687   832.6265   832.6265
0.0
 TOTAL FLOW:
   KMOL/HR                1110.1687  1110.1687   832.6265   832.6265
114.4318
   KG/HR                  2.0000+04  2.0000+04  1.5000+04  1.5000+04
2.9335+04
   L/MIN                   346.8336   352.1701   260.1252  8.2764+04
602.5640
 STATE VARIABLES:
   TEMP   C                 25.0000    41.6046    25.0000   102.0834
143.7393
   PRES   BAR                1.0000     1.0000     1.0000     1.0000
2.3000
   VFRAC                     0.0        0.0        0.0        0.1922
0.0
```

```
   LFRAC                   1.0000     1.0000     1.0000     0.8078
1.0000
   SFRAC                   0.0        0.0        0.0        0.0
0.0
 ENTHALPY:
   CAL/MOL             -6.8993+04 -6.8650+04 -6.8993+04 -6.5424+04 -
1.8220+05
   CAL/GM              -3829.7161 -3810.6268 -3829.7161 -3631.5994  -
710.7442
   CAL/SEC             -2.1276+07 -2.1170+07 -1.5957+07 -1.5132+07 -
5.7915+06
 ENTROPY:
   CAL/MOL-K             -38.9675   -37.9921   -38.9675   -29.8119  -
373.4381
   CAL/GM-K               -2.1630    -2.1089    -2.1630    -1.6548    -
1.4568
 DENSITY:
   MOL/CC               5.3348-02  5.2539-02  5.3348-02  1.6767-04
3.1651-03
   GM/CC                   0.9611     0.9465     0.9611  3.0206-03
0.8114
 AVG MW                   18.0153    18.0153    18.0153    18.0153
256.3496

 SUBSTREAM: CIPSD         STRUCTURE: CONVENTIONAL
 COMPONENTS: KMOL/HR
   N-HEX-01                0.0        0.0        0.0        0.0
0.0
   ACETI-01                0.0        0.0        0.0        0.0
0.0
   1-TET-01                0.0        0.0        0.0        0.0
0.0
   1-OCT-01                0.0        0.0        0.0        0.0
1.1354-03
   WATER                   0.0        0.0        0.0        0.0
0.0
 TOTAL FLOW:
   KMOL/HR                 0.0        0.0        0.0        0.0
1.1354-03
   KG/HR                   0.0        0.0        0.0        0.0
0.4459
   L/MIN                   0.0        0.0        0.0        0.0
8.7302-03


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                                 STREAM SECTION

 23 24 25 26 3 (CONTINUED)

 STREAM ID                23         24         25         26         3

 STATE VARIABLES:
   TEMP   C               MISSING    MISSING    MISSING    MISSING
143.7393
```

```
   PRES   BAR              1.0000     1.0000     1.0000     1.0000
2.3000
   VFRAC                  MISSING    MISSING    MISSING    MISSING
0.0
   LFRAC                  MISSING    MISSING    MISSING    MISSING
0.0
   SFRAC                  MISSING    MISSING    MISSING    MISSING
1.0000
 ENTHALPY:
   CAL/MOL                MISSING    MISSING    MISSING    MISSING -
1.3730+05
   CAL/GM                 MISSING    MISSING    MISSING    MISSING  -
349.5933
   CAL/SEC                MISSING    MISSING    MISSING    MISSING   -
43.3023
 ENTROPY:
   CAL/MOL-K              MISSING    MISSING    MISSING    MISSING  -
678.2121
   CAL/GM-K               MISSING    MISSING    MISSING    MISSING    -
1.7268
 DENSITY:
   MOL/CC                 MISSING    MISSING    MISSING    MISSING
2.1675-03
   GM/CC                  MISSING    MISSING    MISSING    MISSING
0.8513
 AVG MW                   MISSING    MISSING    MISSING    MISSING
392.7526
 SUBSTREAM ATTRIBUTES:
 PSD
   FRAC1                  MISSING    MISSING    MISSING    MISSING
1.0000
   FRAC2                  MISSING    MISSING    MISSING    MISSING
0.0
   FRAC3                  MISSING    MISSING    MISSING    MISSING
0.0
   FRAC4                  MISSING    MISSING    MISSING    MISSING
0.0
   FRAC5                  MISSING    MISSING    MISSING    MISSING
0.0
   FRAC6                  MISSING    MISSING    MISSING    MISSING
0.0
   FRAC7                  MISSING    MISSING    MISSING    MISSING
0.0
   FRAC8                  MISSING    MISSING    MISSING    MISSING
0.0
   FRAC9                  MISSING    MISSING    MISSING    MISSING
0.0
   FRAC10                 MISSING    MISSING    MISSING    MISSING
0.0
```

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STREAM SECTION

4 5 6 7 8

STREAM ID	4	5	6	7	8
FROM :	H-101	R-101	HX-101	F-101	F-101
TO :	R-101	HX-101	F-101	H-102	----
CLASS:	MIXCIPSD	MIXCIPSD	MIXCIPSD	MIXCIPSD	MIXCIPSD
TOTAL STREAM:					
KG/HR	2.9335+04	2.9335+04	2.9335+04	2.7445+04	1889.8962
CAL/SEC	-4.0237+06	-3.9247+06	-5.5317+06	-5.2163+06	-3.1542+05
SUBSTREAM: MIXED					
PHASE:	VAPOR	VAPOR	LIQUID	LIQUID	LIQUID
COMPONENTS: KMOL/HR					
N-HEX-01	114.2808	96.4994	96.4994	91.6744	4.8250
ACETI-01	7.4685-07	17.0293	17.0293	16.1778	0.8515
1-TET-01	0.1510	15.8940	15.8940	15.0993	0.7947
1-OCT-01	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
KMOL/HR	114.4318	129.4228	129.4228	122.9516	6.4711
KG/HR	2.9335+04	2.8889+04	2.8889+04	2.7445+04	1444.4551
L/MIN	6.3600+04	5.5415+04	624.5968	593.5583	31.2399
STATE VARIABLES:					
TEMP C	380.0000	380.0000	175.0000	175.0420	175.0420
PRES BAR	1.5000	1.9500	1.9500	1.0000	1.0000
VFRAC	1.0000	1.0000	0.0	0.0	0.0
LFRAC	0.0	0.0	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
CAL/MOL	-1.2658+05	-1.0856+05	-1.5273+05	-1.5273+05	-1.5273+05
CAL/GM	-493.7948	-486.3282	-684.2276	-684.2280	-684.2280

```
   CAL/SEC             -4.0237+06 -3.9027+06 -5.4908+06 -5.2162+06 -
2.7454+05
 ENTROPY:
   CAL/MOL-K            -273.4550  -232.9050  -311.0076  -310.9885  -
310.9885
   CAL/GM-K               -1.0667    -1.0434    -1.3933    -1.3932    -
1.3932
 DENSITY:
   MOL/CC               2.9987-05  3.8925-05  3.4535-03  3.4524-03
3.4524-03
   GM/CC                7.6873-03  8.6886-03     0.7709     0.7706
0.7706
 AVG MW                  256.3496   223.2150   223.2150   223.2150
223.2150

 SUBSTREAM: CIPSD         STRUCTURE: CONVENTIONAL
 COMPONENTS: KMOL/HR
   N-HEX-01                 0.0        0.0        0.0        0.0
0.0
   ACETI-01                 0.0        0.0        0.0        0.0
0.0
   1-TET-01                 0.0        0.0        0.0        0.0
0.0
   1-OCT-01             1.1354-03     1.1353     1.1353  1.1354-03
1.1342
   WATER                    0.0        0.0        0.0        0.0
0.0
 TOTAL FLOW:
   KMOL/HR              1.1354-03     1.1353     1.1353  1.1354-03
1.1342
   KG/HR                   0.4459   445.8871   445.8871     0.4459
445.4412
   L/MIN                9.7656-03     9.7651     8.8539  8.8546-03
8.8452


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                                 STREAM SECTION

 4 5 6 7 8 (CONTINUED)

 STREAM ID               4          5          6          7          8

 STATE VARIABLES:
   TEMP   C              380.0000   380.0000   175.0000   175.0420
175.0420
   PRES   BAR               1.5000     1.9500     1.9500     1.0000
1.0000
   VFRAC                    0.0        0.0        0.0        0.0
0.0
   LFRAC                    0.0        0.0        0.0        0.0
0.0
   SFRAC                    1.0000     1.0000     1.0000     1.0000
1.0000
 ENTHALPY:
```

```
   CAL/MOL           -6.9940+04 -6.9940+04 -1.2976+05 -1.2975+05 -
1.2975+05
   CAL/GM             -178.0768  -178.0768  -330.3948  -330.3683  -
330.3683
   CAL/SEC             -22.0575 -2.2056+04 -4.0922+04   -40.9210 -
4.0878+04
 ENTROPY:
   CAL/MOL-K          -551.8731  -551.8731  -660.7771  -660.7539  -
660.7539
   CAL/GM-K             -1.4051    -1.4051    -1.6824    -1.6824    -
1.6824
 DENSITY:
   MOL/CC             1.9377-03  1.9377-03  2.1371-03  2.1370-03
2.1370-03
   GM/CC                 0.7610     0.7610     0.8393     0.8393
0.8393
 AVG MW                392.7526   392.7526   392.7526   392.7526
392.7526
 SUBSTREAM ATTRIBUTES:
 PSD
   FRAC1                 1.0000     1.0000     1.0000     1.0000
1.0000
   FRAC2                 0.0        0.0        0.0        0.0
0.0
   FRAC3                 0.0        0.0        0.0        0.0
0.0
   FRAC4                 0.0        0.0        0.0        0.0
0.0
   FRAC5                 0.0        0.0        0.0        0.0
0.0
   FRAC6                 0.0        0.0        0.0        0.0
0.0
   FRAC7                 0.0        0.0        0.0        0.0
0.0
   FRAC8                 0.0        0.0        0.0        0.0
0.0
   FRAC9                 0.0        0.0        0.0        0.0
0.0
   FRAC10                0.0        0.0        0.0        0.0
0.0


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                                 STREAM SECTION

 9
 -

 STREAM ID              9
 FROM :                 H-102
 TO   :                 DC1
 CLASS:                 MIXCIPSD
 TOTAL STREAM:
   KG/HR              2.7445+04
   CAL/SEC           -4.6534+06
 SUBSTREAM: MIXED
```

```
PHASE:                    MIXED
COMPONENTS: KMOL/HR
  N-HEX-01                 91.6744
  ACETI-01                 16.1778
  1-TET-01                 15.0993
  1-OCT-01                  0.0
  WATER                     0.0
TOTAL FLOW:
  KMOL/HR                 122.9516
  KG/HR                  2.7445+04
  L/MIN                  1.5819+04
STATE VARIABLES:
  TEMP   C                278.0000
  PRES   BAR                1.0000
  VFRAC                     0.1656
  LFRAC                     0.8344
  SFRAC                     0.0
ENTHALPY:
  CAL/MOL               -1.3625+05
  CAL/GM                 -610.3907
  CAL/SEC               -4.6533+06
ENTROPY:
  CAL/MOL-K              -278.0240
  CAL/GM-K                 -1.2455
DENSITY:
  MOL/CC                 1.2954-04
  GM/CC                  2.8916-02
AVG MW                    223.2150

SUBSTREAM: CIPSD          STRUCTURE: CONVENTIONAL
COMPONENTS: KMOL/HR
  N-HEX-01                  0.0
  ACETI-01                  0.0
  1-TET-01                  0.0
  1-OCT-01               1.1354-03
  WATER                     0.0
TOTAL FLOW:
  KMOL/HR                1.1354-03
  KG/HR                     0.4459
  L/MIN                  9.2900-03
```

```
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                                 STREAM SECTION

 9 (CONTINUED)

 STREAM ID              9

 STATE VARIABLES:
   TEMP   C           278.0000
   PRES   BAR           1.0000
   VFRAC                0.0
   LFRAC                0.0
   SFRAC                1.0000
 ENTHALPY:
   CAL/MOL           -1.0192+05
   CAL/GM            -259.4919
   CAL/SEC            -32.1419
 ENTROPY:
   CAL/MOL-K         -605.0025
   CAL/GM-K            -1.5404
 DENSITY:
   MOL/CC            2.0369-03
   GM/CC                0.8000
 AVG MW               392.7526
 SUBSTREAM ATTRIBUTES:
 PSD
   FRAC1                1.0000
   FRAC2                0.0
   FRAC3                0.0
   FRAC4                0.0
   FRAC5                0.0
   FRAC6                0.0
   FRAC7                0.0
   FRAC8                0.0
   FRAC9                0.0
   FRAC10               0.0
```

```
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                              PROBLEM STATUS SECTION

 BLOCK STATUS
 ------------


***********************************************************************
*****
 *
*
 * Calculations were completed with warnings
*
 *
*
 * The following Unit Operation blocks were
*
 * completed with warnings:
*
 *   R-101
*
 *
*
 * All streams were flashed normally
*
 *
*
 * All Convergence blocks were completed normally
*
 *
*

***********************************************************************
*****
```

APPENDICES

Table 19.2. Permissible Average Radiant Rates

Type of furnace	Allowable rate, Btu/(hr)(ft² of circumferential tube area)
Crude	10,000–16,000
Vacuum	5,000–10,000
Naphtha reforming	1,000–18,000
Gas oil cracking:	
Heating	10,000–15,000
Soaking	10,000
Visbreaking	10,000–12,000

Figure 13-1 Permissible average radiant rates

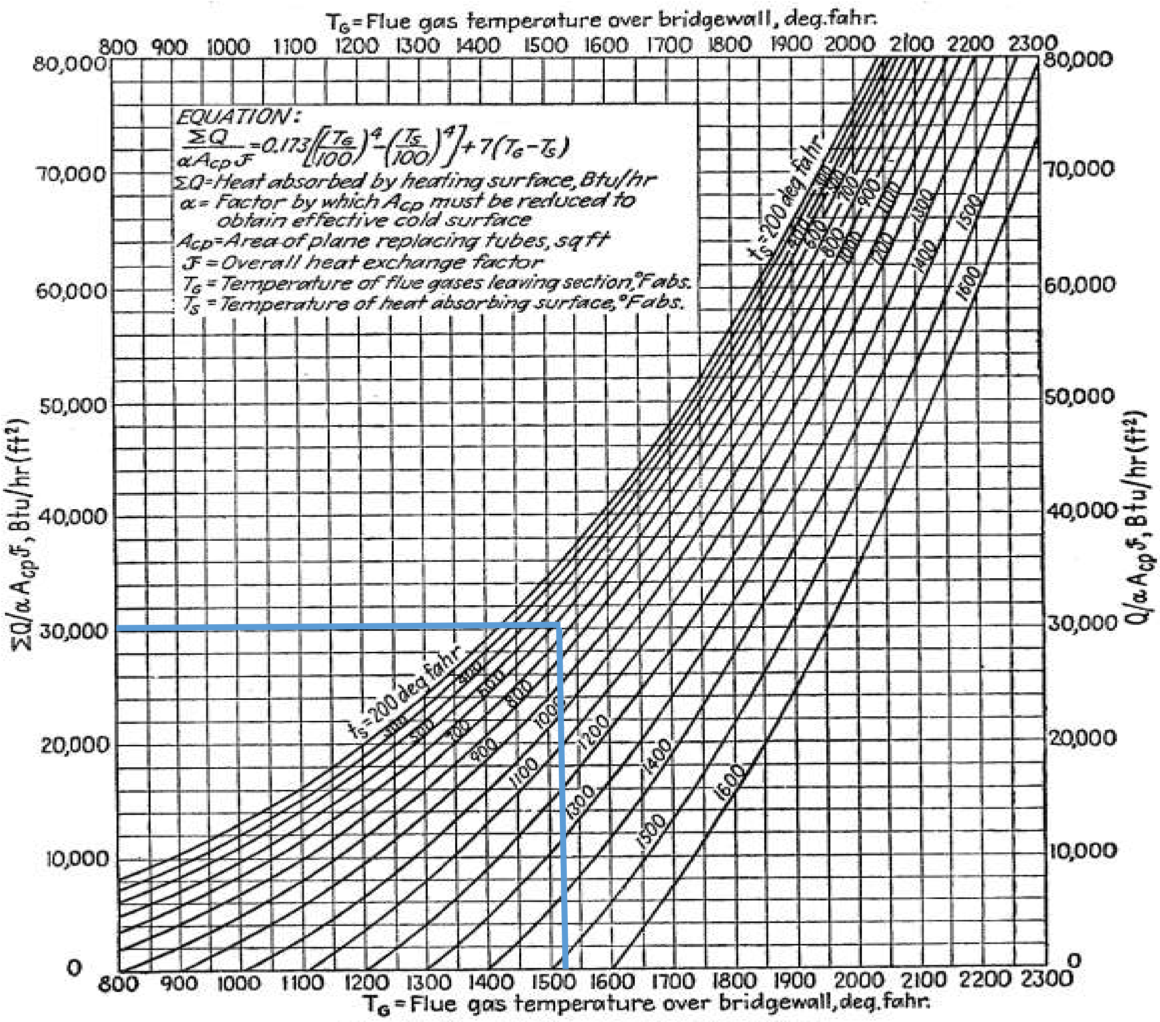


Fig. 19.14. Radiant-section heat flux.

Figure 13-2 Radiant section heat flux

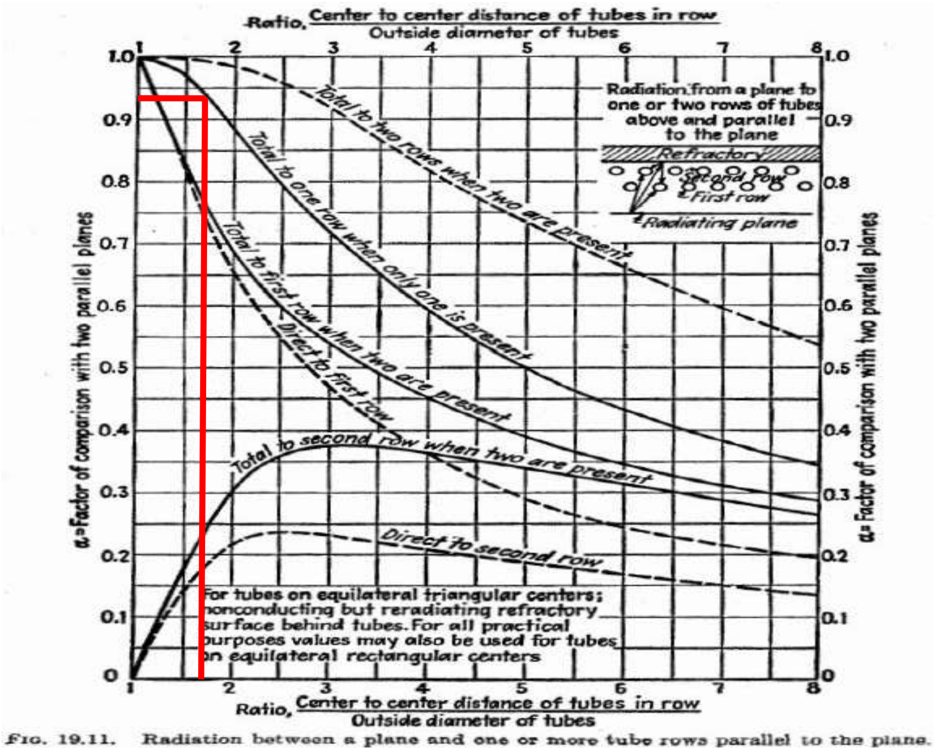


FIG. 19.11. Radiation between a plane and one or more tube rows parallel to the plane.

Figure 13-3 Radiation between a plane and one or more tube rows parallel to the plane

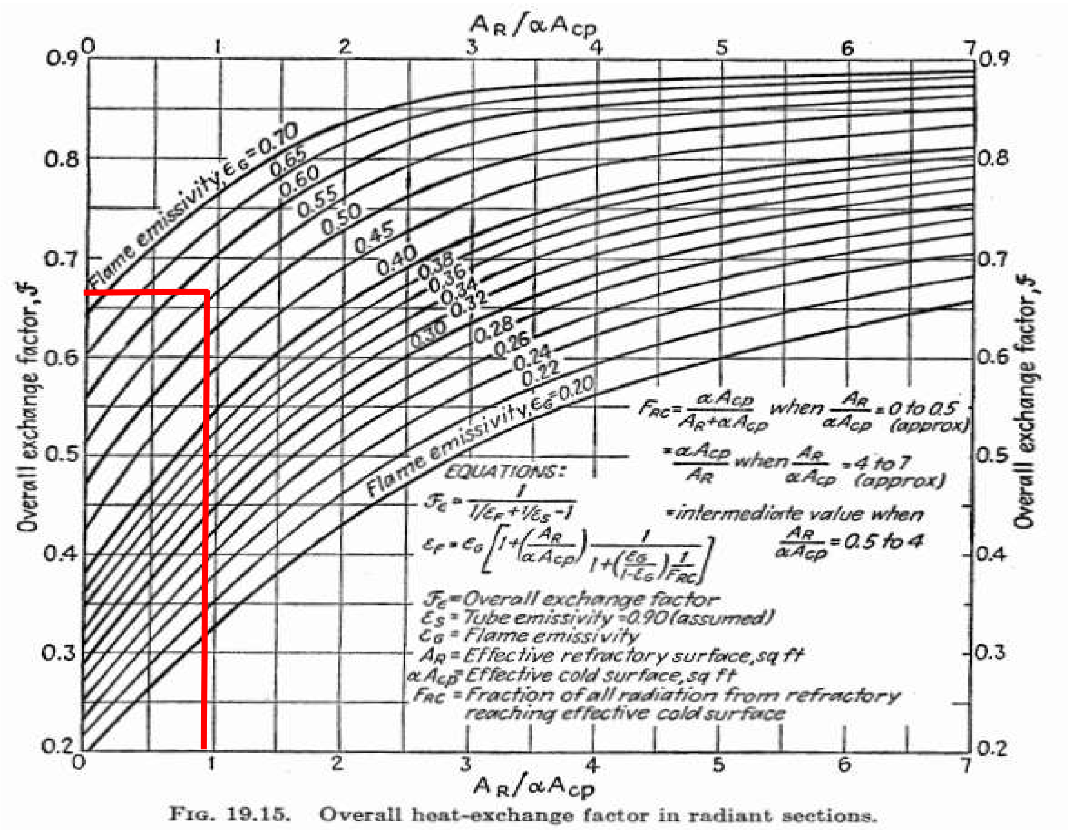


FIG. 19.15. Overall heat-exchange factor in radiant sections.

Figure 13-4 Overall heat exchange factor in radiant sections

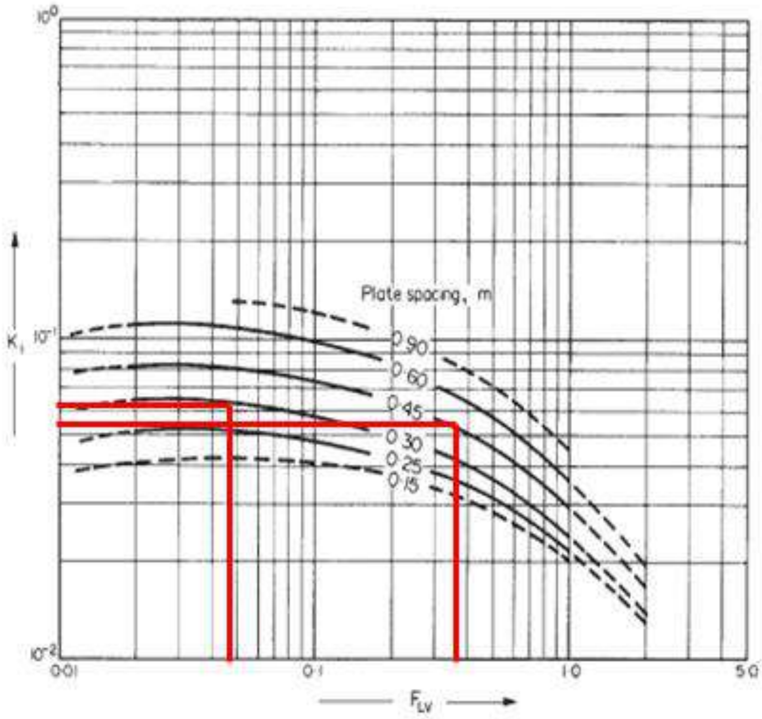


Figure 13-5 plate spacing

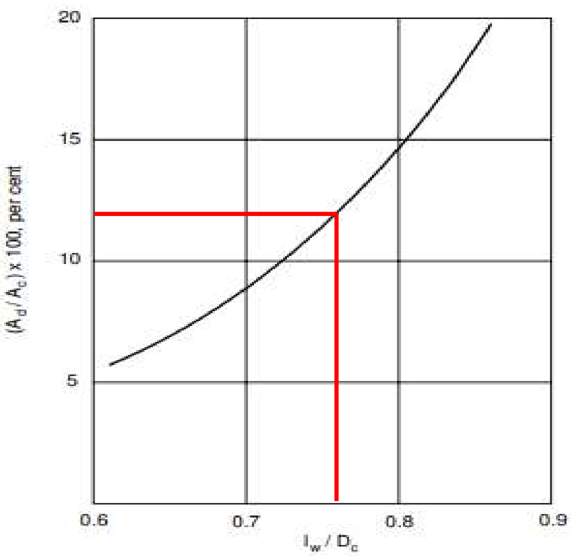


Figure 11.31. Relation between downcomer area and weir length

Figure 13-6 Relation between downcommer area and weir length

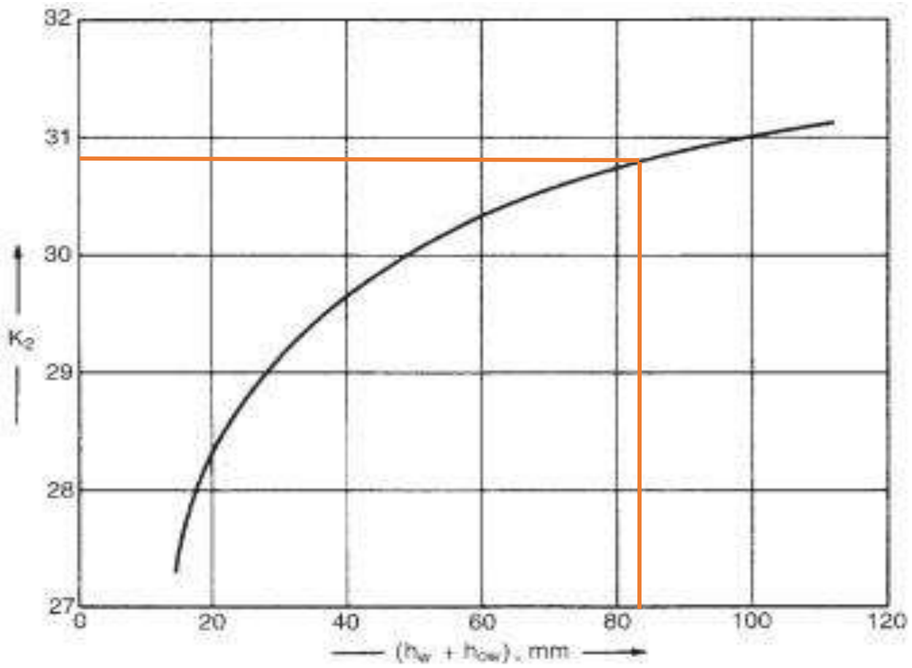


Figure 13-7 Weeping point correlation

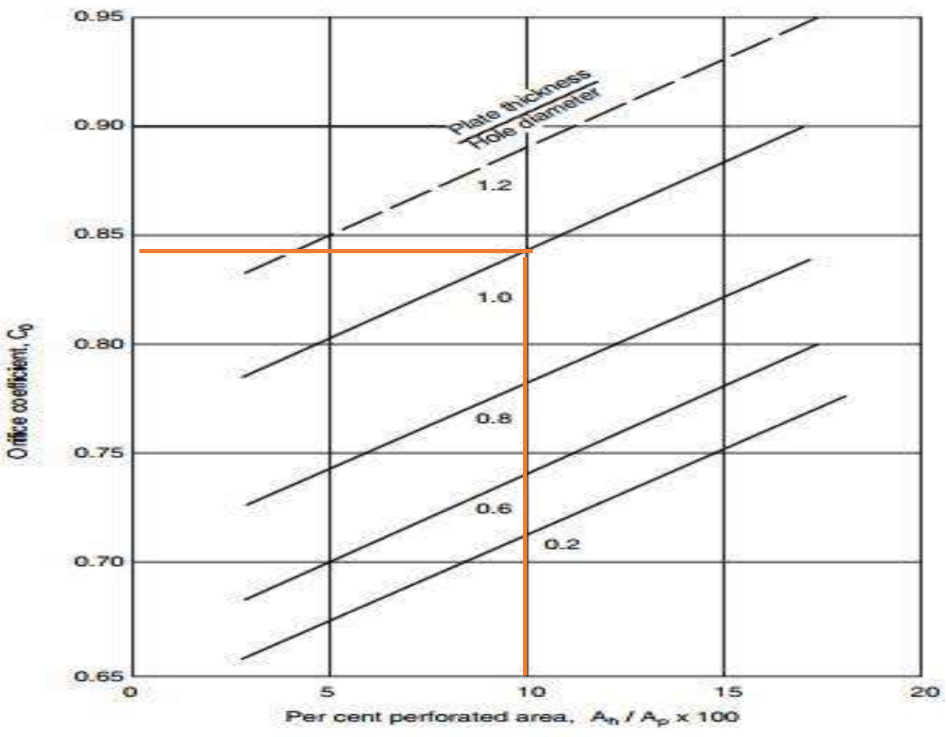


Figure 13-8 Orifice coeffient graph

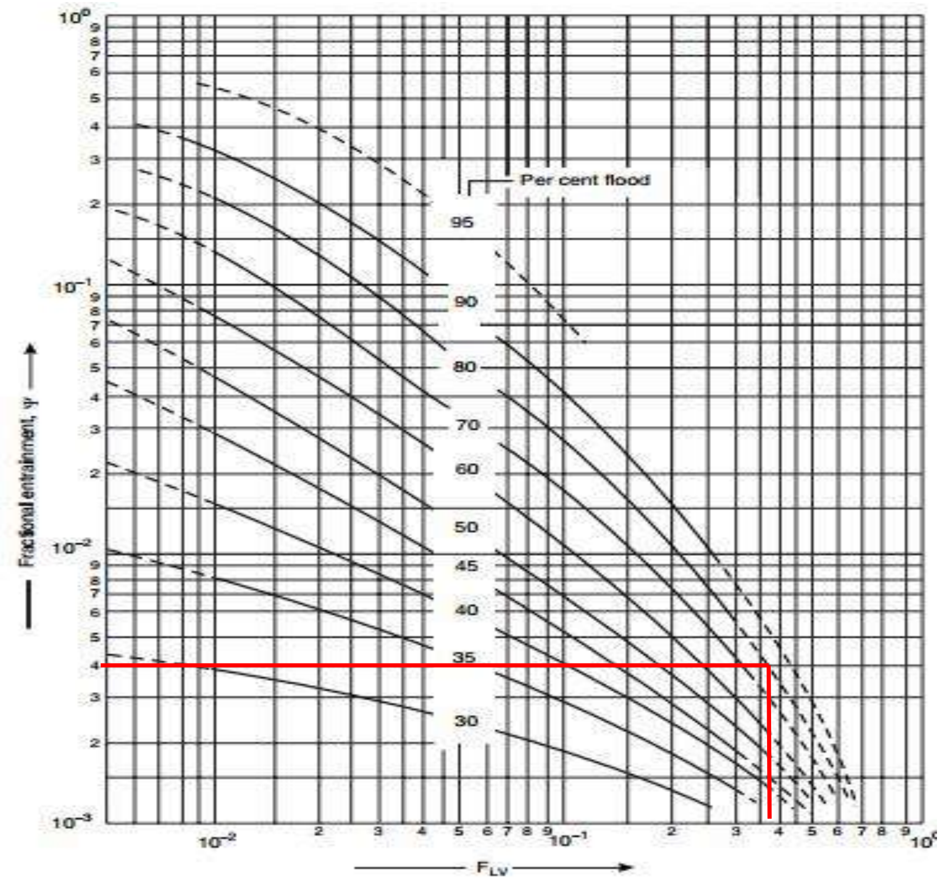


Figure 13-9 Fractional entrainment graph

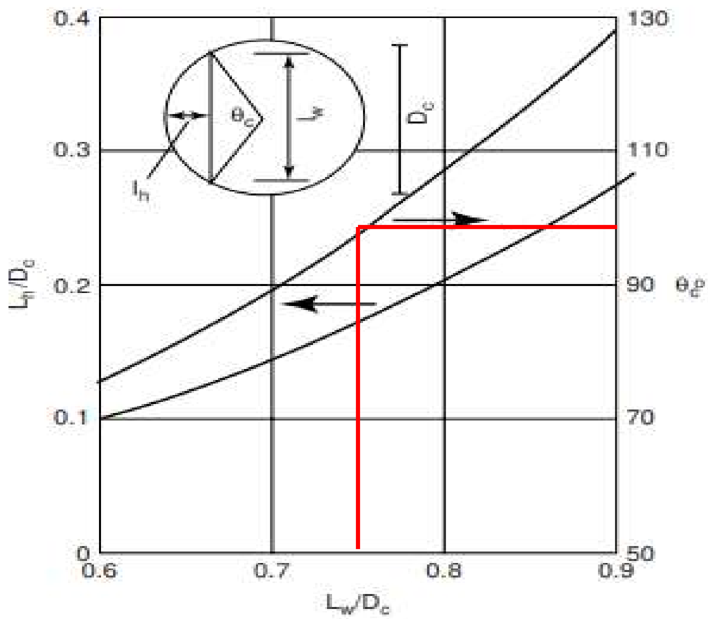
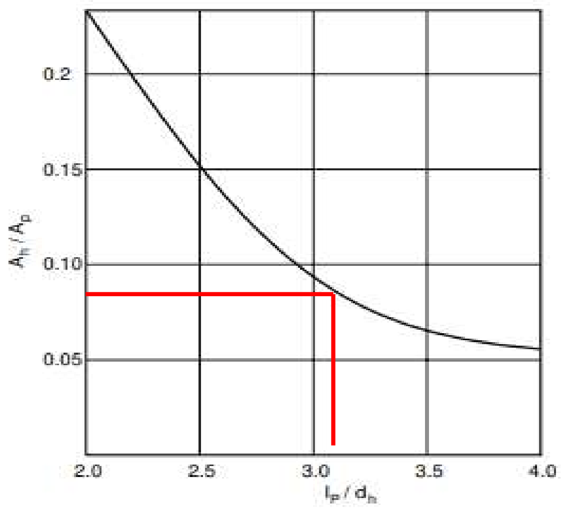


Figure 13-10 Perforated area



CEPCI 2001 to Present

Year	CEPCI
2022 Feb Prim	806.3
2022 Jan	797.6
2021 Dec	776.3
2021 Nov	773.1
2021 Oct	761.4
2021 Sep	754.0
2021 Aug	735.2
2021 Jul	720.2
2021 Jun	701.4
2021 May	686.7
2020	596.2
2019	607.5
2018	603.1
2017	567.5
2016	541.7
2015	556.8
2014	576.1
2013	567.3
2012	584.6
2011	585.7
2010	550.8
2009	521.9
2008	575.4
2007	525.4
2006	499.6
2005	468.2
2004	444.2
2003	402.0
2002	395.6
2001	394.3
1957-1959	**100.0**

Chemical Engineering plant cost index, 1957D 1959 = 100
324
343
355
357.6
361.3
358.2
359.2
368.1
381.1
381.7
386.5
389.5
390.6
394.1
394.3
390.4†,§

Figure 13-11 Costs of horizontal vessels and distillation colums plates

Table 10-8 Corrosion resistance of construction materials[†]

Code designation for corrosion resistance

A = Acceptable, can be used successfully
C = Caution, resistance varies widely depending on conditions; used when some corrosion is permissible
X = Unsuitable
Blank = Information lacking

Code designation for gasket materials[‡]

a = Asbestos, white (compressed or woven)
b = Asbestos, blue (compressed or woven)
c = Asbestos (compressed and rubber-bonded)
d = Asbestos (woven and rubber-frictioned)
e = GR-S or natural rubber
f = Tefln

	Metals								Nonmetals					
			Stainless steel											
Chemical	Iron and steel	Cast iron (Ni-resist)	18-8	18-8 Mo	Nickel	Monel	Red brass	Aluminum	Industrial glass	Carbon (Karbate)	Phenolic resins (Haveg)	Acrylic resins (Lucite)	Vinylidene chloride (Saran)	Acceptable nonmetallic gasket materials
Acetic acid, crude	C	C	C	C	C	C	C	A	A	A	A	A	C	b, c, d, f
Acetic acid, pure	X	X	C	A	C	A	X	A	A	A	A	X	X	b, c, d, f
Acetic anhydride	C	C	A	A	A	A	X	A	A	A	A	X	C	b, c, d, f
Acetone	A	A	A	A	A	A	A	A	A	A	C	X	C	a, e, f
Aluminum chloride	X	C	X	X	C	C	A	A	A	A	A	...	A	a, c, e, f
Aluminum sulfate	X	C	C	A	C	C	X	A	A	A	A	A	A	a, c, d, e, f
Alums	X	C	C	A	C	A	X	A	A	A	A	A	A	a, c, d, e, f
Ammonia (gas)	A	A	C	A	A	A	X	C	A	...	A	...	C	a, f
Ammonium chloride	C	A	C	C	A	A	C	C	A	A	A	A	A	b, c, d, e, f
Ammonium hydroxide	A	A	A	A	C	C	X	C	A	...	A	A	C	a, c, d, f
Ammonium phosphate, monobasic	X	C	A	A	...	C	X	X	A	A	A	...	...	b, c, d, e, f
Ammonium phosphate, dibasic	C	A	A	A	...	A	C	C	A	A	A	...	...	a, c, d, c, f
Ammonium phosphate, tribasic	A	A	A	A	A	A	X	C	A	A	A	...	...	a, c, d, e, f
Ammonium sulfate	C	A	C	C	A	A	C	A	A	A	A	A	A	b, c, d, e, f
Aniline	A	A	A	A	...	A	X	...	A	A	C	...	C	a, f
Benzene, benzol	A	A	A	A	A	A	A	A	A	A	A	...	C	a, f
Boric acid	X	C	A	A	A	A	C	A	A	A	A	...	A	a, c, d, e, f
Bromine	X	C	C	C	C	C	C	...	A	C	X	...	X	b, f

Figure 13-12 Corrosion resistance of construction materials

Calcium chloride	C	A	C	C	A	A	C	C	A	A	A	A	A	b, c, d, e, f
Calcium hydroxide	A	A	A	A	...	A	C	...	...	...	...	...	...	a, c, d, e, f
Calcium hypochlorite	X	C	C	A	C	C	C	C	A	A	C	...	C	b, c, d, f
Carbon tetrachloride	C	C	C	A	A	A	C	C	A	A	A	A	C	a, f
Carbonic acid	C	C	A	A	A	A	C	A	A	A	A	A	A	a, e, f
Chloracetic acid	X	...	X	X	C	C	X	C	A	...	A	...	...	b, f
Chlorine, dry	A	A	C	A	A	A	A	A	A	A	A	...	X	b, e, f
Chlorine, wet	X	X	X	X	X	X	X	X	A	C	A	...	X	b, e, f
Chromic acid	C	C	C	C	C	C	X	C	A	X	X	X	A	b, f
Citric acid	X	C	C	A	C	A	C	A	A	A	A	A	A	b, c, d, e, f
Copper sulfate	X	C	A	A	C	C	X	X	A	A	A	X	...	b, c, d, e, f
Ethanol	A	A	A	A	A	A	A	A	A	A	A	...	A	a, c, e, f
Ethylene glycol	A	A	A	A	A	A	A	A	A	A	A	A	C	a, c, e, f,
Fatty acids	C	C	A	A	A	A	C	A	A	A	A	...	A	a, e, f
Ferric chloride	X	X	X	C	X	X	X	X	A	C	A	...	A	b, e, f
Ferric sulfate	X	X	C	A	C	C	X	C	A	C	A	...	A	b, c, e, f
Ferrous sulfate	C	A	A	A	A	A	C	C	A	A	A	...	C	
Formaldehyde	C	C	A	A	A	A	C	A	A	A	A	...	A	a, c, e, f
Formic acid	X	...	C	C	C	C	X	X	A	A	A	...	A	b, c, e, f
Glycerol	A	A	...	A	A	A	A	A	A	A	C	A	C	a, c, e, f
Hydrocarbons (aliphatic)	A	A	A	A	A	A	A	A	A	A	A	A	C	a, c, d, f
Hydrochloric acid	X	X	X	X	C	C	X	X	A	A	A	A	C	b, c, d, f
Hydrofloric acid	C	X	X	X	C	C	X	X	X	A	C	...	C	b, f
Hydrogen peroxide	C	...	C	C	C	C	C	A	A	A	A	A	C	a, e, f
Lactic acid	X	C	C	A	C	C	A	C	A	A	A	...	...	a, b, c, d, e, f
Magnesium chloride	C	C	C	C	A	A	C	C	A	A	A	...	A	b, c, e, f
Magnesium sulfate	A	A	A	A	A	A	A	A	A	...	A	...	A	b, c, e, f
Methanol	A	A	A	A	A	A	A	A	A	A	A	...	A	a, c, e, f
Nitric acid	X	C	C	C	X	X	X	C	A	C	C	...	C	b, f
Oleic acid	C	C	A	A	A	A	C	A	A	A	A	...	A	a, e, f
Oxalic acid	C	C	C	C	C	A	C	C	A	A	A	...	...	b, c, d, e, f

Material	Grade	Min Tensile Strength (ksi)	Min Yield Strength (ksi)	Maximum Temperature (°F)	Maximum Allowable Stress at Temperature °F (ksi = 1000 psi)				
					100	300	500	700	900
Carbon steel	A285 Gr A	45	24	900	12.9	12.9	12.9	11.5	5.9
Killed carbon steel	A515 Gr 60	60	32	1000	17.1	17.1	17.1	14.3	5.9
Low alloy steel 1¼ Cr, ½ Mo, Si	A387 Gr 22	60	30	1200	17.1	16.6	16.6	16.6	13.6
Stainless steel 13 Cr	410	65	30	1200	18.6	17.8	17.2	16.2	12.3
Stainless steel 18 Cr, 8 Ni	304	75	30	1500	20.0	15.0	12.9	11.7	10.8
Stainless steel 18 Cr, 10 Ni, Cb	347	75	30	1500	20.0	17.1	15.0	13.8	13.4
Stainless steel 18 Cr, 10 Ni, Ti	321	75	30	1500	20.0	16.5	14.3	13.0	12.3
Stainless steel 16 Cr, 12 Ni, 2 Mo	316	75	30	1500	20.0	15.6	13.3	12.1	11.5

Note:

1. The stress values for type 304 stainless steel are not the same as those given for stainless steel 304L in Table 7.8 of this book.
2. 1 ksi = 1000 psi = 6.8948 N/mm^2

Figure 13-13 Mechanical properties of materials

Table 6.1. Typical factors for estimation of project fixed capital cost			
Item	Process type		
	Fluids	Fluids–solids	Solids
1. Major equipment, total purchase cost	PCE	PCE	PCE
f_1 Equipment erection	0.4	0.45	0.50
f_2 Piping	0.70	0.45	0.20
f_3 Instrumentation	0.20	0.15	0.10
f_4 Electrical	0.10	0.10	0.10
f_5 Buildings, process	0.15	0.10	0.05
* f_6 Utilities	0.50	0.45	0.25
* f_7 Storages	0.15	0.20	0.25
* f_8 Site development	0.05	0.05	0.05
* f_9 Ancillary buildings	0.15	0.20	0.30
2. Total physical plant cost (PPC)			
PPC = PCE $(1 + f_1 + \cdots + f_9)$			
= PCE ×	3.40	3.15	2.80
f_{10} Design and Engineering	0.30	0.25	0.20
f_{11} Contractor's fee	0.05	0.05	0.05
f_{12} Contingency	0.10	0.10	0.10
Fixed capital = PPC $(1 + f_{10} + f_{11} + f_{12})$			
= PPC ×	1.45	1.40	1.35

*Omitted for minor extensions or additions to existing sites.

Figure 13-14 Typical factors for estimation of project fixed capital cost from Coulson Richardson volume 6

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Table 6.6. Summary of production costs

Variable costs	*Typical values*
1. Raw materials	from flow-sheets
2. Miscellaneous materials	10 per cent of item (5)
3. Utilities	from flow-sheet
4. Shipping and packaging	usually negligible
Sub-total A	....
Fixed costs	
5. Maintenance	5–10 per cent of fixed capital
6. Operating labour	from manning estimates
7. Laboratory costs	20–23 per cent of 6
8. Supervision	20 per cent of item (6)
9. Plant overheads	50 per cent of item (6)
10. Capital charges	10 per cent of the fixed capital
11. Insurance	1 per cent of the fixed capital
12. Local taxes	2 per cent of the fixed capital
13. Royalties	1 per cent of the fixed capital
Sub-total B	....
Direct production costs A + B	....
13. Sales expense	20–30 per cent of the direct production cost
14. General overheads	
15. Research and development	
Sub-total C	....
Annual production cost = A + B + C =	....

$$\text{Production cost £/kg} = \frac{\text{Annual production cost}}{\text{Annual production rate}}$$

Figure 13-15 Summery of production costs from Coulson Richardson volume 6

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

Equipment	Size unit, S	Size range	Constant C,£	Constant C,$	Index n	Comment
Agitators						
Propeller	driver	5–75	1200	1900	0.5	
Turbine	power, kW		1800	3000	0.5	
Boilers						
Packaged						oil or gas fired
up to 10 bar	kg/h steam	$(5–50) \times 10^3$	70	120	0.8	
10 to 60 bar			60	100	0.8	
Centrifuges						
Horizontal basket	dia., m	0.5–1.0	35,000	58,000	1.3	carbon steel
Vertical basket			35,000	58,000	1.0	×1.7 for ss
Compressors						
Centrifugal	driver power, kW	20–500	1160	1920	0.8	electric, max. press. 50 bar
Reciprocating			1600	2700	0.8	
Conveyors						
Belt	length, m	2–40				
0.5 m wide			1200	1900	0.75	
1.0 m wide			1800	2900	0.75	
Crushers						
Cone	t/h	20–200	2300	3800	0.85	
Pulverisers	kg/h		2000	3400	0.35	
Dryers						
Rotary	area, m^2	5–30	21,000	35,000	0.45	direct
Pan		2–10	4700	7700	0.35	gas fired
Evaporators						
Vertical tube	area, m^2	10–100	12,000	20,000	0.53	carbon steel
Falling film			6500	10,000	0.52	
Filters						
Plate and frame	area, m^2	5–50	5400	8800	0.6	cast iron
Vacuum drum		1–10	21,000	34,000	0.6	carbon steel
Furnaces						
Process						
Cylindrical	heat abs, kW	$10^3–10^4$	330	540	0.77	carbon steel
Box		$10^3–10^5$	340	560	0.77	×2.0 ss

Figure 13-16 Purchase cost of miscellaneous equipments, Cost factors , Cost basis mid 2004

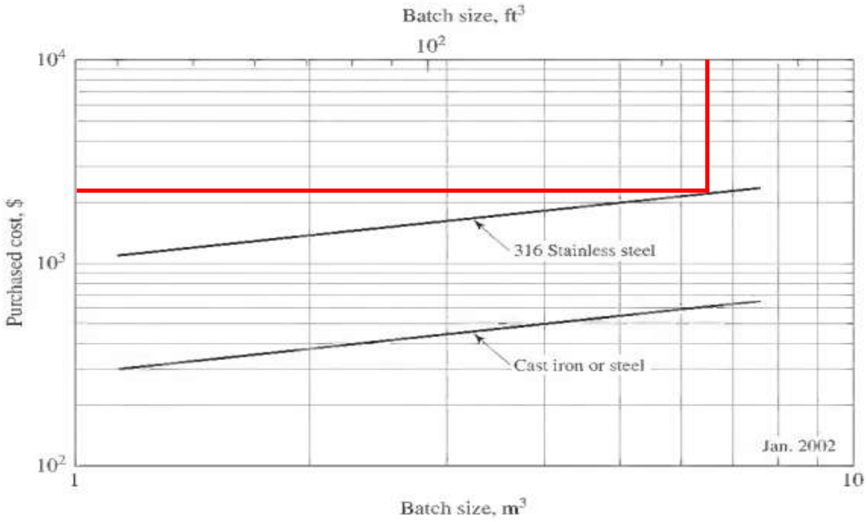
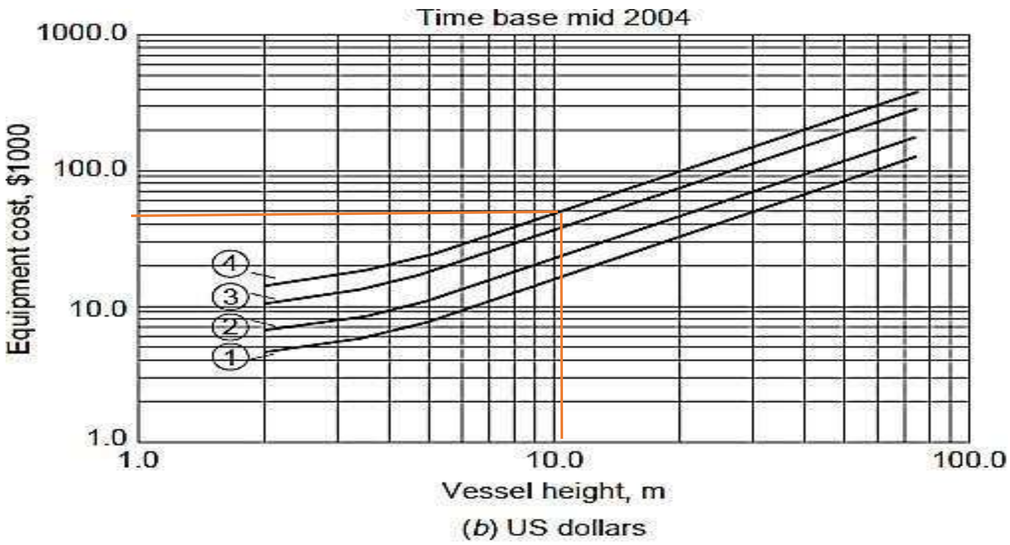


Figure 15-41
Purchased cost of cartridge-type filters

Figure 13-17 Purchased cost of Cartridge-type filter



Diameter, m		Material factors		Pressure factors	
①—0.5	③—2.0	C.S.	× 1.0	1–5 bar	× 1.0
②—1.0	④—3.0	S.S.	× 2.0	5–10	× 1.1
		Monel	× 3.4	10–20	× 1.2
		S.S. clad	× 1.5	20–30	× 1.4
		Monel clad	× 2.1	30–40	× 1.6
				40–50	× 1.8
				50–60	× 2.2

Figure 13-18 Bare costs of vertical vessels

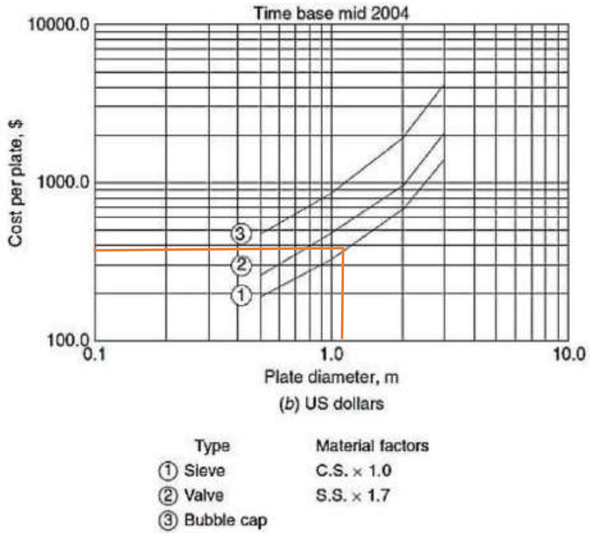


Figure 13-19 Bare Cost of plates

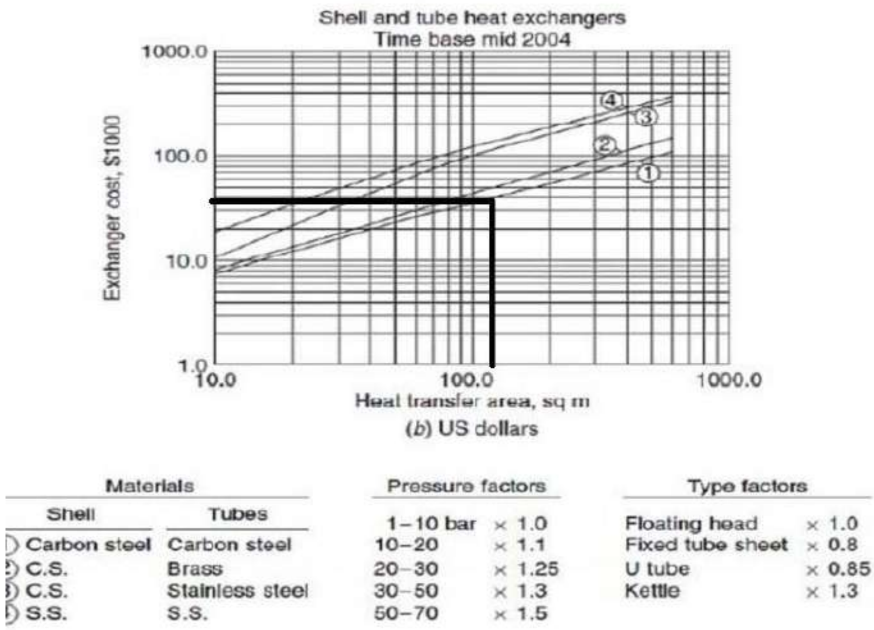


Figure 13-20 Bare cost of shell and tube heat exchangers

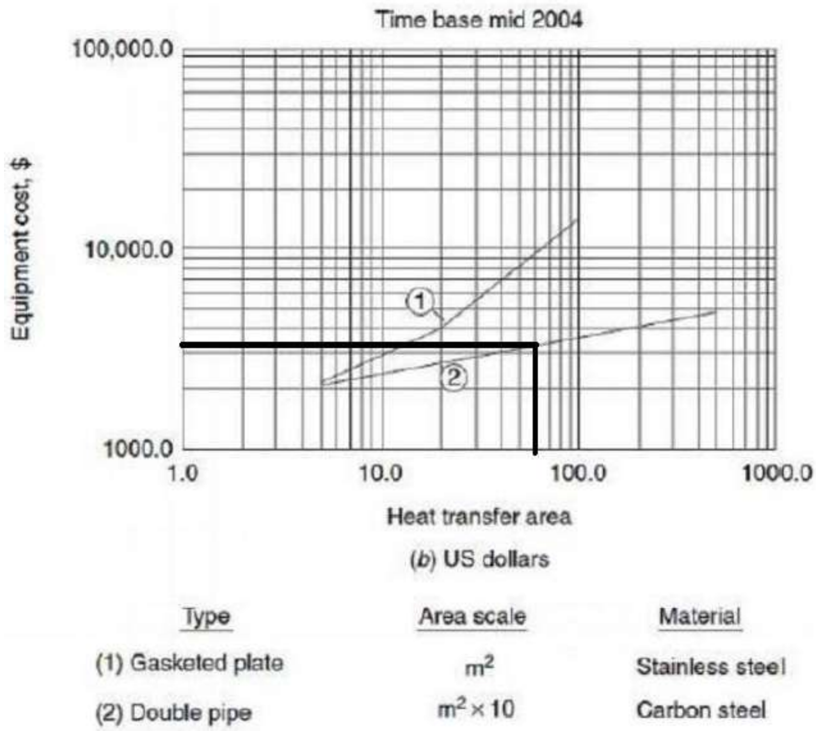


Figure 13-21 Bare cost of double pipe heat exchanger

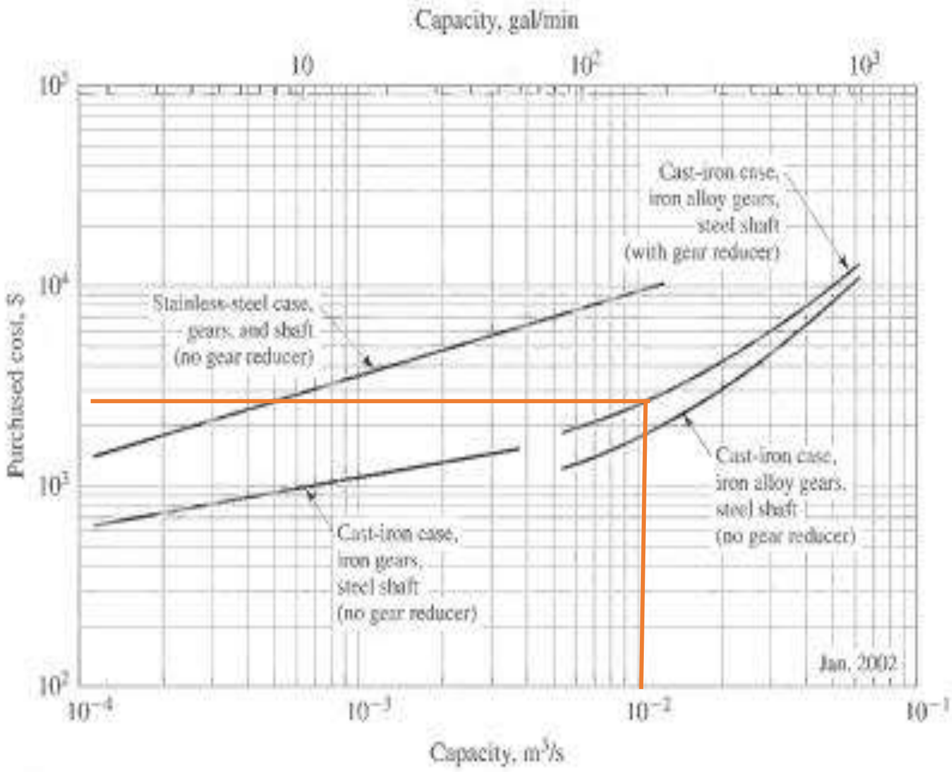


Figure 13-22 Purchased equipment cost of pump (P-101)

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