

FINAL YEAR PROJECT DESIGN REPORT

Pyrolysis of Waste Plastics into Fuels



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Abstract

The municipal solid waste (MSW) is one of the long-lasting environmental, health and economic problems in most developing countries. In recent decades, there has been a dramatic increment in plastic consumption. Used plastic is one of the major wastes in many countries. A lot of money is spent in land filling to process plastic wastes which can pose a threat to environment in long run. The incineration of plastic wastes leads to severe air pollution. Evaluations show that less than 5% of the plastic manufactured each year is recycled, with manufacturing of the material set to increase by 3.8% every year until 2030, adding to the 6.3 billion tonnes mixed out since production began 60 years ago. The solution of plastics-to-fuel holds promise in not only limitation such general pollution but also providing a significant economic benefit to regions. Plastic pyrolysis process is a widely used technique to handle plastic wastes in many foreign countries. Pyrolysis process converts plastic waste into liquid oil, solid residue (char) and gases at high temperatures (300-900°C) via thermal decomposition. Pyrolysis can be carried out via thermal or catalytic routes. However, there are certain limitations in the conventional thermal pyrolysis, where the whole process is temperature-dependent but thermal pyrolysis is more favorable than the catalytic pyrolysis where more amount of liquid oil is required to produce. Thermal pyrolysis produces liquid oil and gasses. The factors affecting the thermal pyrolysis process such as the temperature, retention time, feedstock composition. It involves melting plastic wastes, vaporizing them, condensing the vapor and distilling to obtain fuel. In the pyrolysis reactor, plastics are heated, vaporized and the vapor thus produced is

passed to shell and tube condenser to condense them. The liquid thus obtained is called pyrolysis oil and char remains in pyrolysis reactor as residue. The yields depend on various factors like plastic type used, cracking temperature of plastic, rate of heating, operation pressure of reactor, type of reactor, residence time, etc. A plant is being designed for the production of diesel oil. Diesel oil being produced by this plan is 8250.8 kg/day from 10,000 kg/day of plastic. This production can be obtained on daily basis by continuous process. Pyrolysis process consists of two stages. First stage is the plastic pyrolysis plant which is mainly used to turn waste plastic into fuel oil, and then through the distillation equipment, it can make the fuel oil processed into diesel. The main beauty of this process is that the fuel is generated from the waste plastic which is a most critical issue these days. We can get the plastic waste easily at low prices. We can get very high profit by the sale of this fuel and the increasing demand of this product in Pakistan. By keeping these points in mind construction of the plant is highly recommended.

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Chapter: 1

Introduction

1.1 History:

Pyrolysis is the thermal decomposition of the substance into its constituent compound fundamentals to a high temperature in an oxygen denied environment [1]. At the point when the gasses shaped by Pyrolysis are cool to room temperature, the heavier gasses consolidate to fluids, which are called bio-oil [2]. The lighter gasses, similar to hydrogen and carbon monoxide, which stays gasses at room temperature, are called "sync-gas" (blend gas). By modifying the temperature and term of Pyrolysis it is conceivable to upgrade for at least one of the three by results of Pyrolysis: sync-gas, bio-oil and bio roast [3]. For instance, moderate Pyrolysis underneath lower temperatures will create more bio roast while quick Pyrolysis at higher temperatures will produce more bio-oil. With quick Pyrolysis, the sync gas that is created can be singed inside the framework to keep up the temperature, bringing about bio-oil and bio burn as the sole results of Pyrolysis [4].

The execution of Pyrolysis was utilized a large number of years back in the Amazon tropical forest to make bio sync-gas, a charcoal like formation that was used to enhance and diminish the supplement poor rainforest soil [5]. The local people groups began fires and when the fuel was consuming sufficiently hot secured it with earth to evacuate the fire of oxygen [6]. The high warmth would keep on breaking down the fuel however without oxygen bio roast was framed as opposed to powder. More recently Pyrolysis was utilized with wood squander feedstock amid the two World Wars to produce conveying fuel when non-renewable get-up-and-go source were inaccessible. By 1945 trucks, transports and rural hardware were controlled by gasification. It is evaluated that there were near 9,000,000 motor vehicles running on bio-determined gas in many places far and wide [7].

John Bordynuik arranged a research facility desktop centralized computer substance that utilization an impetus to change over blends of unwashed waste plastic into gainful fuel [8].

After his prosperity with MIT and NASA, Bordynuik start purchasing up disposed of information storage room gadgets, particularly old information tape, eventually developing an assembling chronicle of 60 million archives, speaking to a considerable measure of examine information to be mined. Maybe it was

in succession from that accumulation that drove him to the disabled breakdown of plastic squanders into Pyrolysis oil. Bordinuik concentrated on nonrecyclable waste plastics [9]. In the late 1970's the Kelan Team and it relates first popularized tire Pyrolysis and have maintained to extend various interesting advancement. It took 10 years for the tirelessness to get up to speed to K lean group who were really the main movers and trailblazers to change over piece tires, squander plastics, and metropolitan strong waste into fluid fuel, Nano carbons, and clean vitality [10].

In 1980's, America was the nation to build up this technology for the waste plastic into the oil on the expansive scale. Presently it turns into a billion-dollar industry in the USA [11]. The main setup was of 2TPD that produces diesel from the waste plastic. In any case, around then the fuel properties weren't up to the check and there were parcel of toxins gasses creating from the operation [12].

In 1990's Germany additionally made his first nearby plant from the tires because of the utilization of the tires in nation is substantial. A short time later Germany made group Pyrolysis procedure of 3 TPD that was of least difficult innovation [13].

After this China and Japan made developments in this innovation and many procedures sorts of Pyrolysis were found in the field. Developments were about changing the procedure parameters to get the required diesel properties as that of the petroleum product properties [14].

1.2 Properties of Plastics:

The properties of different plastic materials give information about physical appearance and chemical reactivity.

	Polypropylene (PP)	Polyvinyl chloride (PVC)	High-density poly (HDPE)	Polystyrene (PS)
Plastic is color-coded	Blue	Green	Red	Yellow
Flexibility	Fairly flexible	Very flexible	Fairly flexible	Not very flexible
Crease color	Slightly white	Still green	Still red	White
Hardness	Gets scratched	Gets scratched	Gets scratched	Gets scratched
Density relative to alcohol	Sinks	Sinks	Sinks	Sinks
Density relative to water mixture	Floats	Sinks	Sinks	Sinks
Density relative to water	Floats	Sinks	Floats	Sinks
Density relative to salt	Floats	Sinks	Floats	Floats

Effect of acetone	None	Softens	None	Softens greatly
Effect of heat	None	Bends	None	Bends greatly
Reaction with HCl	None	None	None	None

1.3 Raw Material Resources

1.3.1: Main sources of plastic waste

Plastics waste falls into two main sources:

1. Pre-use plastic (production scrap)
2. Post-use plastic

1.3.1.1 Pre-use Plastic:

Pre-use plastic waste is to be expected either to be plastic that has not met the requirement required for its designed use, or off-cuts rising during installation. Examples of off-specification substantial might include material that has the wrong color, wrong hardness, or wrong handling characteristics. Although this material is not suitable for its planned use, it may be suitable for other applications and has the possible to be recycled. Off-cuts can be recycled into the same or different applications. For example, off-cuts from the making of cups from polystyrene sheet can be recycled into cups, or into cassette cases. Pre-use plastic waste is expected to be the main source of plastics suitable for reprocessing from manufacturers of plastic products. In many instances off-cuts can be reprocessed in-house. It is typically more valued than post-use plastics waste, as it generally requires minute processing to use in a new product [16].

1.3.1.2 Post-use plastic:

Post-use plastic waste fit for recycling generally falls into one of five main categories: Plastic bottles, pots, tubs and trays [16].

Plastic bottles :

Plastic bottles and pots, tubs and trays are found mostly in the household waste stream, yet they may also be one of the main plastic applications appropriate for recycling from SMEs [16].

Plastic film :

Plastic film is a thin-gauge packing used as a bag or wrap. Examples include plastic shopping bags, rubbish bags, bubble wrap, and plastic or give wrap.

Plastic films compose a general category of materials that can be relatively simple or complex, depending on the demand of a specific product or package. It can be clear or colored, printed or plain, single or multi-layered, therefore the only thing that all plastic film in fact has in common is that it is flexible in nature [16].

The principal points where large quantities of recoverable film are produced are those business areas that involve usage and reshipping of products. Wholesale activities produce the widely held of post-consumer profitable film wastes suitable for recovery [16].

Rigid plastics:

Rigid plastics cover a wide range of products, such as pipes, crates, packaging, moldings, drums and other containers. These products are made from a variety of different polymer types and can come from nearly any source, from hospitals and caterers to agriculture [16].

Plastic foams :

Plastic foams are frequently used in packaging, the most common being extended polystyrene (EPS). Main electrical and car manufacturers, such as Sony, Panasonic, Sanyo, Hitachi and Honda and leading electrical retailers like Dixons and Powerhouse, all have successful, profitable EPS recycling schemes[16].

Flexible plastics:

Flexible plastics can include cable sheathing, strapping and additional products. These products are made from a variety of different polymer categories and can come from a variety of sources [16].

1.4 Categories of Plastic:

Plastic is an important component of many items, including water bottles, combs, and drink containers. Knowing the difference, will help us make more informed decisions about recycling. There are seven categories of plastics Polystyrene is pre-use plastic and others are post-use plastics

The seven Categories of plastics are following.

- Polyethylene Terephthalate (PETE or PET)

- High-Density Polyethylene (HDPE)
- Polyvinyl Chloride (PVC)
- Low-Density Polyethylene (LDPE)
- Polypropylene (PP)
- Polystyrene or Styrofoam (PS)
- Miscellaneous plastics

For the sake of the environment, it's important to distinguish the different categories of plastic and their uses. Take a walk over your house or office and you're guaranteed to spill across a variety of plastic products. No material is more commonly used in our everyday lives, It's easy to classify everything as simply "plastic "However, there are seven different categories you should know about it [17].

1.4.1 Polyethylene Terephthalate (PETE or PET):

It is familiarized by J. Rex Whinfield and James T. Dickson in 1940, this plastic is one of the most widely used on the planet. Interestingly enough, it took another 30 years ago it was used for crystal-clear beverage bottles, such as the ones made by Coca-Cola and Pepsi [18].

PETE plastics make up 96% of all plastic bottles and containers in the United States, however only 25% of these products are recycled. By being mindful and making assured to recycle code 1 plastics, you're helping to make sure a cleaner environment and less landfill pollution [18].

1.4.2 High-Density Polyethylene (HDPE) :

In 1953, Karl Ziegler and Erhard Holzkamp used catalysts and low pressure to generate highdensity polyethylene. It was mainly used for pipes in storm sewers, drains, and culverts. Today, this plastic is used for a wide range of products.HDPE is the most commonly recycled plastic as it will not break under contact to extreme heat or cold. According to the EPA, 12% of all HDPE products created are recycled in a year. HDPE wastes have a mind-boggling potential to be used as a piece of pyrolysis process since it can take high liquid yield depends on upon the setup parameters [19].

1.4.3 Polyvinyl Chloride (PVC):

PVC is one of the oldest materials in industrial production. It was in fact discovered on accident twice; once in 1838 by French physicist Henri Victor and again in 1872 by German chemist Eugen Baumann. On both times, these men found it inside vinyl chloride flasks left visible to sunlight. PVC is one of the smallest amount recycled materials, generally less than 1% of PVC plastic is recycled every year. It has been called the “poison plastic” because it contains abundant poisons and is unsafe to our health and the environment [20].

1.4.4 Low-Density Polyethylene (LDPE):

LDPE was the first polyethylene to be produced. It has less mass than HDPE, it's considered a distinct material for recycling. Packaging and containers made from LDPE make up about 56% of totally plastic waste, 75% of which originates from domestic households. Fortunately, many recycling programs are progressing to handle these products. This means less LDPE will end up in landfills and unpleasantly affect the environment [21].

1.4.5 Polypropylene (PP):

J. Paul Hogan and Robert L. Banks of Phillips Petroleum Company introduced polypropylene in 1951. At the time, they were simply trying to change propylene into gasoline. Simply about 3% of polypropylene products are recycled in the US, but interestingly enough, 325 million pounds of non-bottle plastics were composed for recycling over a year. In other words, a lot of this plastic is created, but only a small part is actually recycled. The typical applications are to join window box, office envelopes, auto protects, and basins, floor covers, furniture, boxes and anything is possible from that point[22].

1.4.6 Polystyrene or Styrofoam (PS):

In 1839, German apothecary Eduard Simon accidentally came across polystyrene while making medication. He isolated a substance from natural resin and didn't recognize what he had discovered. Later, German chemist Hermann took research this polymer and expand on its uses.

As polystyrene is lightweight and easy to make into plastic materials, it also breaks effortlessly, making it more injurious to the environment. Beaches all over the world are spread with pieces of polystyrene, including the health of marine animals. PS is by and large not isolated what's more, not economically to gather for reusing because of its low thickness polystyrene froth.

Subsequently, the main way the PS waste can be completely used is through pyrolysis handle in which it can be transformed into more significant oil item instead of to wind up in the landfills until the end of time [23].

1.4.7 Miscellaneous Plastics:

The remaining plastics include: polycarbonate, polylactide, acrylic, acrylonitrile butadiene, styrene, fiberglass, and nylon. Of course, there are many changes in the plastics classified as miscellaneous by recycling programs. Many BPA products fall into this category, which means it's best to avoid them, especially for food products. It is not very easy to break down these plastics once they are formed, except they are exposed to high temperatures. This means they are approximately impossible to recycle [24].

Table 2: Proximate analysis of plastic [25]

Types of plastics	Moisture wt %	Fixed Carbon wt%	Volatile wt %	Ash wt %
Polyethylene	0.46	7.77	91.75	0.02
Terephthalate	0.61	13.17	86.83	0.00
High Density	0.00	0.01	99.81	0.18
polyethylene	0.00	0.00	98.57	1.40
Poly vinyle	0.80	6.30	93.70	0.00
Chloride(PVC)	0.74	5.19	94.82	0.00
Low Density	0.30	0.00	99.70	0.00
Polyethylene	—	—	99.60	0.40
Polypropylene	0.15	1.22	95.08	3.55
	0.18	0.16	97.85	1.99
Polystyrene	0.25	0.12	99.63	0.00

	0.30	0.20	99.50	0.00
Miscellaneous Plastic	0.13	1.18	98.41	1.00

1.4.8 Characterization of Plastic Waste

Plastic waste is considered as a potentially inexpensive source of chemicals and energy. Many of us have experienced a variety of products that use plastic materials today. As a result of the increasing level of private consumption of these plastic materials large amount of wastes are disposed of to the environment. Plastic materials are a type of material that cannot be decayed easily in a short period of time. Large quantities of plastic have gathered in the natural environment and in landfills. Those wastes can be divided according to their origins. They are: 1. Industrial

2. Municipal

Detailed estimation for the composition of the plastic waste products shows impurities 28% (wet weight) of the plastic waste, and that about 75% of the plastic waste was characterized as Low Quality applications indicating some legislative recovery restrictions. By considering the level/type of impurities the overall recycling potential was found to be 52% for hard plastics, 59% for plastic films and 79% for PVC waste [26].

1.5 Necessity of using plastics waste for production of fuel

Evaluations show that less than 5% of the plastic manufactured each year is recycled, with manufacturing of the material set to increase by 3.8% every year until 2030, adding to the 6.3 billion tonnes mixed out since production began 60 years ago. The common ends up in our oceans; a disturbance to marine ecosystems, which researchers forecast would take a minimum of 450 years to biodegrade, if ever. The solution of plastics-to-fuel holds promise in not only limitation such general pollution but also providing a significant economic benefit to regions. The American Chemistry Council estimates plastic-to-fuel services in the US alone would create nearly 39,000 jobs and almost \$9 in financial output, making the global market potential of such an industry. Plastic-derived fuels are also capable of producing a domestic burning fuel than traditional sources because of their low sulphur contents [27].

1.6 Local Survey

Pakistan produces about 48.5 million tons of solid waste a year, which has been increasing more than 2 percent yearly out of which nine percent are plastics. Here, 55 billion plastic bags a year are generated. Like other developing countries, Pakistan lacks waste management infrastructure, which causes serious environmental problems.

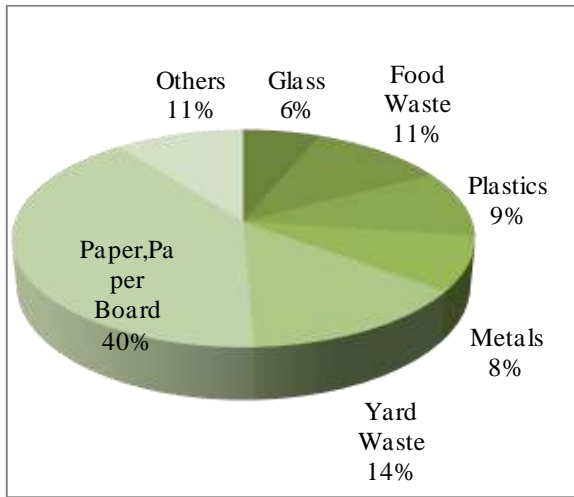


Figure 1: Pakistan waste material data chart [28].

It is estimated that food wrappers and containers cause 31.15% of pollution in the environment. Bottles and containers cap cause 15.5% of pollution in the environment. Plastic bags produce 11.18% environmental pollution, straw and stirrers cause 8.13%, beverage bottles produce 7.27% pollution in the environment.

1.6.1 Generation of Solid Waste in Major Cities of Pakistan

The data regarding generation of solid waste in major cities of Pakistan is represented in table 3[29].

Table3: Generation of Solid Waste in Major Cities of Pakistan [29]

City	Population in million	Solid waste generation tons
Karachi	20,500,000	11,000
Lahore	10,000,000	8,000
Faisalabad	7,500,000	5,900
Rawalpindi	5,900,000	5,400
Hyderabad	5,500,000	4,880
Multan	5,200,000	4,600
Gujranwala	4,800,000	4,400
Sargodha	4,500,000	4,000

Peshawar	2,900,000	3,000
Quetta	600,000	1,100

1.7 World Wide Survey:

The world wide survey on the plastic waste performed by the United Nations Environment Program exhibits the following details:

- Every year the world is producing 500 billion plastic bags
- Each year, minimum eight million tons of plastic end up in the oceans, almost equal to a full garbage truck every minute.
- In the **last decade**, we generate more plastic than in the whole **last century**.
- Fifty percent of the plastic we use is **single-use** or disposable.
- We purchase 1 million plastic bottles **every minute**.
- Plastic consists of **10% of all of the waste** we generate.
- Only 14% of total plastic used the world over is recant for recycling, rest is throw away into oceans and soil [28].

Pyrolysis units are located in Germany, USA, China, Spain, Czechia, Cyprus, Philippines and Japan. Japan is using pyrolysis oil, SPR Japan is the world largest waste plastic to oil recovery plant. The Sapporo Plastic Recycling ("SPR") organized a fully commercial plastic liquefaction facility on the island of Hokkaido in 2000 that has the efficiency to reuse over fifty tons a day of mixed plastic waste. From this waste stream, the leading thermal process recovers light oil that is used as a chemical feedstock for the generation of new plastics, a medium fuel oil comparable to diesel and a heavy oil that is used to produce electricity for export to the grid [30].

- Over 90% recovery of total plastic feed
- 15,000 tons per year (TPA) of mixed plastic wastes remove from landfill
- 4 MWe of electricity exported to the grid
- 8.75 million liters of high quality oil recovered from waste
- 4 MWe of thermal energy for district heating of similar
- 3,000 TPD solid recovered fuel
- 150 TPA of Hydrochloric acid
- 100-125 TPA of aluminum (used in plastic packaging)
- 15,000 TPA of carbon dioxide emissions offset [31].

1.7 Consumption and Production of Diesel

The average value of consumption for Pakistan during that period was 290.31 thousand barrels per day with a minimum of 104 thousand barrels per day in 1980 and a maximum of 450 thousand barrels per day in 2014. Pakistan produces 85,500 bbl/day of oil but imports 166,000 bbl/day, and it only refines 517,000 bbl/day of products while importing 381,200 bbl/day of refined products [32].

1.8.1 Estimated Amount of Oil from Pakistan Plastic Waste

In Pakistan, each year, 48.5 million tons of solid waste is, out of which nine percent are plastics, which is nearly equals to 4.3 million tons of plastic waste. Fuel yield estimates will be different for each system, and each technology manufacturer notes produced that yields will vary from batch to batch depending on the quality of the feedstock being used. The more contamination and non-resin materials present, the less the fuel yield will be. Higher presence of PS (polystyrene), PP(polypropylene)and LLDPE(linear low density polyethylene), the higher the yield will be [32].

Table 4: Estimated percentage of overall output [32]

Output	Percentage of overall output
Fuel/Oil	Ranges average from 80%-90%
Natural Gas	Ranges on average from 8% to 10%
Char	Ranges on average from 2%-13% (one system negligible amounts of char when the system is continuous feed versus a batch feed)

1.8 Waste Plastic Pyrolysis Oil:

Pyrolysis oil is the end product of plastic pyrolysis, the oil is widely used as industrial fuel to substitute furnace oil or industrial diesel. Typical industrial applications of pyrolysis oil as a fuel, the Pyrolysis oil is mainly used in machine that do not require high quality pyrolysis oil. The pyrolysis oil is extracted from waste plastic by our pyrolysis plant, the pyrolysis plant converts waste plastic to pyrolysis oil. During the process of converting waste plastic to Pyrolysis oil, there will be results in reduction of the pollution and solid waste. The end product of pyrolysis plant is Pyrolysis oil, carbon black, and oil gases [33].The raw material waste plastic will be heated in reactor, then the waste plastic will vaporize, the vaporize oil gases will go into the condenser and condensed into liquid pyrolysis oil. The Pyrolysis oil is a good energy. The dedusting system will deal with the waste perfectly, the oil gas which cannot

be condensed will be recycled back to the heat reactor [34].

The pyrolysis oil is mainly used in heavy industry such as construction heating, steel factory, cement factory, boiler factory; hotel heating etc, the oil is closed to NO₂ diesel. By direct combustion in a boiler or furnace pyrolysis oil can be used to produce heat. This is the most simple and straight forward application combustion of pyrolysis oil in heavy industry. This application offers some companies the possibility to partly from natural gas, or heating oil to a renewable alternative fuel[35]. Pyrolysis oil is competitive with the price of heating oil, more and more countries are using pyrolysis oil to replace natural gas. Pyrolysis oil has the potential to be available in large amounts and competitively priced. Once the plastic oil refined it can be used many different ways. Such as truck, tractor, ship, diesel power generation and so on. The pyrolysis oil is mainly used in heavy industries for heating purpose as fuel, usually used in industry or machine which doesn't require high stand oil like steel factory, cement factory, brick factory and glass factory etc, especially steel factory and cement factory [36].

1.9.1 PROPERTIES OF WPPO:

The waste plastic product oil obtained from the plastic have following characteristics.

Table 5: Properties of WPPO [37].

Properties PPO	
Density at 40°C (g/cc)	0.747
Viscosity at 40°C (cSt)	1.980
Flash point (°C)	15
Fire point (°C)	20
Calorific value (kcal/Kg)	9829.35

1.10 Solid Waste Treatment in Lahore:

As the current cost of the waste management on the basis of 60% collection of the total waste and the cost of recommended improved system of management on the basis of 100% waste collection facilities is also provided. The total waste produced per year is 500,000 tons, or 0.84 Kg/cap/day.

Pakistan has a population of 204.73 million, 45% people living in urban areas. Solid waste produced in urban areas of Pakistan is predictable at 55,000 tons/day .The areas under the control of the Lahore City

District Government with a population of 12 million produce 8000 tons/day. The solid waste management system for the city of Lahore was certified when it became part of Lahore Urban Development Project (LUDP), which was introduced in 1978. At present, the Solid Waste Management Department of City District Govt. Lahore (CDGL) is answerable for the collection and throwing away of the solid waste within the boundaries of City District Govt. Lahore. The solid waste streams are regarded as their sources and the categories of wastes produced [38].

The composition and quantity of the solid waste made in Lahore is given in Table 6

1.10.1 Solid waste storage system:

The storage of solid waste in suitable containers is not commonly practiced.

Table 6: Composition and quantity of solid waste produced source [39]

Series No.	Description	Tons Per Day	%Weight
1	Paper	69.1	5.04
2	Glass	30	2.19
3	Ferrous metal	0.3	0.02
4	Nonferrous metal	6.5	0.47
5	Film plastics	177.3	12.94
6	Rigid plastics	76	5.55

7	Organics	917.9	67.02
8	Textiles	13.7	1.00
9	Other	79	5.77
Total		1369.8	100

Today, Environment is dirtied impurity by plastic misuses is an overall event today. Reusing waste plastics into reusable plastic items is an ordinary technique taken after to address this issue for quite a long time It is expected that around 10 thousand tons of plastics waste every day is created in our nation [39].

1.11 Social Benefits:

The energy crisis and environmental destruction are the principal problems in the present day due to the rapid industrialization and growing population. Degradation of solid waste such as plastic bottles, grocery bags, etc. in nature takes many years. Besides, plastic disposing methods like landfill, reusing, and burning can create severe risks to the human health and environment. Therefore, plastic must be kept under control from damaging the environment. One of the most favorable and effective disposing methods is pyrolysis, which is an environmentally friendly and efficient way [38].

The pyrolytic oil produced is converted into pyrolytic fuel very similar to diesel or gasoline by upgrading. The calorific value of the pyrolytic fuel is similar to that of diesel and gasoline. Pyrolytic fuel can be used in internal combustion engines without significant loss in engine performance [38].

By using this technique not only plastic waste is reduced or lessened from our environment and ecosystem, but also the pyrolytic fuel is produced which serves as the purpose of diesel oil in many agricultural and process industries, which is environmental friendly technique and has sustainable impact on our social environment. This is indeed a worthwhile technique which not only reduces the non-degradable plastic waste from our environment but also saves the resources for the coming generations. This technique has been widely adopted by many developed countries.

Chapter: 2

Process Selection:

Diesel can be produced from various processes. The common thermal conversion technologies are:

1. Incineration
2. Gasification
3. Pyrolysis

2.1 Incineration:

The first one which requires high temperatures 1100°C results in products with flue gases and ash. This is because of the unanalyzed thermal degradation which gives rise to low molecular weight substances. Uncontrolled incineration of plastics at higher temp above 850°C to produces polychlorinated dibenzo-p-dioxins, a carcinogen (cancer causing chemical). Open-air burning of plastic occurs at lower temperatures, and normally releases such toxic fumes and many oxid gases. So flue gases treatment use for protect environment and health problems in incineration plant [37].

2.2 Gasification:

The second one is the gasification in which partial oxidation of waste and plastic at about 800°C in which organic compounds are converted to syngas comprising CO, H₂, CH₄, tar a,nd ash. The gas resulting from gasification of municipal wastes contains various tars, particulates, halogens, heavy metals and alkaline compounds depending on the fuel composition and the particular gasification process. It leaves waste without its intended disposal route. Small amounts of tar are released in the gas [37].

2.3 Pyrolysis:

The most well-known process is Pyrolysis. Pyrolysis is the one of the best process through which biomass can be converted into useful oil. As this report has the intend to provide the reader with the latest technologies to convert the biomass. Many researchers have been made for this process as it's the most useful process to produce the oil and gases for the other use.

The selected one is process of Pyrolysis is the thermally degrading long chain polymer molecules into smaller, less complex molecules through heat and pressure. Pyrolysis is the main which process requires intense heat with shorter duration and in absence of oxygen. Products that are produced during Pyrolysis are oil, gas which are valuable for industries especially production and refineries. As Pyrolysis is chosen

by many industries due to its high yield production up to 80% at 500 °C. The major advantage of this process is it is flexible because the process parameters can be changed to obtain different yields of oil and gas based on preference. The liquid oil produced can be used for different applications such as for diesel engines, furnaces, boilers without the needs of upgrading or treatment. With recycling, many issues were coming with environment pollution, Pyrolysis does not cause water pollution and also believe as green technology when the Pyrolysis by-product which is gaseous has considerable calorific value that can be reused to give back the overall energy necessity of the Pyrolysis plant. The process handling is also much easier and flexible than the common recycling method since it does not need an intense sorting process, thus less labor intensive.

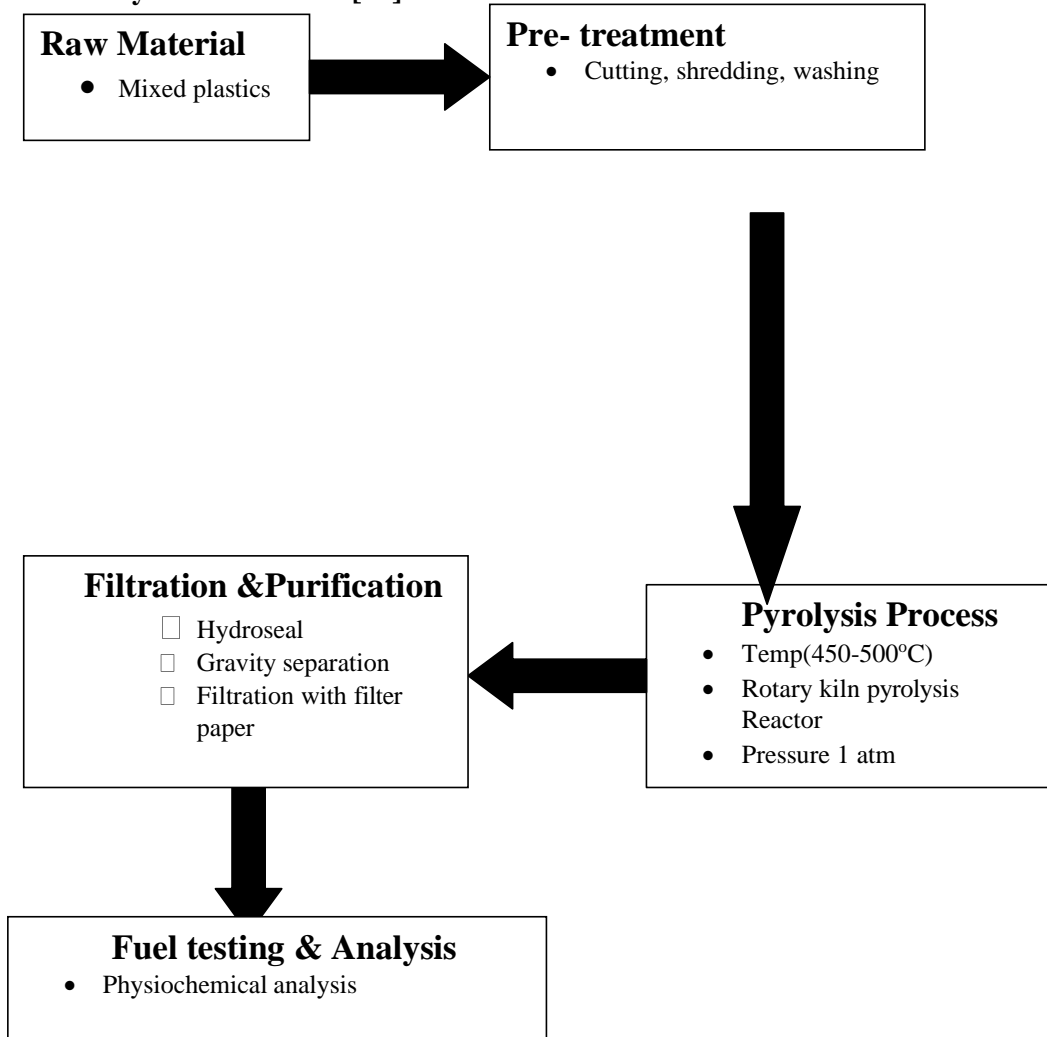
Method can be superior by the adding up of catalysts that can reduce the temperature and reaction time. It permits the hydrocarbons manufacture with a higher added value, such as fuel oils and petrochemical feed stocks. Use of catalysts will give an extra value to the Pyrolysis and the cracking effectiveness of these catalysts depends both on its chemical and physical characteristics. These catalytic properties have an advantage like to promote the breaking of C-C bonds and determine the length of the chains of the products obtained. Taking all the factors under consideration our selected process is “Pyrolysis” [38].

2.4 Process Description:

- Stream 1 contains plastic (HDPE, LDPE) enters into the crusher of about 10,000Kg/day for crushing and shredding of the plastic.
- From the furnace, heating fuel is given to the rotary kiln pyrolysis reactor.
- Before starting reaction, nitrogen gas, a fluidizing gas was purged into the reactor to create an inert atmosphere. Nitrogen is used as a carrier gas.
- After heating at 450-500°C and 1atm pressure, water evaporates.
- From the reactor, waste residue is also produced.
- From the reactor oil gases are generated.
- Next stage is condenser. The cooling water is circulated and condensation takes place.
- Oil gases produced are passed through the condenser. Through condenser, heavy sledge oil will be liquefied
- The vapours coming out after melting of the waste were passed through a condenser and liquid fuel was collected in a tank.
- Uncondensed gases produced during the experiment were allowed to pass through a cold water bath.

- From the condenser, unified combustible gases will be produced sent to the hydro seal.
- The combustible gases are Hydrogen, Carbon dioxide, CO, Methane, Ethane, 1,3Butadiene, Propene, n-butane and other miscellaneous hydrocarbons
- The hydro seal can eliminate sulfur and impurities of the drain gas and then the clean gas can be recycled to the burning room to be use as fuel. In addition, the hydro seal can also prevent the gas burning back
- Liquid oil pass through the fractionating column from where light oil ,gasoline and diesel are separated
- Then filtration and purification of liquid fuels is done by gravity separation and filtration with filter paper and after fuel testing and analysis liquids fuels are transported.
- HDPE and LDPE start melting at about 130°C. The maximum yielding temperature range was 450- 550°C and at a temperature about 500°C, very fast rate of oil was obtained. Time required for completion of the pyrolysis process can take several hrs [38].

2.1 Fuel Synthesis Process [38]



Process Flow Diagram:

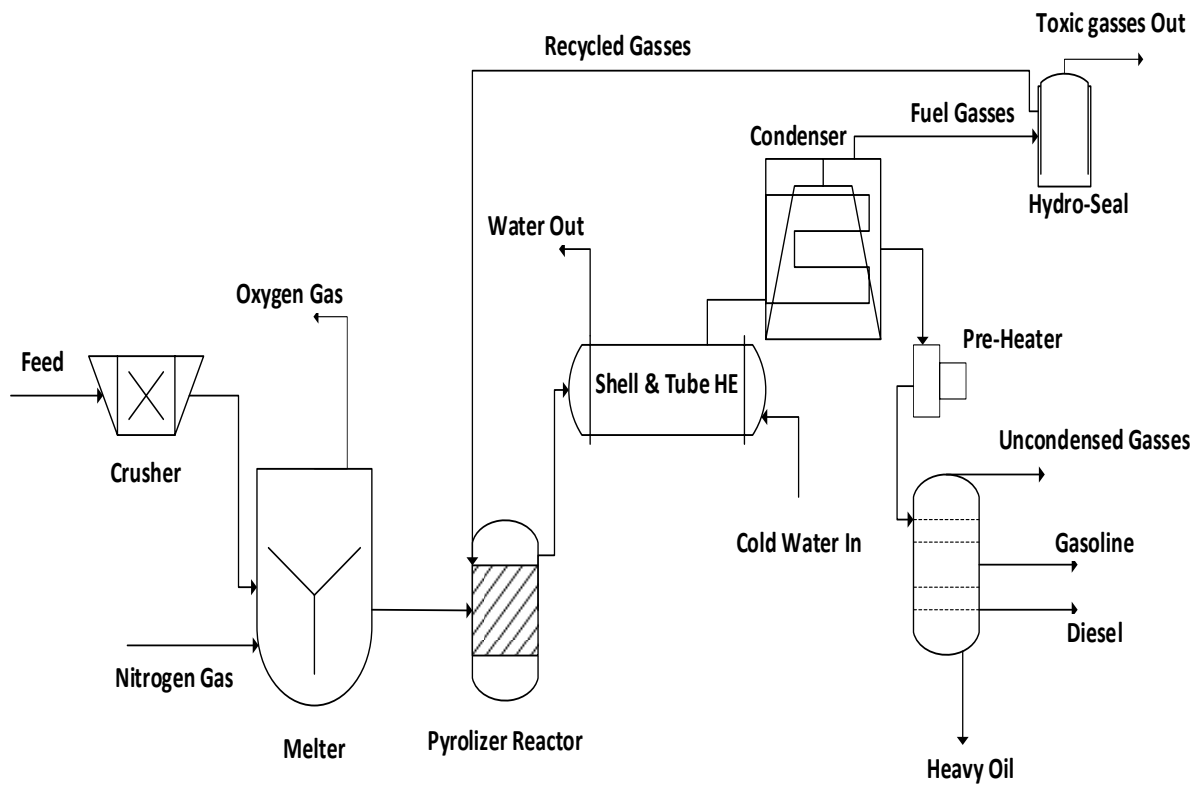


Table 7: Testing Methods Of Fuel Properties [39]

Properties	Test Method
Denstiy	IP 131/57
Kinematic Viscosity	ASTM D 445
Flash Point	ASTM D 93
Fire Point	ASTM D 93
Water content	ASTM D 49
Pour Point	ASTM D 97
Calorific value	Bomb-calorimeter-12/58
Sulphur content	ASTM D 129-00
Carbon Residue	ASTM D 189-65
Ash content	ASTM D 48

2.6 Analysis of Waste Plastic Pyrolysis Oil

2.6.1 Physiochemical Analysis:

The waste plastic has high unstable substance 77.03% by weight which is reasonable for pyrolysis transformation of waste plastic to oil. The attributes of waste plastic pyrolysis oil gotten at 425°C is appeared in Table 8. The density measurement is done with accuracy of ± 0.0005 g/mL and the other parameters such as pour point, flash point, and fire point are measured with $\pm 1^\circ\text{C}$ accuracy [39].

Table 8: Characteristics Of Waste Plastic Pyrolysis Oil [39]

Properties	WPPO
Viscosity at 40°C (cSt)	1.980
Density at 40 °C (g/cc)	0.7477
Carbon residue (wt%)	0.5
Ash content (%)	0.036
Sulphur content (% of wt.)	0.246

Flash point (°C)	15
Fire point (°C)	20
Pour point (°C)	<-15
Calorific value (kcal/Kg)	9829.35

2.6.1 Viscosity

Viscosity changes with feedstock, pyrolysis environment, high temperature, and unusual factor. The higher the viscosity, the higher the fuel utilization, engine temperature, and load on the motor. Then, again, if the oil viscosity is too high, higher friction may happen. The viscosity was calculated by the IP-50 procedure at a temperature of 40°C. From table 8 it is seen that the consistency of waste plastic pyrolysis oil acquired at 4250°C pyrolysis temperature was 1.98 cSt which was similarly higher than lamp oil and lower than diesel [39].

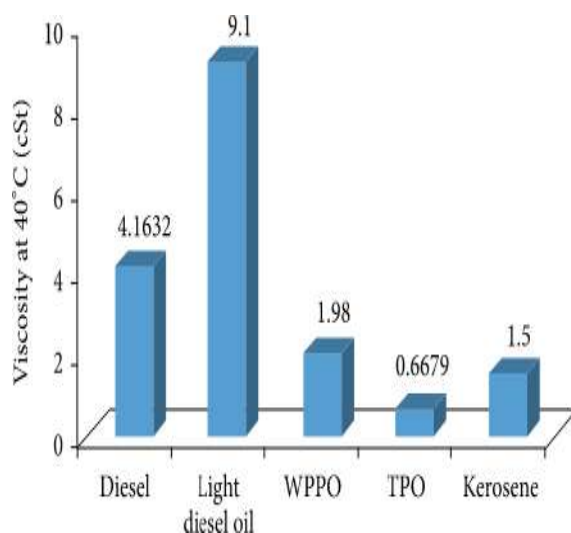


Figure 2: Different Oil's viscosity [39]

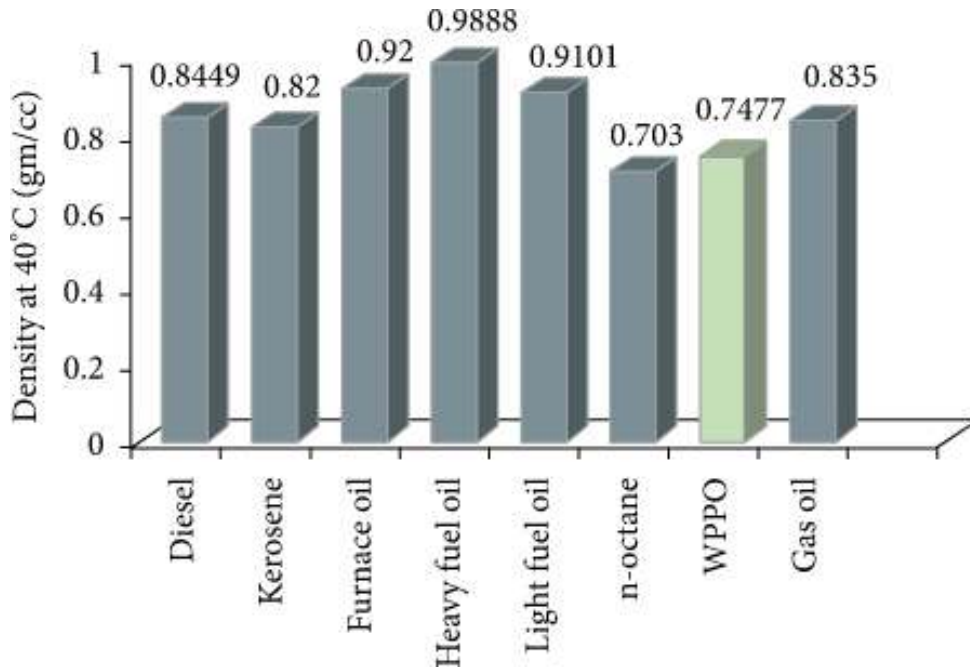
2.6.1 Density

Density is a fundamental property of a fuel oil. If the density of fuel is high; the fuel usage will be less. On the other hand, the oil with low thickness will utilize more fuel which may make hurt the engine or motor. In this, too low or too high density of fuel oil is not appealing. It is clear from table 8 that the densities of WPPO and WPPO50 were seen to be 0.7477 g/cc and 0.7943 g/cc, independently, which is close to the density of light oil, diesel, and gas oil. So, the customary fuel, for instance, diesel oil,

lightoil, and gas oil may be supplanted by plastic Pyrolysis oil (39)

Figure 3: Density of different fuels [39]

2.6.4. Flash Point



Flash point is the least or low temperature at which oil can vaporize to shape a flammable mixture in air. flash point out is exploiting to characterize the fire danger of power. The flash point of WPP0 was calculated by ASTM D 93-62 method. The flash point of WPP0 was approximately 15°C. Low flash point shows the occurrence of extremely volatile materials in the fuel that is an actual security worry in taking care and transport. The flash point of heater oil, diesel, and lamp oil is higher than WPP0 (table 8) which shows that these are anything but difficult to deal with. By evacuating lighter parts, (for example, naphtha/gas) the flash point of WPP0 will be increased [39].

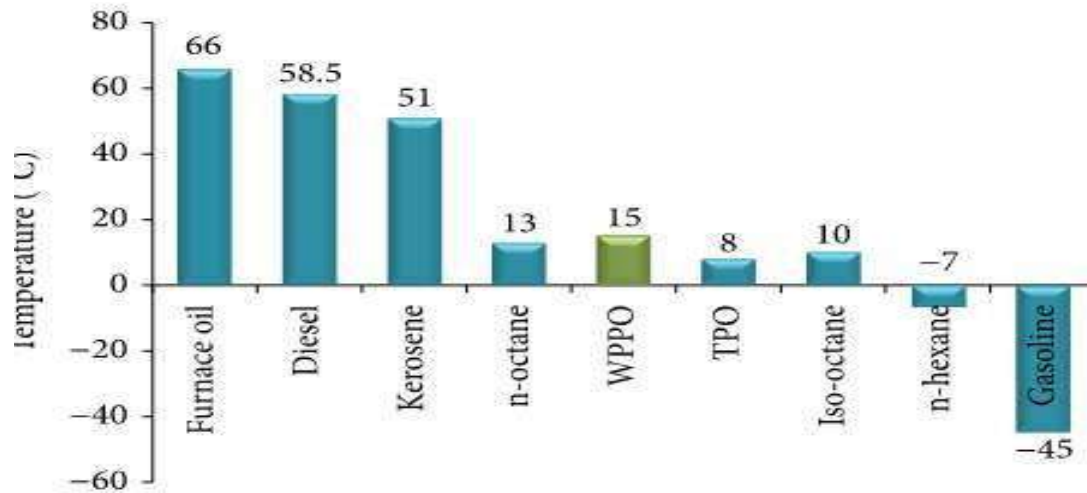


Figure 4: Flash point of different oils [39]

2.6.2 Fire Point and Pour Point

Fire point of a fuel (temperature at which it will continue burning for no less than 5 seconds after start by an open fire. The fire point is utilized to survey the danger of the materials capacity to support ignition. For the most part, the fire point of any fluid oil is thought to be around (5–10) °C higher than the flash point. The fire point of waste plastic pyrolysis oil was 20°C.

The pour point is the temperature at which the oil will just stops to flow when cooled at a standard rate in a standard apparatus. Pour point decides the suitability of oil for low temperature establishments. The pour purpose of WPPO was measured by utilizing ASTM D 97-57 procedure. The pour point was <-15°C. The low pour point estimation of WPPO demonstrates that it is not appropriate in chilly climate nation [37].

2.6.3 Calorific Value

One of the vital properties of a fuel on which its proficiency is judged is its calorific value. The calorific value is characterized as the energy given out when unit mass of fuel is burned totally in adequate air. The calorific estimation of WPPO was evaluated by IP 12/58 technique. The calorific estimation of WPPO was 9829.3515 kcal/Kg. Table 8 speaks to the correlation of calorific estimation of WPPO with different sorts of oil [37].

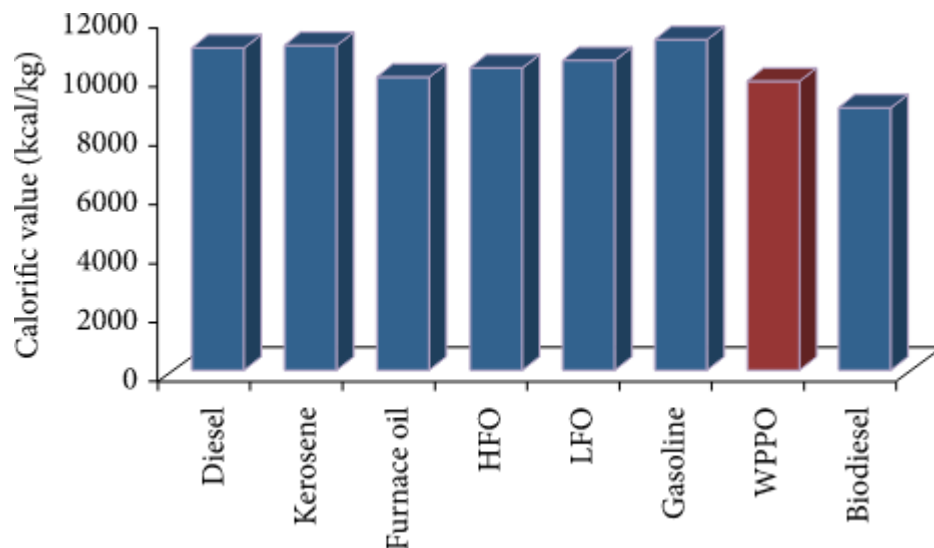


Figure 5: Calorific value of oils [39]

2.6.4 Sulphur and Ash Content

Sulfur presence in vehicle fuels causes discharges that are a natural issue. High sulfur reduces the catalytic capacity in the system, therefore increases the discharges of nitrous oxides, carbon monoxide (CO), hydrocarbons, and unstable organic fluids (VOCs). The sulfur substance of WPPO was measured by utilizing ASTM D 129-00 system. The sulfur substance of waste plastic pyrolysis oil was 0.246%. Sulfur substance of WPPO is somewhat higher than gas (0.014%), diesel (0.15%), and different sorts of fuel oil since waste plastic contains some sulfur (Table 8) [37].

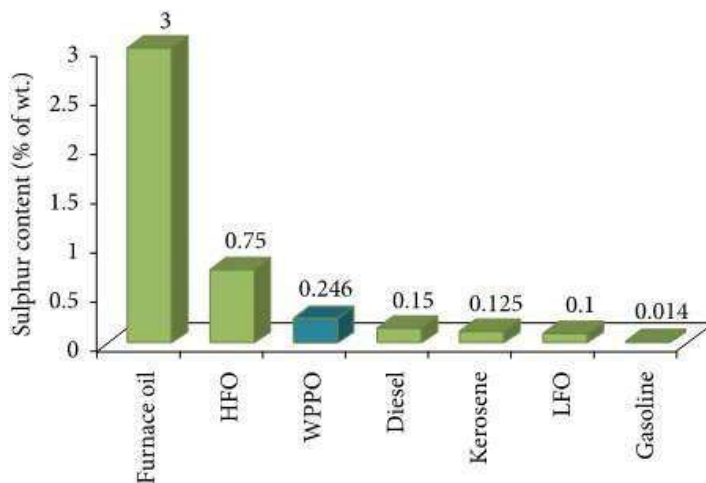


Figure 6: Sulphur in different oils [39]

2.6.8 Carbon Residue

Carbon residue shows the propensity of oil to store a carbonaceous solid deposit on a hot surface, for example, a burner or injection nozzle, when its vaporizable constituents dissipate. The carbon deposit of WPPO was measured by ASTM D 189-65 technique. Oil which stores least measure of carbon is ideal.

Table 8 demonstrates that the carbon residue of the plastic pyrolysis oil was 0.5%. In another review, 0.05% of carbon deposit was accounted for. The carbon deposit of the diesel fuel and light fuel oil was relatively higher than WPPO. This shows diesel powers will shape higher stores. Fills with high carbon deposit substance could bring about expanded fouling of the gas ways; more incessant cleaning is important, particularly of the turbocharger and fumes gas kettle [39].

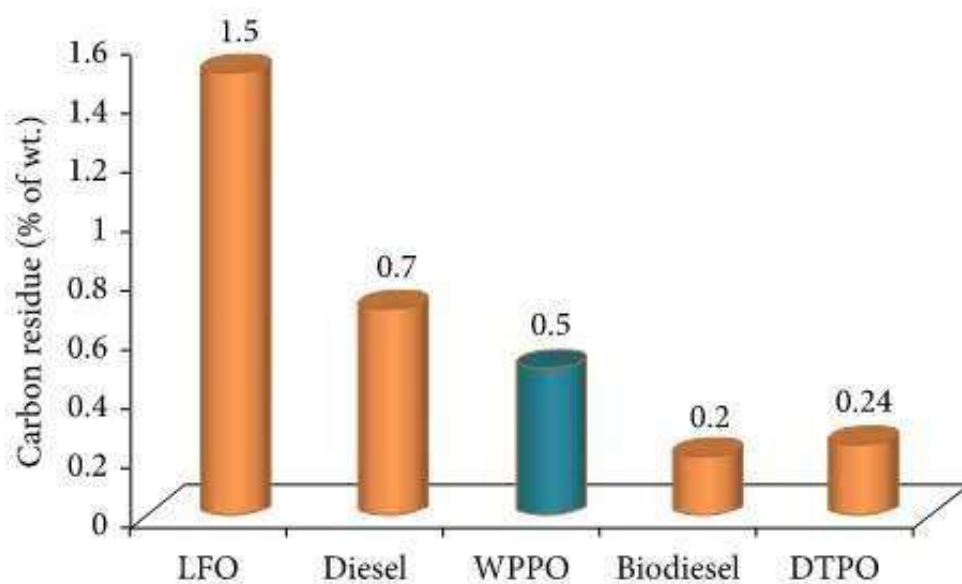


Figure 8: Carbon Residue [39]

Chapter: 3

Material And Energy Balance

Material Balance

⇒ **Basis 10,000 kg/day of plastics**

1. Reaction Used:

1kgmol plastics \longrightarrow 0.85 C₁₂H₂₄+ 0.1 C₃H₈ - C₁₂H₂₄+ 0.05 (Solid Residue)

54.35Kmol plastics \longrightarrow 46.2 C₁₂H₂₄Kmol + 5.4Kmol C₃H₈ - C₇H₁₆+ 2.7Kmol (Solid Residue)

⇒ **For 85 % conversion of Plastics**

Molecular weight = 184kg/Kmol [02]

Molecular weight of diesel = 178.6 kg/Kmol [03]

Weight of plastics = moles * molecular weight

$$= 1\text{Kmol } 184\text{kg/Kmol} = 184\text{kg}$$

Weight of diesel = 0.85 Kmol 178.6kg/Kmol = 151.81kg

For,

$$\begin{aligned} 1 \text{ Kmol of plastics} &= 10,000 \text{ kg/day } 1\text{Kmol}/184\text{kg} \\ &= 54.35 \text{ Kmol/day} \end{aligned}$$

1 Kmol of plastics = 0.85 Kmol of heavy oil

$$= 0.85 * 54.35$$

$$= 46.2 \text{ Kmol/day}$$

Heavy oil/ Fuel produced = 46.2 Kmol/day 178.6 kg/Kmol

$$= 8250.8 \text{ kg/day}$$

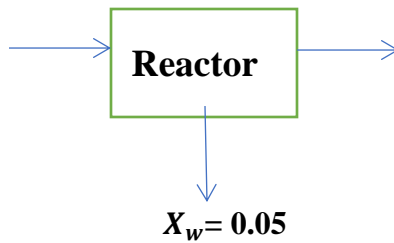
Reactor Balance :

Feed $X_f = 1$

10,000 kg/day

Or

417 Kg/hr.



distillate (Pyro Gas)

$X_d = 0.85 + 0.1 = 0.95$

D = ? Kg/hr

D = ? Kg/day

W = ? Kg/hr. or Kg/day

Component Balance: 1

$$F_{x_f} = D x_d + W x_w$$

Overall Balance: 2

$$F = D + W$$

For component balance:

$$X_w = 0.057 F$$

$$\begin{aligned} W &= 0.05 * 10,000 \text{ kg/day} = 500 \text{ kg/day} \\ &= 21 \text{ kg/hr.} \end{aligned}$$

Putting this value in equation 2 we get,

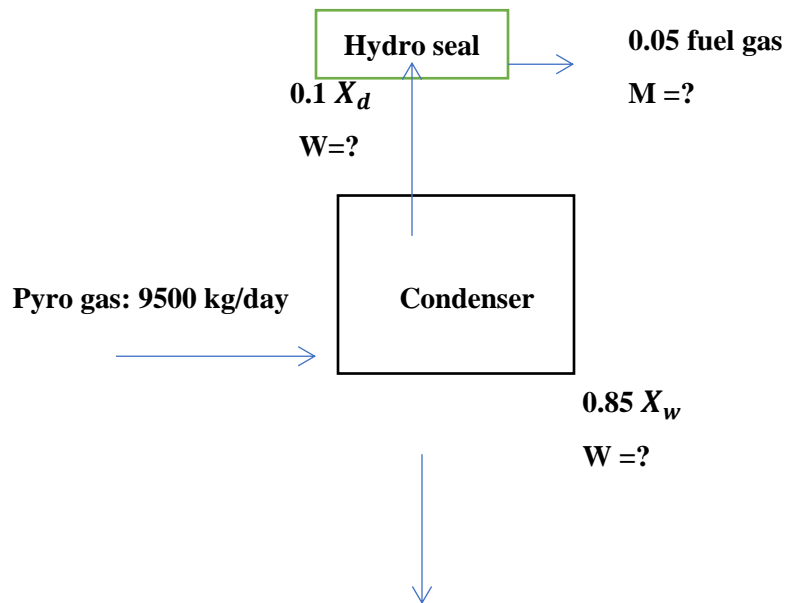
$$F = D + W$$

$$10,000 \text{ kg/day} = D + 500 \text{ kg/day}$$

$$D = 9500 \text{ kg/day}$$

Or 396 kg/hr.

2. Condenser Balance:



$$\mathbf{F = D + W} \quad (\text{Overall Balance})$$

$$\mathbf{X_f F = X_{dw}D + X_w W} \quad (\text{Component Balance})$$

By component balance:

$$W = X_w F$$

$$\begin{aligned} W &= 0.85 * 9500 \text{ kg/day} \\ &= 8075 \text{ kg/day} \end{aligned}$$

Putting the same value for X_d

$$\begin{aligned} D &= X_d \cdot F \\ &= 0.1 * 9500 \text{ kg/day} \\ &= 950 \text{ kg/day} \end{aligned}$$

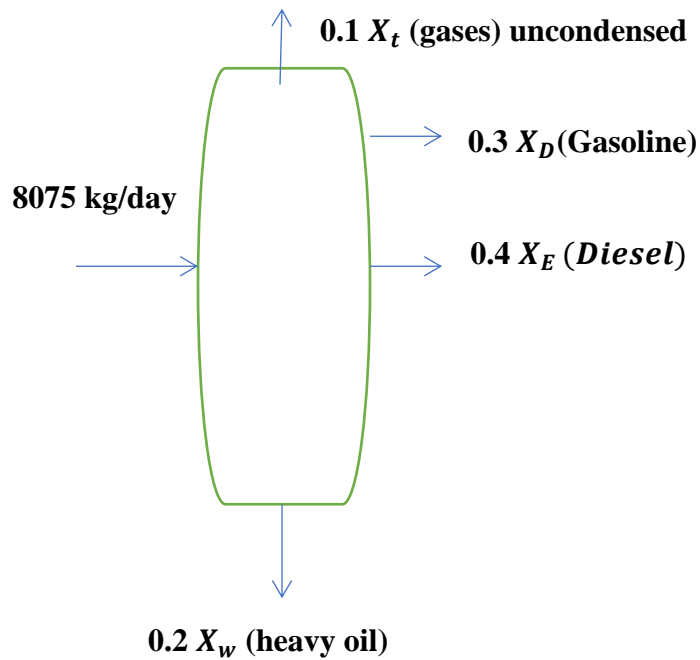
For Fuel Gases

$$\begin{aligned} M &= X_m * F \\ &= 0.05 * 9500 \text{ kg/day} \\ &= 475 \text{ kg/day} \end{aligned}$$

This proves overall balance and we can't apply material balance on heat exchangers as this can only transfer heat or manage temperature.

Gases vapors condense at 60°C [04]

Fractional Column Balance:



Overall Balance:

$$F = t + D + E + w$$

Component Balance:

$$X_f F = X_t t + X_d D + X_E E + X_w w$$

From component balance

$$D = X_d * F \quad (i)$$

$$= 0.3 * 8075 \text{ kg/day}$$

$$= 2442 \text{ kg/day}$$

$$E = X_E * F \quad (ii)$$

$$= 0.4 * 8075 \text{ kg/day}$$

$$= 3230 \text{ kg/day}$$

$$W = X_w * F \quad (iii)$$

$$= 0.2 * 8075 \text{ kg/day}$$

$$= 1615 \text{ kg/day}$$

Putting all these values in overall balance

$$F = t + D + E + w$$

$$8075 = 2442.5 + 3230 + 1615 + t$$

$$t = 807.5 \text{ kg/day}$$

Which are uncondensed gases and can be used as a heat source?

$$X_t = 0.1$$

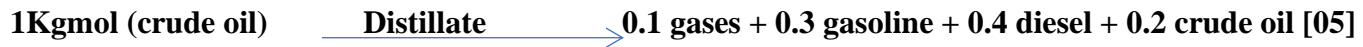
$$t = 0.1 * 8075 \text{ kg/day}$$

$$= 807.5 \text{ kg/day}$$

Composition reaction for plastic-fuel fractions is carried by Fang GAO Thesis which states:

“A 1Kg plastic produces 0.9 crude/heavy oil which further, consist of gases, gasoline and diesel.

Distillation is carried out on the basis of boiling points.”



Energy Balance

1. Reactor Balance:

$$\text{Pre-heater temp} = 33\text{C}^\circ \quad [06]$$

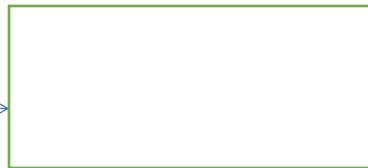
$$\text{Reference temp} = 25\text{C}^\circ$$

Equation

$$Q = m C_p \Delta T \quad [07]$$

10,000 kg/day

417 kg/hr.



9500 kg/day

396 kg/hr.



$$Q_{in} =$$

10,000kg	1.90KJ	(33-25)C°
Day	Kg. C°	

$$= 1.52 * 10^5 \text{ KJ/day}$$

$$Q_{out} =$$

9500 kg	2.05 KJ	(450-33)C°
Day	Kg. C°	

$$= 8.17 * 10^6 \text{KJ/day}$$

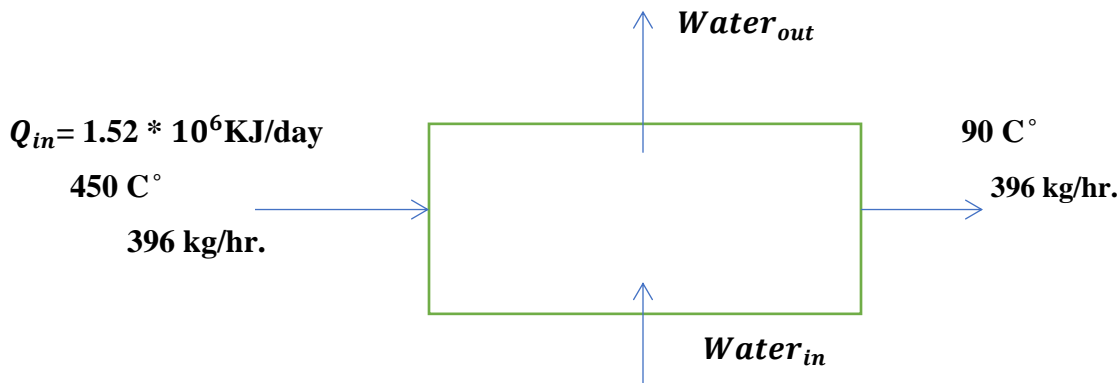
$$Q_{in} = Q_{out}$$

$$= 8.17 * 10^5 + x = 1.52 * 10^6$$

$$= 8.02 * 10^6 \text{KJ/day}$$

X is amount of heat in steam to achieve product.

Energy balance on heat exchanger



$$Q_{in} = 8.17 * 10^6 \text{KJ/day}$$

$$Q_{out} = m C_p \Delta T$$

396 kg	2.05KJ	(450-90)C°
day	Kg.C°	

$$= 2.92 * 10^5 \text{ KJ/hr.}$$

$$Q_{in} = Q_{out}$$

$$Q_{in} + x = Q_{out}$$

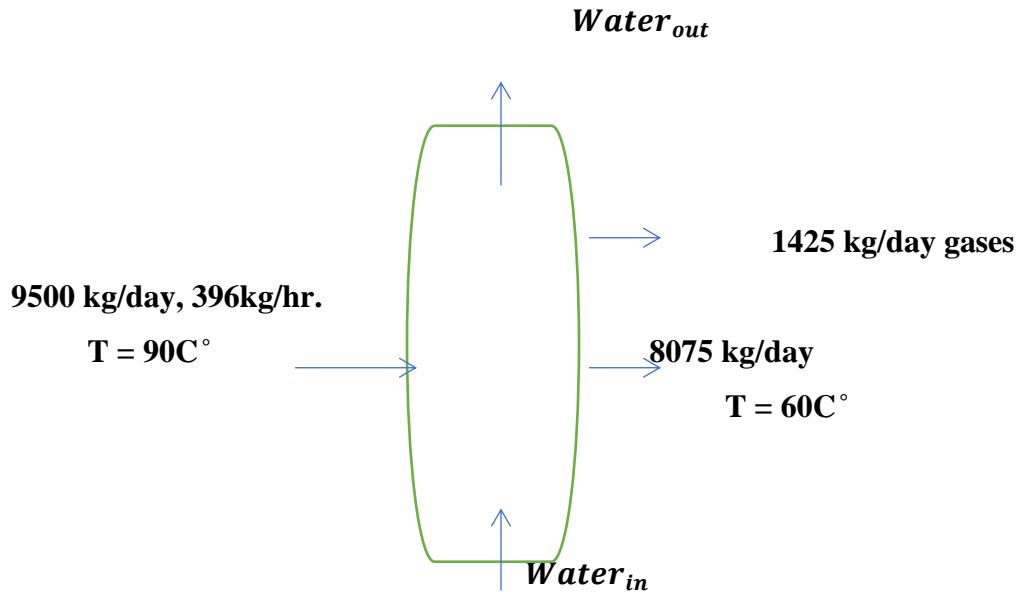
$$Q_{in} = Q_{out} - x$$

$$8.17 * 10^6 \text{KJ/day} = 2.92 * 10^5 \text{ Kg/day} - x$$

$$X = -7.87 * 10^6 \text{KJ/hr.}$$

Amount of heat required to carry a balance.

Energy balance on Condenser



$$Q_{in} = 2.92 * 10^5 \text{ KJ/day}$$

$$Q_{out} = m C_p \Delta T$$

9500kg	2.05KJ	(90 -60)C°
day	Kg. C°	

$$= 2.4 * 10^4 \text{ KJ/hr.}$$

$$Q_{in} = Q_{out}$$

$$Q_{in} + x = Q_{out}$$

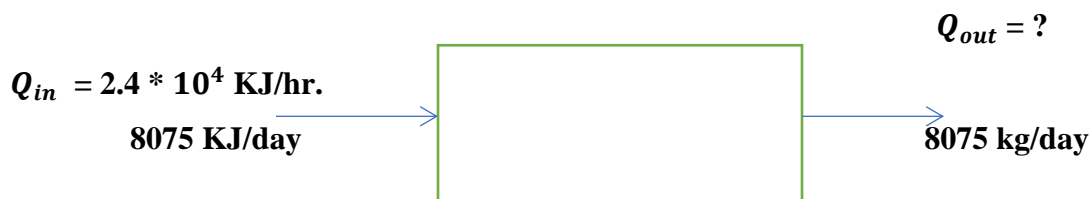
$$x = Q_{out} - Q_{in}$$

$$= 2.4 * 10^4 - 2.92 * 10^5$$

$$= -2.68 * 10^5 \text{ KJ/hr.}$$

This amount of energy is required to carry balance.

Energy balance on pre-heater



$$T = 60C^{\circ}$$

$$T = 360C^{\circ}$$

$$Q_{in} = Q_{out}$$

$$Q_{out} = m C_p \Delta T$$

8075 kg	2.01 KJ	(360-60)C [°]
day	Kg. C [°]	

$$= 2.02 * 10^5 \text{ KJ/hr.}$$

$$Q_{in} + x = Q_{out}$$

$$2.4 * 10^4 \text{ KJ/hr.} + x = 2.02 * 10^5 \text{ KJ/hr.}$$

$$X = 1.78 * 10^5 \text{ KJ/hr.}$$

This amount of energy is given to achieve product.

Chapter: 4

Equipment Design

Reactor Design

Mass Flow Rate Of Material = 417 Kg/hr

Density Of Material = 950 Kg/m³

Time = 1 Hr

Volume = $417/950 = 0.438 \text{ m}^3 * 2 = 0.876 \text{ m}^3$

Capacity = flow rate * time = 417kg

L/D = 3 (By Jhones M.Douglas)

D = 0.71 m

L = 2.15 m

Reactor Pressure = 1 atm

Reactor Temperature = 450 c

Material Of Construction = Carbon Steel

Allowable Stress = 60 psi = 410 Kpa

Cylindrical Design Section

Taking the design pressure 50% above operating pressure

Design Pressure = $410 * 1.1 = 450 \text{ Kpa}$

Pressure Due To Head = Pgh

= $950 * 9.8 * 2.15 = 9.26 \text{ kpa}$

Total pressure = $450 + 9.26 = 460 \text{ kpa}$

Thickness of cylinder = $t = \frac{PiDi}{2SJ - 1.2Pi}$ (coulson vol 6)

J (weld joint efficiency) = 1

S = material of construction = carbon steel = Allowable Stress = 95121kpa

$t = \frac{450 * .71}{(2 * 95121 - 1.2 * 450)} = .00168 \text{ m}$

= 1.68mm

Corrosion allowance = $1.68 + 3 = 4.68\text{mm}$

Head thickness

$$t = \frac{P_i D_i}{2 S J - 1.2 P_i}$$

$$= \frac{460 \times .71}{(2 \times 95121 - 1.2 \times 460)}$$

$$= 1.72 \text{ mm}$$

$$\text{Corrosion allowance} = 1.75 + 3 = 4.72 \text{ mm [46]}$$

Kiln model we used according to our feed is 350 TPD Kiln reactor

$$\text{Angle of inclination} = \Theta = 1.43^\circ$$

Kiln inclined angle = 2.5 % of its length

$$\text{Kiln RPM} = 0.356 \text{ rpm}$$

Specification Sheet

Capacity	417kg
Volume	.876m ³
diameter	0.71m
Length	2.15m
Pressure	1 atm
Material of construction	Carbon steel
Allow able stress	95121kpa
Shell thickness	4.68mm
Head thickness	4.72mm
Angle of inclination(Θ)	1.43°
Kiln RPM	0.356rpm
Reactor Temperature	450 °c
Resident time	1 hr

4.1 Designing Of Heat Exchanger

Specification Sheet

Identification

Item: Heat Exchanger

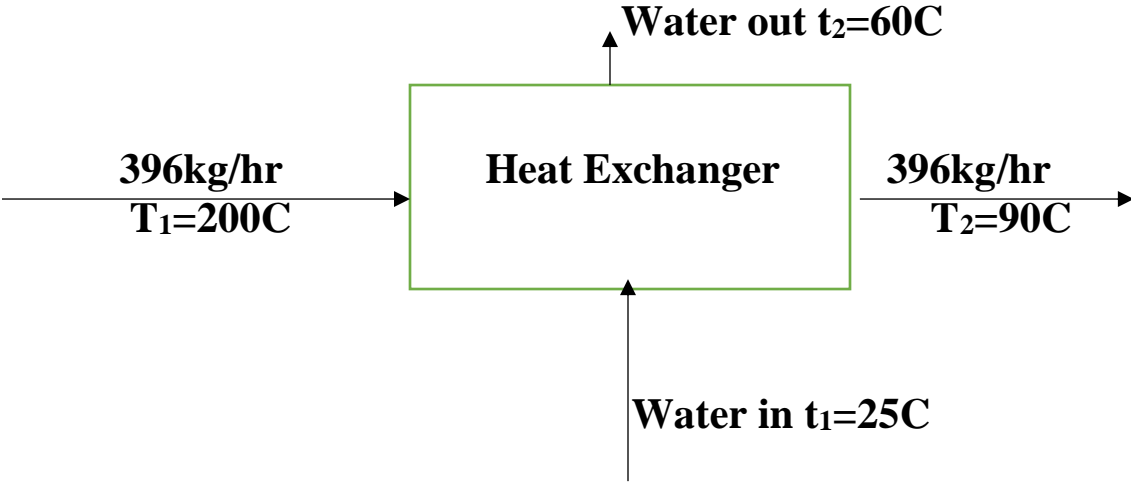
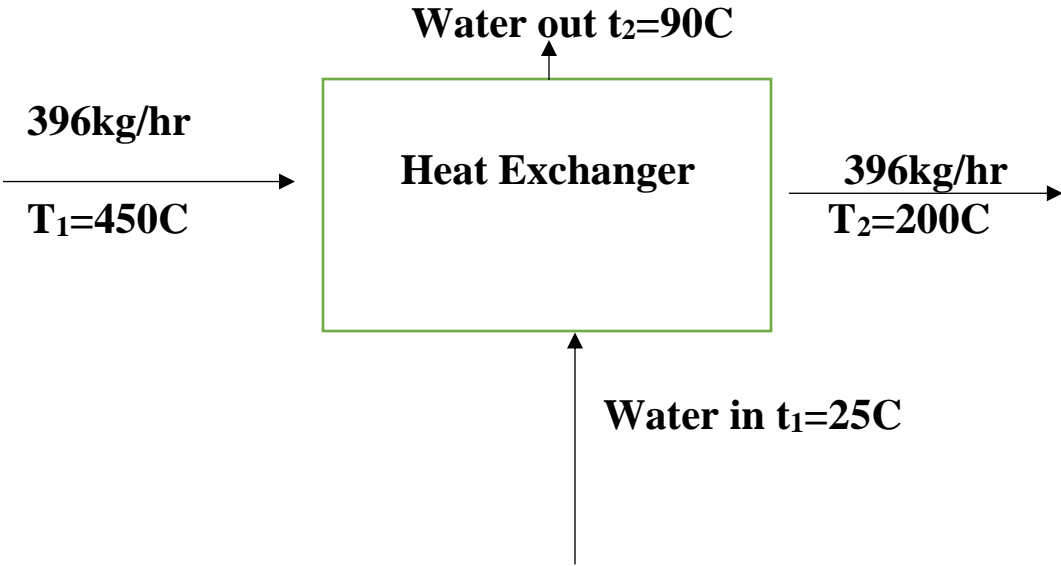
Type: Shell and tube

Area= 21m²

Calculated R,S,F_t for corrected temperature

Tube side	Shell side
Organics	cooling. tower. Water
flow rate= 396kg/hr	Flow rate= 616 kg/hr
Temp= 450C-200C	Temp 25C-90C
OD=19.05x 10 ⁻³ m BWG=14,224 tubes 23.81x10 ⁻³ Triangular Pitch L=5m	shell inside Dia=0.471m, No of baffles=45
Material. used. = Plain C steel	Material. used= Plain C steel
Pressure drop = 1.2 psi	Pressure Drop= 9.6 psi
Tube. Sheet thickness=0.00969 m	Shell. thickness. =6.52x10 ⁻⁴ m

Block Diagram



Designing:

Heat exchanger is a apparatus build for well-organized heat from one medium to another, the media are divided by a solid wall, or the medium are in straight contact. They are extensively used in petroleum refrigeration, petrochemical, power plants, chemical plants, air conditioning and processing. General example of a heat exchanger is the radiator in a car., in which a hot engine-cooling fluid, like antifreeze, transport heat to air curving through the radiator.

Step 1:

For process stream duty or heat transfer rate

$$q = m C_p \Delta T$$
$$q = 396 \times 2.05 \times (200 - 90)$$

$$q = 8.92 \times 10^4 \text{ KJ/hr}$$

For water process steam

$$q = m C_p \Delta T$$
$$8.92 \times 10^4 = m \times 4.18 \times (60 - 25)$$

$$M = 610.6 \text{ kg/hr}$$

Step 2:

Physical Properties Of Process stream

Properties	INLET	MEAN	OUTLET	UNITS
Temperature	200	145	90	⁰ C
Specific heat (C _p)		2.05		KJ/Kg ⁰ C
Thermal conductivity (k)		0.044		W/m K
Density (□)		950		Kg/m ³
Viscosity		8.87 x10-4		kgm-1s-1

For Water

Properties	INLET	MEAN	OUTLET	UNITS
Temperature	25	42.5	60	C
Specific heat (C _p)		4.18		KJ/Kg C
Thermal conductivity (k)		0.6154		W/m K
Density (□)		998		Kg/m ³

Viscosity (μ)

1.028×10^{-3}

$\text{Kg m}^{-1}\text{s}^{-1}$

Step 3:

For system of water & light organics, the value of U_o lies in the range of 375-750W/m² K, so assume,

$$U_o = 650 \text{ W/m}^2 \text{ K}$$

Step 4:

Usually an even number of tube passes the preferred arrangement

For 1 shell and 2 tube passes

L.M.T.D

$$\text{L.M.T.D.} = [(T_1 - t_2) - (T_2 - t_1)] / \ln[(T_1 - t_2) / (T_2 - t_1)]$$

$$\begin{aligned} \text{LMTD} &= [(200-60) - (90-25)] / \ln[(200-60) / (90-25)] \\ &= 97.7 \text{ C}^0 \end{aligned}$$

R, S & F_t

$$\begin{aligned} R &= (T_1 - T_2) / (t_2 - t_1) \\ &= (200 - 90) / (60 - 25) \\ &= 3.14 \end{aligned}$$

$$\begin{aligned} S &= (t_2 - t_1) / (T_1 - t_1) \\ &= (60 - 25) / (200 - 25) \\ &= 0.2 \end{aligned}$$

From Fig 12.19 (Coulson 6) Temp correction factor

$$F_t = 0.9$$

Corrected L M T D

$$\begin{aligned} \text{Corrected LMTD} &= T_m = F_t * \text{LMTD calc} \\ &= 0.9 * 97.7 \\ &= 87.93 \text{ C}^0 \end{aligned}$$

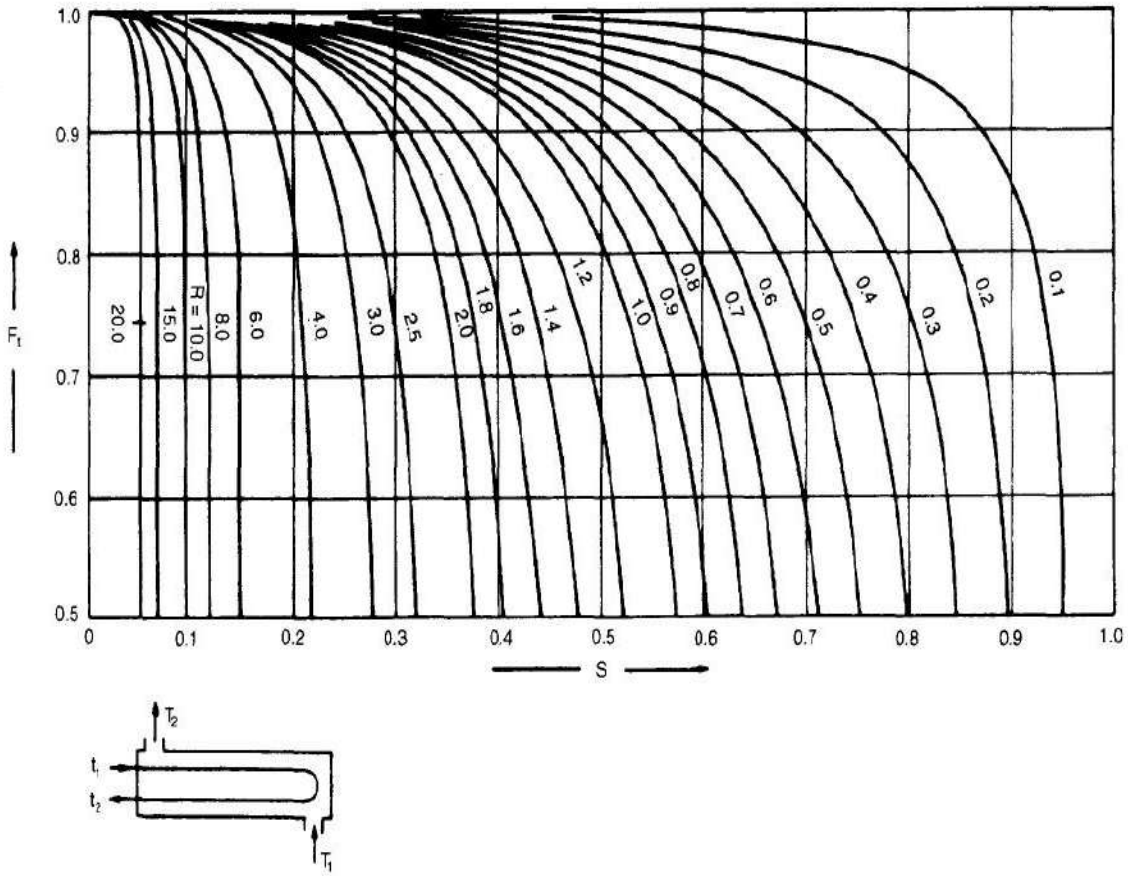


Figure 9: LMTD table

Step 5:

Heat Transfer Area:

$$Q = U_0 A_0 \Delta T_m$$

$$A_o = Q / U_o \Delta T_m$$

$$A_o = 8.92 \times 10^4 / 500 \times 97.7$$

$$A_o = 21 \text{ m}^2$$

Tubes Layout

ODt = 1 in from TEMA std (AES) type

Corresponding to BWG= 14

Tube ID $t = 14.83 \times 10^{-3} \text{m}$

Tube OD = $19.05 \times 10^{-3} \text{m}$

Tube thickness = 0.002m

Length of tube = 5 m

Baffle spacing.=.6

Shell diameter = 25% cut segmental

Fouling film. coefficient = .000176 $\text{vm}^2\text{K/W}$

Step. 6

$$\begin{aligned}A_t &= (\text{area of one tube}) = \Delta d_o L \\ &= 3.14 \times 19.05 \times 10^{-3} \times 5 \\ &= 0.299\text{m}^2\end{aligned}$$

No. of tubes = provisional area /area of 1 tube

$$\text{Number. of tubes} = 21 / 0.299 = 70$$

Tubes to. nearest count = 70

$$\text{Tubes / pass} = 70/2 = 35$$

Step.7

$$\begin{aligned}\text{Tube cross sectional area} &= \Delta / 4 (d_i^2) \\ &= \Delta / 4 \times (14.83 \times 10^{-3})^2 \\ &= 1.72 \times 10^{-4} \text{m}^2\end{aligned}$$

$$\text{Tubes per pass} = 70/2 = 35$$

$$\begin{aligned}\text{Total flow area} &= 1.72 \times 10^{-4} * 35 \\ &= 0.00602 \text{ m}^2\end{aligned}$$

Mass. Velocity:

$$\begin{aligned}G_t &= m * a_t \\ &= 396 * .00602 \\ &= 1.82 \text{ kg/sec. m}^2\end{aligned}$$

Linear Velocity:

$$\begin{aligned}U_t &= G_t / \rho \\ &= 1.82 / 950\end{aligned}$$

$$U_t = 0.0019 \text{ m/sec } (< 4 \text{ m/sec } \text{ acceptable})$$

Step 8:

Tube Bundle and Shell Dia

From table 12.4 for 2 tube passes and triangular pitch (Coulson 6)

$$K_1 = 0.249 \qquad n_1 = 2.207$$

$$D_b = d_o (N_t / K_1)^{1/n_1}$$

$$= 19.05 \times 10^{-3} (224 / 0.249)^{1/2.207}$$

Tube bundle dia $D_b = 0.415$

For a split ring floating head exchanger the typical shell clearance from (fig 12.10 coulson 6)

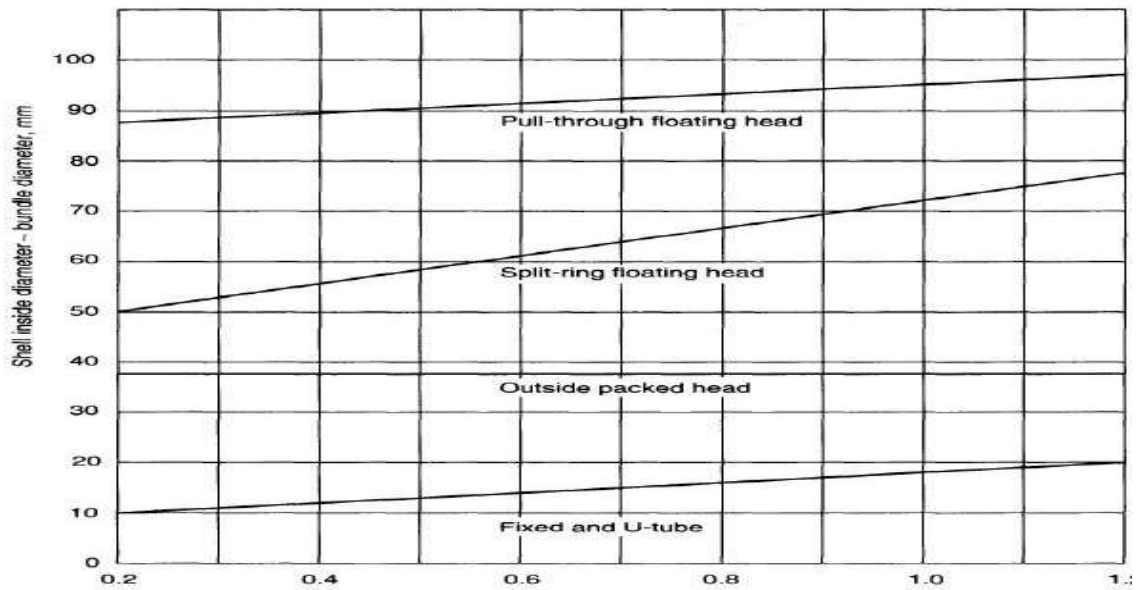
$$\text{Shell clearance} = 56 \times 10^{-3} \text{ m}$$

So,

$$D_s = \text{Shell Inside Dia} = 0.415 + 56 \times 10^{-3} = 0.471 \text{ m}$$

Table:9 Constants [41]

Triangular pitch, $p_t = 1.25d_o$					
No. passes	1	2	4	6	8
K_1	0.319	0.249	0.175	0.0743	0.0365
n_1	2.142	2.207	2.285	2.499	2.675
Square pitch, $p_t = 1.25d_o$					
No. passes	1	2	4	6	8
K_1	0.215	0.156	0.158	0.0402	0.0331
n_1	2.207	2.291	2.263	2.617	2.643



Step 9 :

Reynold Number:

$$R_e = G_t \times d_i / \mu$$

$$R_e = 1.82 \times 14.83 \times 10^{-3} / 6.31 \times 10^{-4}$$

$$R_e = 52.7$$

Prandtl Number:

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

$$= (2050 \times 8.87 \times 10^{-4} / 0.044)^{1/3}$$

$$P_r = 3.45$$

Now :-

$$L/d_i = 5 / 14.83 \times 10^{-3}$$

$$= 337$$

Using L/d_i , the corresponding JH value from.

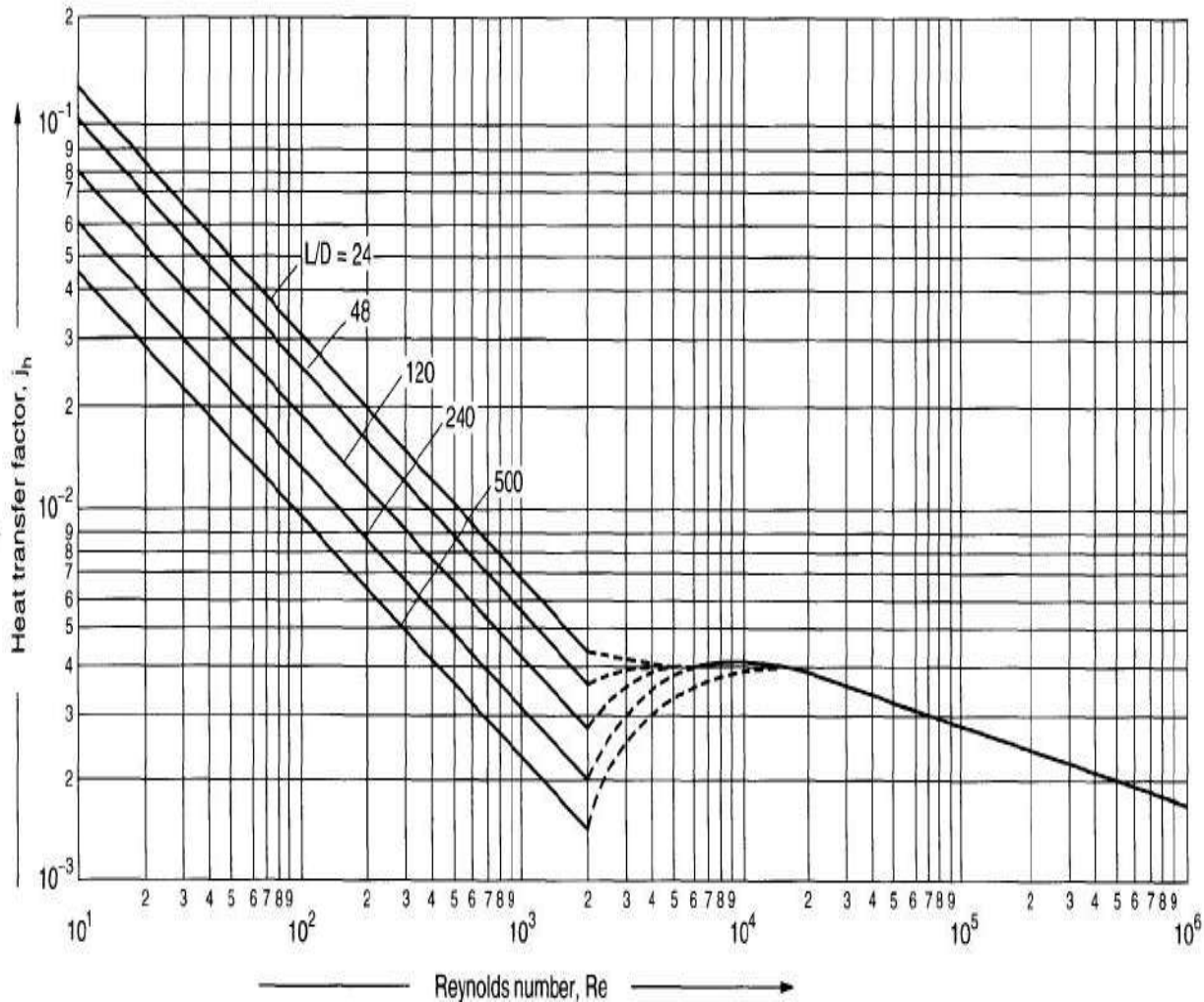
Fig 12.23 (Coulson. - vol 6) is

$$j_H = 3.5 \times 10^{-3}$$

$$h_i = J_H R_e P_r (k / d_o)$$

$$= 3.5 \times 10^{-3} \times 52.7 \times 3.45 \times (0.044 / 19.05 \times 10^{-3})$$

$$h_i = 146 \text{ W/m}^2 \text{ K}$$



Shell Side Heat. Transfer Coefficient

(D_s) = inside. dia of shell = 0.471m

Range of baffle spacing is $D_s/5$ to D_s/D_s

Assume take a baffle spacing = 94.2×10^{-3} m

This baffle spacing gives good heat transfer without. too much high- pressure drop.

A_s = cross flow. area = $(P_t - d_o / P_t) \times D_s \times$ Baffle spacing

$$= (23.81 \times 10^{-3} - 19.05 \times 10^{-3} / 23.81 \times 10^{-3}) \times 0.471 \times 94.2 \times 10^{-3}$$

$$A_s = 0.0103 \text{m}^2$$

Shell Side. Equivalent. Dia

$$d_e = 1.1 / d_o (p_t^2 - 0.917 d_o^2)$$

$$= 1.1 / 19.05 \times 10^{-3} ((23.81 \times 10^{-3})^2 - 0.917 \times (19.05 \times 10^{-3})^2)$$

$$d_e = 0.01352 \text{m}$$

$$\begin{aligned} \text{Mass velocity on shell side} &= m / A_s \\ &= 615.2 / 0.0103 \\ &= 31.11 \text{ kg /sec.m}^2 \end{aligned}$$

$$\begin{aligned} U_s = \text{shell -side velocity} &= \text{mass velocity} / \text{density} \\ &= 33.66 / 998 \\ U_s &= .0337 \text{ m/sec} \end{aligned}$$

Reynolds. No

$$\begin{aligned} Re &= G_s \times d_{e \text{ shell}} / \mu \\ &= 33.66 \times 0.01352 / 1.028 \times 10^{-3} \\ &= 46,238 \end{aligned}$$

Prandtl. No

$$\begin{aligned} Pr &= (C_p \mu / k)^{1/3} \\ &= (4180 \times 1.028 \times 10^{-3} / 0.6912)^{1/3} \\ &= 1.838 \end{aligned}$$

Use 25% Cut Segmental Baffles

From. Fig 12.29 Coulson 6

$$\begin{aligned} J_H &= 7.8 \times 10^{-1} \\ h_o &= j_H \times Re \times Pr \times (k/d_e) \\ &= 7.8 \times 10^{-1} \times 46,238 \times 1.838 \times (0.6912 / 0.01352) \\ \mathbf{h_o} &= \mathbf{3169.10 \text{ W/m}^2 \text{ K}} \end{aligned}$$

Overall. Coefficient

$$1/U_o = (1/h_i + 1/h_{io}) d_o/d_i + d_o \ln d_o/d_i / 2k_w + 1/h_o + 1/h_{od}$$

U_o = the overall coefficient based. on the. outside. area of the tube , $\text{W/m}^2 \text{ K}$

h_o = outside fluid. film coefficient, $\text{W/m}^2 \text{ K}$.

h_i = inside. fluid film coefficient, $\text{W/m}^2 \text{ K}$

h_{od} = outside dirt. coefficient (fouling factor) , $\text{W/m}^2 \text{ K}$

h_{id} = inside dirt coefficient, $\text{W/m}^2 \text{ K}$

k_w = thermal. conductivity of the tube wall material, , W/m K

d_i = tube inside diameter, m,

d_o = tube outside diameter, m

$$1/U_o = (1/2590 + 0.0002) 19.05 \times 10^{-3} / 14.83 \times 10^{-3} + 19.05 \times 10^{-3} \ln 19.05 \times 10^{-3} / 14.83 \times 10^{-3} / 2 \times 45 + 1/3169.107 + 0.00035$$

$$1/U_o = 7.5 \times 10^{-4} + 5.3 \times 10^{-5} + 1.14 \times 10^{-4} + 0.00035$$

$$U_o = 514.00 \text{ W/m}^2 \text{ K}$$

Step 10

Pressure Drop

Tube Side. Pressure. Drop-

For $Re = 52.7$

$$J_f = 3.2 \times 10^{-3} \quad (\text{from Fig 12.24 coulson 6})$$

No. of passes = $(N_p) = 2$

Pressure drop for the tube side is given by

$$\begin{aligned} \Delta P_t &= N_p [8j_f (L/d_i) (\mu/\mu_w)^{0.14} + 2.5] P u_t^2 / 2 \quad \text{neglecting } (G/G_w)^{0.14} \\ &= 2[8 \times 3.2 \times 10^{-3} (5/14.83 \times 10^{-3}) + 2.5] 800.4 \times (2.06)^2 / 2 \end{aligned}$$

$$\Delta P_t = 8.724 \text{ KPa} = 1.2 \text{ psi}$$

Allowable. pressure drop = $\Delta P_T = 10 \text{ psi}$

Hence, the tube-side pressure drop is satisfactory for service

Shell Side Pressure Drop

The formula for pressure drop on shell side is

$$\begin{aligned} \Delta P_s &= 8 \times J_f (D_s / d_e) (L/I_B) (G u_s^2 / 2) (G / G_w)^{0.14} \\ &\quad \text{for } Re = 46,282 \end{aligned}$$

Fanning friction factor (from Fig 12.30 coulson 6)

$$j_f = 4.5 \times 10^{-2}$$

Where L = length of tube

I_B = Baffle spacing [Neglecting $(G/G_w)^{0.14}$]

$$\begin{aligned} \Delta P_s &= 8 \times 4.5 \times 10^{-2} \times (0.471/0.01352) (5/94.2 \times 10^{-3}) \times 445 \times (2.2)^2 / 2 \\ 67.9 \text{ KPa} &= 9.6 \text{ psi} \end{aligned} \quad \Delta P_s =$$

Allowable pressure drop = $\Delta P_T = 10 \text{ psi}$

Hence, the tube-side pressure drop is satisfactory for service.

Designing Of Storage Tank

Flow rate of diesel oil = 343.7kg/hr

Storage time = 1 week

Capacity = flow rate * time = $343.7 * 7 * 24 = 57750\text{kg}$

Volume = capacity / density

Density = 959kg/m^3

$V = 57750\text{kg} / 959\text{kg/m}^3 = 60.2\text{m}^3$

Maximum operating volume will be 90%

Maximum operating volume = $90\% * 60.2 = 54.2\text{m}^3$

We assume that

$L/D = 0.8$

$V = \pi D^2 / 4 * L$

$D = 4.57\text{m}$

$L = 3.66\text{m}$

Material of construction = carbon steel

allow able stress $S = 88.94\text{N/mm}$

Pressure = 1 atm

Design temperature = 30°c

J(weld joint efficiency) = 1

Taking the design pressure 50% above operating pressure

$$= 0.101325\text{N/mm}^2$$

Cylindrical thickness = $t = P_i D_i / 2SJ - 1.2P_i$

$$T = 0.151987 * 4.57 / (2 * 1 * 88.94) - (1.2 * 0.151987) = 3.96$$

Corrosion allowance = 3mm

Total thickness = $3.96 + 3 = 7\text{mm}$

Head thickness:

$t = P_i D_i / 2SJ - 0.2P_i$

$t = 0.151987 * 4.57 / (2 * 88.94 * 1) - (0.2 * 0.151987) = 3.9\text{mm}$

Corrosion allowance = 3mm

Total thickness = 6.9mm

Specification Sheet

Capacity	57750kg
Volume	60.2m ³
diameter	4.57m
Length	3.66m
Pressure	1 atm
Material of construction	Carbon steel
Allow able stress	88.94N/mm
Shell thickness	7mm
Head thickness	6.9mm
Support type	Skirt support

Chapter: 5

Instrumentation

5.1 Instrumentation and control

A control system is able to, commands, directs, or regulates the behavior of devices or systems using control loops. It can choice of variety single home heating controller using a thermostat controlling a domestic boiler to large Industrial control systems which are used for controlling processes or machines. An instrumentation control system is an electrical, electronic system which may perform some or all of the following functions: [48]

- Monitoring, recording and classification of plants station and process parameters.
- Providing of operator information about the plant station and process parameters.
- Providing of operator controls to affect changes to the plant station.
- These functions are normally provided by, alarm, protection (trip, interlocks and emergency shutdown), and process control systems [48].

These engineered systems are exclusively and collectively described as control systems, and may be independent, or elements such as the human crossing point, plant boundary, logic, utilities, and environment and management systems [48].

5.1.1 Instrumentation and Control Objective

These following are objective of instrumentation and control system.

To decrease the effect of external disturbance.

To ensure stability.

To achieve optimization [48].

5.2 Hardware Elements of control system

In every control system we can distinguish the following hardware elements [49].

- Primary element/sensor

- Transducer
- Converter
- Transmitter
- Signal
- Indicator
- Recorder
- Controller
- Correcting element/final control element
- Actuator

5.2.1 Primary Element/Sensors

Sensors are the first element in the control system which measures the change in the process and reporting the process variable so they are also called as the primary element. Sensors are devices which cause alteration when affected by a change in the process variable. There are many types of sensors for measuring variables like Pressure, Temperature, Flow, Level, pH, Vibration etc. [49].

There are different types of sensors available for various process variable: [49]

- Thermocouples, RTD for Temperature measurement.
- Strain gauge, Pressure sensing diaphragm, capacitive cells for pressure measurement.
- Orifice plate, Pitot tube, Magnetic flow tube etc., for flow measurement.

There are so many other sensors used to measure many variables like vibration, pH, force, weight etc. [49].

5.2.2 Transducers:

A transducer converts any form of energy into another form. In electrical instrumentation field Transducers are devices which converts a physical variable into electrical signals. In process control, a converter used to convert current signal into pneumatic signal is called a current-to- pressure converter [49].

5.2.3 Transmitters:

Transmitters are devices that conversion the signal into a standard signal that can be transmittable

through the control loop and the parameters can be checked at all [49].

- Pressure transmitters
- Flow transmitters
- Temperature transmitters
- Level transmitters

5.2.4 Signals:

Signals are used to transfer process variable from transmitter to the controller and sent back the feedback signal from the controller to the final control elements. There are three types of signal in industries [49].

- **Pneumatic signal:** Air pressure in the pneumatic pipeline adjustment according to the change in the process variable. The standard pneumatic pressure in the signal pipe in industries are in a range of 3-15psi [49].
- **Analog signal:** Analog signals are mostly used control signals, the transmitter sends the signal through a set of electrical wire [49].
- **Digital signal:** Digital signals are special protocols used for communication in industries [49].

5.2.5 Indicators:

An indicator is human understandable devices that show the process variable. There are analog indicators such as used in pressure, temperature gauges and there are digital indicators that display process variables as the digits [49].

5.2.6 Recorder:

Recorders are used in industries to provide history on the process and to be submitted to regulatory agencies for verification. By recording the readings of critical measurement points and comparing those readings over time with the results of the process, the process can be improved [49].

5.2.7 Controllers:

Controllers are the center of process control, which receives process variable then compare with set point stored in the controller and sends a feedback as the controller output to control the final control element. There are pneumatic and electronic or programmable [49].

PLC (Programmable Logic Controller): PLCs are usually computers connected to a set of input/output (I/O) devices. The computers are programmed to respond to inputs by sending outputs to maintain all processes at set point [49].

DCS (Distributed Control Signal): DCSs are controllers that, in addition to performing control functions, provide readings of the status of the process [49].

5.2.8 Final control element:

Final control elements are the correcting elements that receives signal from the controller and make a change in process to regulate the process variable at the desired parameter. Many of the technological developments in final control elements are related to improving their response time [49].

5.2.9 Actuator:

An actuator is the essential part of the final control element, a device that causes physical change in the final control element. For a valve actuator is the valve steam actuator and for a heater, it is the heating coil. It can be controlled by pneumatically, Hydraulically, Electrically [49].

5.3 Control System Configuration:

Control system configuration is a general term that includes many types of control systems and related to instrumentation used for industrial process control. Such systems can range in size from a limited modular panel-mounted controllers to large interrelated and interactive distributed control systems with various thousands of field connections. Systems take delivery of data expected from remote sensors measuring process variables , equate the collected data with desired set points , and develop command functions which are used to control a process through the final control elements , such as control valves.

Many systems are commonly applied by supervisory control and data acquisition (SCADA) systems, or distributed control systems (DCS), and programmable logic controllers (PLCs), though SCADA and PLC systems are scalable down to minor systems with limited control loops. Such systems are extensively used in industries such as chemical processing, paper manufacture, power generation, oil and gas processing [50].

5.3.1 Distributed Control System (DCS):

A distributed control system (DCS) is a digital processor control system for a process or plant, where in controller operations and field connection modules are distributed all over the system. As the number of control loops grows, DCS becomes less cost than discrete controllers. Moreover a DCS delivers guiding and management over large industrial processes. In a DCS, a hierarchy of controllers is connected by communication networks .A DCS allows easy configuration of plant controls such as cascaded loops and interconnects and easy interfacing with other computer systems such as production control .A DCS usually uses custom-designed processors as controllers, and uses either proprietary interconnections or regular protocols for communication. The processors take information from input modules, process the information and select control actions to be performed by the output modules. The input modules take information from sensing instruments in the process (or field) and the output modules transfer information to the final control elements, such as control valves [50].

5.3.2 Supervisory Control and Data Acquisition (SCADA):

Supervisory control and data acquisition (SCADA) is a control system that uses computers, networked data public services and graphical user interfaces for high-level process guiding management. The operator operates that enable checking and the issuing of process commands, such as controller set point variations, are handled through the SCADA supervisory computer system. Though, the real-time control logic or controller calculations are made by networked modules which connect to other peripheral devices such as programmable logic controllers. The SCADA concept was industrialized as a universal means of remote access to a variety of local control modules, which could be from different manufacturers allowing access through standard automation procedures. In practice, large SCADA systems have grownup to become very analogous to distributed control systems in function, but using multiple means of interfacing with the plant. They can control large-scale processes that can include many sites, and work over wide distances. The SCADA software works on a supervisory level as control actions are made automatically by RTUs or PLCs. SCADA control functions are usually limited to basic overriding or supervisory level involvement. A response of control loop is directly controlled by the RTU or PLC, but the SCADA software observes the overall performance of the loop. The SCADA also enables alarm conditions, such as loss of flow or less temperature, to be exposed and recorded [50].

5.3.3 Programmable logic Controller

PLCs can range from small integrated devices with tens of inputs and outputs (I/O) in a housing central with the processor, to large rack-mounted integrated devices with a count of thousands of I/O, and which are frequently networked to other PLC and SCADA systems. They can be planned for multiple arrangements of digital and similar inputs and outputs, long temperature ranges, exception to electrical noise, and resistance to vibration and influence. Programs to control machine process are usually stored in battery-backed-up or non-volatile memory [50].

5.4 Temperature Measurement and Control

Temperature estimation is utilized to control the temperature of outlet and channel streams in warmth exchangers. Reactors, and so forth. Most temperature estimations in the business are made by methods for thermo-couples to encourage conveying the estimations to concentrated area [51].

For region estimations at the hardware bi-metallic. Or filled framework thermometers are utilized to a lesser degree. For the most part, for high estimation precision, resistance thermometers are utilized [51].

Every one of these meters are introduced with thermo-wells. When utilized locally. This gives assurance against climate and other physical components. Typically the control circles, which are utilized to control. The controlled factors, are input controllers. Just 10% of aggregate controllers are forward controllers [51].

5.5 Weight Measurement and Control

Like temperature weight is a profitable sign of material and arrangement. Truth be told, these are two estimations. Considered together are the essential assessing gadgets of modern materials [51].

Pumps, compressor and different process hardware. Related with weight changes in the process material are outfitted with weight measuring gadgets. In this way weight estimation turns into a sign of vitality increment or reduction [51].

Most weight estimation in industry is versatile component gadgets, either straightforwardly associated for nearby utilize or transmission. Sort to bring together area. Most widely utilized modern weight component is the Bourdon Tube or a Diaphragm or Bellows gages [51].

5.6 Stream Measurement and Control

Stream pointer controllers are utilized to control the measure of fluid. Likewise, all physically set streams. Require some stream sign or some simple means for infrequent example estimation. For book keeping purposes, nourish and item stream are metered [52].

Furthermore, uses to individual and assembled gear are additionally metered. Most stream measures

in the business are by factor head gadgets. To a lesser degree variable territory is utilized, like the numerous accessible sorts as extraordinary metering circumstance emerge [52].

5.7 Control Scheme of Temperature Control

Here we measure the outlet temperature of unrefined petroleum at the exit of heater. And this is utilized to controlled the stream rate of fuel sustain by utilizing fuel bolster controller. A temperature sensor measures the temperature of the outlet raw petroleum. And exchange flag to temperature transducer, transducer change over signs in other shape and the yield of transducer is acknowledged by controller and controller exchange. Its flag to definite control component. Last control component makes move to defeat these aggravations [52].

5.8 Damper Control

Damper is utilized to control the stream rate of the pipe gasses in stack. Really stream rate of the pipe gasses. Manage that how speed and turbulence is given to leave pipe gasses to have the greater part of the warmth assimilated in the brilliant and convection area. Damper controller sends signs and I/P convertor changes over it into pneumatic signs which additionally continue to and the pneumatic situated controls and controls the damper development to control stream rate of vent gasses [53].

5.9 Burner Safety Control

Burner security control really is far reaching control. To have general heater control more compelling. Burner security control picks up the signs from low fuel weight constrain switch. And furthermore, fire sensor gives size and temperature of fire and all factors are computed. And thought about in wellbeing control and an impelling sign is sent to solenoid valves to control channel fuel/wind stream rate [53].

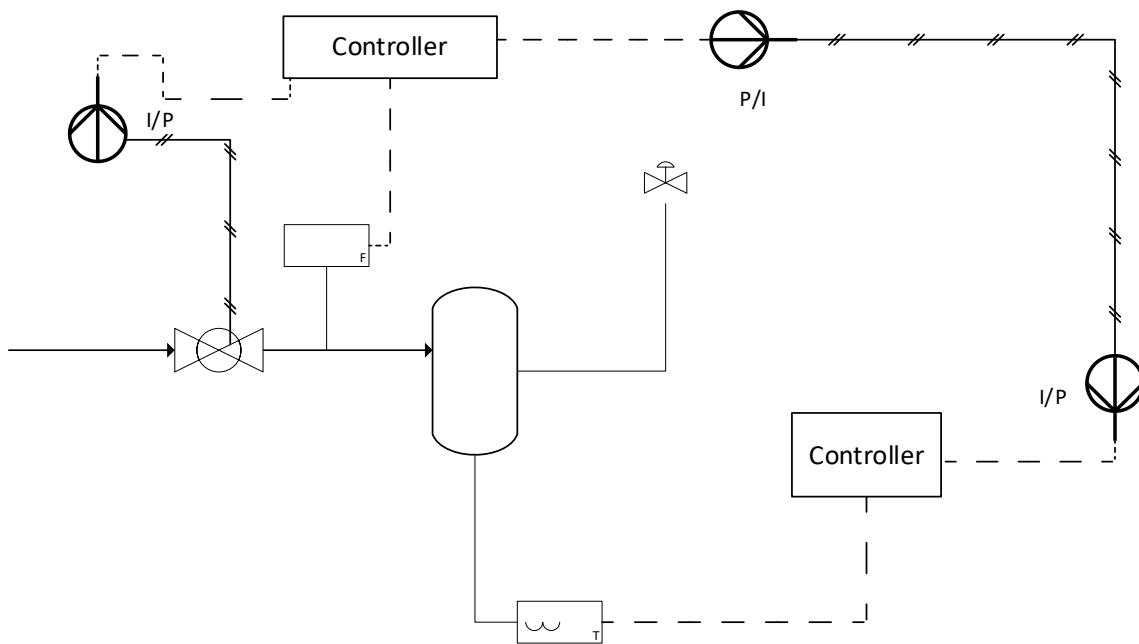
5.10 Cautions and Safety Trips, Interlock

Warnings are utilized to ready administrators of genuine. And possibly dangerous, deviations in process conditions. Key instrument is fitted with changes and transfers to work capable of being heard and visual cautions. On the control boards and enunciator boards. Where deferral or absen of reaction, by the administrator is probably going to prompt the fast improvement of an unsafe circumstance, the instrument would be fitted with a trek framework to make a move naturally to turn away the risk, for example, closing pumps shutting valves. Working crisis frameworks [53].

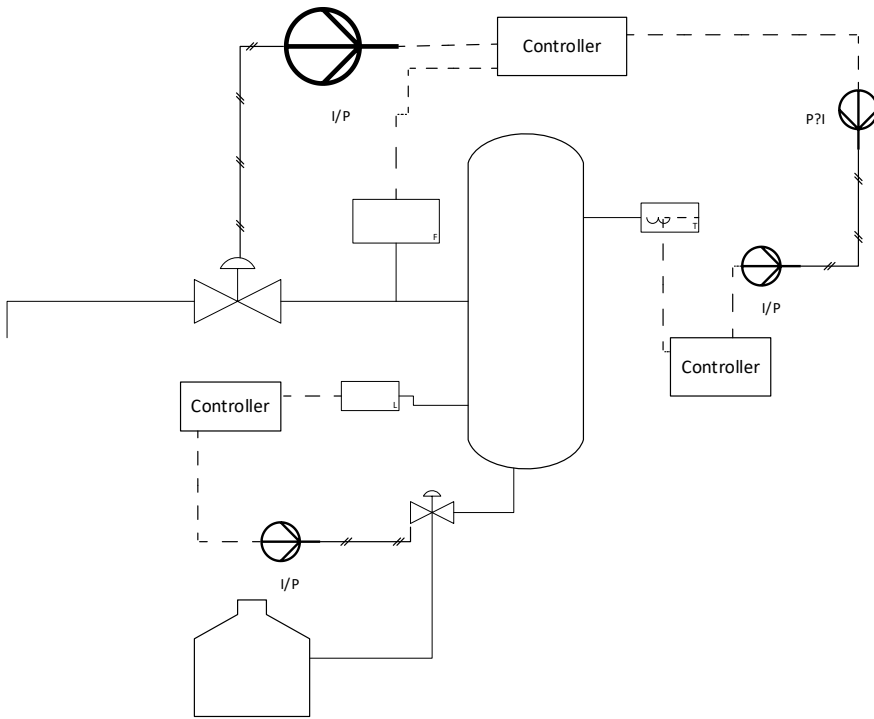
- A sensor to screen the control variable and give as yield signs when a preset esteem is exceeded (the instrument).

- A connect to exchange the flag to the actuator, as a rule comprising of an arrangement of pneumatic or electric postponements.
- An actuator to complete the required activity, close or open valve, turn off an engine [53].

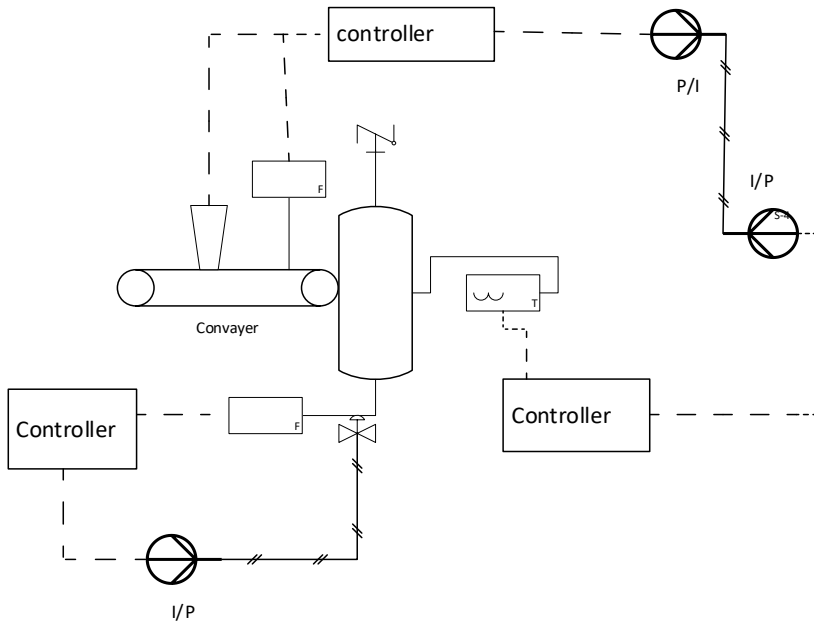
Instrumentation of Condenser



Instrumentation of Distillation Column



Instrumentation of Reactor



Chapter: 6

Cost Estimation

6.1 Cost Estimation

A satisfactory plant configuration must present a procedure that can work under conditions which will yield a profit. Since, Net benefit add up to pay all costs

It is basic that compound designer knows about a wide range of sorts of cost required in assembling forms. Capital must be distributed for direct plant costs, for example, those for crude materials, work, and gear. Other than direct costs, numerous other roundabout costs are brought about, and these must be incorporated if an entire examination of the aggregate cost is to be acquired. A few cases of these aberrant costs are authoritative pay rates, item dissemination expenses and cost for interplant correspondence.

Prior to the plant to be worked, determined cash must be provided to buy and introduce the gear. The capital expected to supply the fundamental plant offices is called settled capital speculation while that for the operation of the plant is known as the working central and entirety of two capitals is called add up to capital venture.

Cost Indexes:

The prices of equipment change noticeably by the time. Prices may change considerably with time due to changes in economic conditions. An index value for the cost of an equipment as compared to the cost index of the equipment at base time is basically the cost index.

$$\text{Present cost} = \frac{\text{Original Cost} \times \text{Index value at present time}}{\text{Index value at time original cost was obtained}}$$

Cost of Distillation Column:

Construction material = (CS) Carbon Steel

Distillation Column height = 14 meter

Form Appendix F Figure F-4

Bare cost= 10000 \$

Equipment Purchased cost = Bare cost x Material factor x Pressure factor

Material factor (C.S) = 1.0

Pressure factor (1-5 bar)= 1.0

Cost of Reaction vessel = 10,000 * 1.0 * 1.0

Cost of reaction vessel in 2004= Ce = 10,000 \$

Plate type = Sieve plate

Cost per plate = 700 \$ x Material Factor

Plate material = C.S

Material factor= 1

Cost per plate= 700 \$

Number of plates= 36

Total Cost of plates= 36 x 700

Total Cost of plates= 25,200 \$

From Appendix F Figure F-4

In 2004 Total Cost of equipment (Ce) = Cost of Column + Cost of plates

Total Cost (Ce)= 10000 + 18,900

= 28900 \$

2004 Cost Index = 509.2

2021 Cost Index = 701

Equipment Cost in 2021 = Ce (*Cost Index 2021 / Cost Index 2004*)

Equipment Cost in 2021 = 34680 \$

Cost of Heat Exchanger:

Area = 21 m²

Construction Material = Carbon Steel

From Appendix F Figure F-5

In 2004 Exchanger Cost = 100000 \$

Pressure Factor (1-10 bar) = 1.3

Type Factor Floating head = 1

In 2004 Equipment Cost = 100000 \$ x Pressure Factor x Type Factor

In 2004 Equipment Cost = 130000 \$

2004 Cost Index = 509.2

2021 Cost Index = 701

Equipment Cost in 2021 = C_e (*Cost Index 2021 / Cost Index 2004*)

Equipment Cost in 2021 = 161200 \$

Equipment	Cost GBP (£)
Storage tank	33208
Heat exchanger	27000
Reactor	34756
Pump	8000
Total	102964

Direct Cost:

Sr No	Description	Cost (£)
01	Purchased equipment cost, E	102964
02	Purchase equipment installation@39% of E	40155.96
03	Instrumentation and process control@13% of E	13385.32
04	Piping installation @ 31% of E	31918.84
05	Electrical installation @10% of E	10296.4
06	Building including services @29% of E	29859.56
07	Yard improvement @ 10% of E	10296.4
08	Service facilities installed@55% of E	56630.2
09	Land @6% of E	6177.84
	Total	301684.52

Indirect Cost:

Engineering & supervision @ 32% of E = 32948.48

Construction expenses @ 34% of E = 35007.76

Contractor's fee @ 18% of E = 18553.52

Contingency @ 36% of E = 37067.4

TOTAL = 123553.28 GBP

Fixed Capital Investment

FCI = Direct Cost + Indirect Cost

FCI = 425237.8 GBP

Working Capital Investment

WCI = 15% FCI

WCI = 63785 GBP

Total Capital Investment

Total Capital Investment = WCI + FCI

= 489023 GBP

Total Capital Investment = 489023 GBP

Manufacturing Cost = Overhead Cost + Direct Production Cost

= 722898 GBP

General Cost = Administrative cost + distribution and selling cost + research and development

General cost = 237170 GBP

Gross Earning Income:

. Diesel Oil Production. Per Day = 7772.4 Kg./Day

. Diesel Oil Production Per Year = 330 X 7772.4 = 2564892 Kg/Year

. Wholesale Selling Price of Diesel Oil Per Kg = 0.49 - 0.55 £

. Total Income = Selling Price * Quantity of Product Manufactured

$$\text{Total Income} = 0.55 * 2564892$$

$$\text{Total Income} = 1282446 \text{ £}$$

$$\text{Gross income} = \text{Total Income} - \text{Total Product Cost}$$

$$\text{Gross income} = 1282446 - 960068.6$$

$$\text{Gross income} = 322378 \text{ £}$$

Let the Tax rate is 45%

$$\text{Taxes} = 40\% \text{ of Gross income}$$

$$= 0.40 * 322378$$

$$\text{Taxes} = 128951.2 \text{ £}$$

$$\text{Net Profit} = \text{Gross income} - \text{Taxes} = \text{Gross income} * (1 - \text{Tax rate})$$

$$\text{Net Profit} = 193426.8 \text{ £}$$

Now, Annual Depreciation Cost

$$\begin{aligned} d &= [V - V_s/n] \\ V &= \text{FCI} = 425237.8 \\ V_s &= 0.05 * \text{FCI} = 21261.89 \\ n &= 10 \\ d &= 40397.5511 \text{ £/yr} \end{aligned}$$

$$\text{Payback Period} = \text{FCI} / (\text{annual profit} + \text{annual depreciation})$$

$$= 425237.8 / (193426 + 40397.5511)$$

$$= \mathbf{1.8 \text{ years}}$$

Chapter: 7

Environment, Hazop study and site selection

7.1 Environment:

Nowadays recycling waste plastic in the way of thermal pyrolysis becomes more and more favoured. Through pyrolysis, we can draw out fuel oil from plastic waste and this kind of fuel oil can be used as industrial heating energy [54]. More and more stress is being placed on environmental protection. Best case is the emission-free green plant, but is such a plant genuinely emission-free during regular operation? "Emission-free" will frequently be defined as "invisible emissions" by low budget suppliers [54].

Significant differences between pyrolysis, incineration and landfill were seen in climate change impact. There was no overall "best" option. Landfill had the least short-term impact on climate change so could be a temporary means of sequestering carbon. Incineration left almost no carbon to landfill, but give rise to the most greenhouse gases. Pyrolysis or incineration rescued most resources, with the balance depending on the source of electricity replaced by incineration. Pyrolysis come out as a strong compromise candidate since the gases and oils produced could be used as fuels and so provided significant resource saving without high impact on climate change or landfill space [55]. WPPO is considered as a promising environmentally friendly substitute resource for carbon-based fuels and chemicals. Existing global supply of energy depends on non-renewable fuels such as oil, gas and coal formed naturally under the earth crust. However, the amount of fossil fuel is restricted now. Due to the growing population of world, the utilization of energy per capita is increasing [55]. Thus the inevitability for continuing alternative to give rise to the possible sources of energy is evident. Utilization of plastic to produce value-added products is receiving great attentiveness by researchers. Furthermore, the inorganic constituent of plastic is negligible and it contains minor quantity of nitrogen, sulphur and ash. Therefore, combustion of plastic is advantageous as it produces less toxic gas such as nitrogen oxides (NO_x), sulphur dioxide (SO₂) and smoke in contrast to other conventional fuels. Even the discharge of carbon dioxide (CO₂) can be controlled by recycling it by photosynthesis [56]. Different types of thermochemical even biological processes have been adopted to transform plastic into value-added products. Among those processes, pyrolysis is more appropriate since it has several advantages of storing, transportation and flexibility in solicitation such as turbines, combustion appliances, boilers, engines, etc [56]

7.2 Hazop study:

A hazard and operability study (HAZOP) is a structured and systematic inspection of a complex planned or existing process or operation in order to point out and evaluate problems that may represent risks to personnel or equipment [57].

This is a comprehensive multi-disciplinary team exercise to critically evaluate (Study) the piping design (Layout/ Routing/Placement of branches/inline instrumentation items/ equipments etc.) with respect to Hazardous and Operational considerations and requirements. Although many companies were addressing this matter, the technique is generally considered to have started in the Heavy Organic Chemicals Division of ICI, which was then a great British and international chemical company [57].

A HAZOP is a qualitative technique based on guide-words and is carried out by a multi- disciplinary team (HAZOP team) throughout a set of meetings [57].

HAZOP is now a compulsory activity. It is in the shape of deviation analysis. Behind the process design, the steady state specifications of each stream in the flow sheet are known. The HAZOP team asks itself questions as to what will happen if this specification deviated on the positive or negative side of the expected steady state value. It discusses the possible causes and consequences of each such eventuality. Anything which appears to them as likely to lead to hazardous situations is discussed further and possible means of avoiding the same or raising alarm if it happens so that remedial action can be taken etc. are recommended. This may lead to recommendation of extra instrumentation on lines and equipment, Hi-Lo alarms and trips etc. may be needed to be provided [57].

The idea of HAZOP is to foresee hazardous situation and take measures and abundant precaution to keep away from them and increase process safety.

Advantage:

The advantage of the HAZOP is that advanced identification and assessment of the critical hazards provides essential input to project development decisions. This leads to a safer and more cost effective design with a lowest possible cost of change penalty [57].

Key Documents required:

- PFD / PFS's (Process Flow Diagram/ Process Flow Schemes)
- P&ID / PEFS's (Piping & Instrument Diagrams/ Process Engineering Flow Schemes)
- Basis of Design
- Operating, Control and safeguarding philosophy
- Plot plans & Hazardous area classification drawings
- Cause & Effect diagrams [57].

Timing:

The HAZOP study should ideally be carried out as early in the design phase as possible – to have impact on the design. On the other hand; to carry out a HAZOP we need a rather finalized design. As a compromise, the HAZOP is generally carried out as a final check when the detailed design has been completed [58].

A HAZOP study may also be conducted on an existing facility to recognize modifications that should be implemented to lessen the risk and operability problems.

Typically HAZOP in EPC design companies are carried out 3 to 4 weeks after the Design review meeting, once the design review points are incorporated in the key documents [58].

Guide words:

A standard set of Guide Words (given as an example in Table 1) is as follows: [58]

Guide Word	Meaning
NO OR NOT	Complete negation of the design intent
MORE	Quantitative increase
LESS	Quantitative decrease
AS WELL AS	Qualitative modification/increase
PART OF	Qualitative modification/decrease
REVERSE	Logical opposite of the design intent
OTHER THAN / INSTEAD	Complete substitution
EARLY	Relative to the clock time

LATE	Relative to the clock time
BEFORE	Relating to order or sequence
AFTER	Relating to order or sequence

Project Name: Plastic to diesel pyrolysis technology							
Hazop study of pyrolysis plant							
Item	Study node	Guide words	Process parameters	Deviations	Possible causes	Possible consequences	Action required
1	Solid feed system	High	Plastic waste inlet	High flow	Screw conveyer is set to high flow rate	Screw conveyer may be damage	Decrease the flow rate
		Low		Low flow	Screw conveyer is set to the low flow rate	Wasting of the time	Increase the flow rate
2	Pyrolysis reactor	No	The screw motor fails	No movement	Unable to move feedstock through kiln	Fire, explosion	Drive failure alarm and high amper- age alarm as interlocks. This would engage an emergency shutdown.
3	Pressure relief valves	High	High gas pressure	High pressure	There is a high gas pressure event of syngas from the pyrolysis kiln	Equipment failure, personnel exposure.	Add a 3-way valve to ensure an open path for ventilation.

4	Feed stream (Inlet)	No	Flow of N ₂	No Flow	1.Closed outlet valve on reactor 2.No reaction/material in reactor 3.Vapor steam condensing in previous heat exchanger	1.No water condensed or recycled steam 2.Shortage in subsequent reactions 3.Excess heat retained in, equipment	1.Consider a valve that fails open 2.Install alarm/sensor
		Less		Less flow	1.Valve on reactor partly closed 2.Some vapor condensing in previous heat exchanger	1.Not enough water recycled; steam shortage 2.Previous HX damaged by condensation	1.Consider a valve that fails open 2.Install a flow meter
		More		More flow	1.More raw material in reactor than expected; more gases evolved as byproducts. 2.Higher temperatures lead	1.More water condensed and recycled than needed; extra energy must be supplied. 2.Condenser experiences a	1.Install a flow regulator and flow splitter 2.Design condenser using storage materials
					to volume expansion of gases.	higher pressure.	
5	Condenser	High	Temperature of condenser	High Temperature	1.Not enough cooling water for previous heat exchanger 2.Gas products leaving reactor hotter than expected	1.Less water will be condensed, causing a steam shortage 2.More water vapor entrained in CO ₂ stream leaving condenser, which can affect the yield of the pyrolyzer	1.Consider valves that fail open and more powerful pumps 2.Install flow meter

		Low		Low temperature	<p>1. Too much cooling water in previous heat exchanger</p> <p>2. High heat loss rates in piping between HX and condenser</p>	<p>1. More water condensed and recycled than needed; extra steam results in high pressures in pipes</p> <p>2. Condensed water leaves condenser at lower temperatures than expected; need more energy to revaporize water to form steam</p>	<p>1. Insulate pipe between HX and condenser</p> <p>2. Install flow regulator</p> <p>3. Design larger steam pipes</p>
6	Distillation column	No	Flow through column	No flow	<p>1. Pipe blockage</p> <p>2. Control valve shut</p> <p>3. Valves fail</p> <p>4. Tubes leakage and blocking</p> <p>5. Pump failure</p>	<p>1. Column dry out</p> <p>2. Possible dangerous concentration</p> <p>3. No operation</p>	<p>1. Install low level alarm</p> <p>2. Check maintenance procedure and schedule</p> <p>3. Make bypass</p> <p>4. Emergency plant shut down</p>
		Less		Less flow	<p>1. Pipe blockage</p> <p>2. Control valve shut</p> <p>3. Valves fail</p> <p>4. Tubes leakage and blocking</p> <p>5. Pump failure</p>	<p>1. Column dry out</p> <p>2. Change in product quality</p>	<p>1. Install low level alarm</p> <p>2. Check maintenance procedure and schedule</p> <p>3. Make bypass</p> <p>4. Emergency plant shut down</p>
		More		More flow	<p>1. Control valve is fully opened</p> <p>2. Increase pumping capacity</p> <p>3. Control valves failure</p>	<p>1. Flooding in the column</p> <p>2. Changes in product quality</p> <p>3. Temperature decrease</p>	<p>1. Install high level alarm</p> <p>2. Check maintenance procedure and schedule</p>

						4.Rise in bottom	
7	Distillation column	High	Level in the column	High Level	Output blockage	1.Over pressure reflux drum 2.Condensed liquid flow back to distillation	1.Install high level alarm 2.Check maintenance procedure and schedule
		Low		Low Level	Pipe partial clogged and leakage	1.Level decrease in level 2.The valve closed 3.Back flow of material	1.Install low level alarm 2.Check maintenance procedure and schedule

7.3 land Location And Site Selection:

The area of the plant can vitally affect the profitability of a venture, and the open door for future advancement. Many effects must be considered while choosing an appropriate site, and just a short audit of the key variables will be given in this area [59].

The following factors should be considered in selecting a plant site:

- Raw material availability.
- Markets.
- Energy availability.
- Climate
- Transportation facilities
- Water supply
- Waste disposal
- Labor supply
- Site characteristics
- Flood and fire protection
- Community factors
- Nearby people group consideration

7.3.1 Raw Material

The source of raw material is the one of the most important factors influencing the selection of plant site. So the plastic should be easily available to near site.

7.3.2 Markets

The location of markets effects the cost of product distribution and the time required for shipping. So the diesel consumers should be nearby so that it should not be expensive to transport.

7.3.3Energy availability

Power and steam requirements are high in most industrial plants. If the plant requires large quantites of coal the supply should be near will be economical. As the Diesel obtained from plastic requires pyrolysis process. As pyrolysis is the process of burning in absence of oxygen.

7.3.5 Climate

If the plant is located in cold climate, costs may be increased by the necessity for construction of protective shelters around the process equipments. As the diesel from plastic is burning process so it is hard to reach the required temperature for process in cold environment.

7.3.6 Transportation facilities:

Water, Railways and Highways are the common means of transportation used by major industries. The kind and amount of products and raw material determine the most suitable type of transportation facilities. So that the transportation of diesel should not become expensive then profit.

7.3.7 Water Supply:

The process industries use large quantities of water for cooling, washing, steam generation and as a raw material. So the plant should be located where dependable supply of water is available

7.3.8 Waste Disposal:

In recent years, many legal restrictions have been placed on the methods of disposing the waste materials from the process industries. The site selection for plant should have adequate capacity and facilities for correct waste disposal. Not all plastic is useful to make diesel some of the plastic will be waste so there should be facility for correct waste plastic.

7.3.9 Labor Supply:

The type and supply of labor available in the vicinity of a proposed plant site must be examined. Consideration should be given to prevailing scales. Labour is the back bone of any industry so when your back bone is strong your industry will be strong.

7.3.10 Site characteristics:

The characteristics of land at a proposed plant site should be examined carefully. The topography of the tract of land and soil should be checked according to plant proposed. The land should be good if we stock plastic it should not give loss.

7.3.11 Flood and Fire protection:

Many industrial plants are located along rivers or near large bodies of water, and there are risks of

flood and hurricane damage.

Fire is another important factor in selecting plant a location. In case of a major fire, Assistance from outside fire departments should be available. Production of diesel from plastic is burning process so it can caught fire easily. We should be prepared for any emergency.

7.3.12 Community Factors:

The character and facilities of a community can have quite effect on location of plant. If a certain minimum number of facilities for satisfactory living of plant personal do not exist, it often becomes a burden for the plant to subsidize such facilities.

7.3.13 Nearby Consideration

The anticipated plant must fit in with and be satisfactory to the nearby group. Full thought must be given to the protected area of the plant with the goal that it doesn't force a significant extra hazard to the group. On another site, the neighborhood group must have the capacity to give palatable offices to the plant work force schools, banks, lodging, and recreational and social offices [59]. So by keeping in mind the above points our selected site for plant is Lahore.

Conclusion

It is obvious that increasing amount of plastic in environment poses a serious threat to the environment. In recent decades, there has been a dramatic increment in plastic consumption. Used plastic is one of the major wastes in many countries. Moreover it is non biodegradable so its removal is also a serious problem. Many techniques have been used for its removal but for every advantage there lies a disadvantage. The increased demand and high price for energy sources are driving efforts to convert organic compounds into useful hydrocarbon fuels. Although much of this work has focused on biomass, there are strong benefits to deriving fuels from waste plastic material. Waste plastic is abundant and its disposal creates large problems for the environment. Plastic does not break down in landfills, it is not easily recycled and degrades in quality during the recycling process, and it can produce waste ash, heavy metals, and potentially harmful gas emissions if incinerated at high temperatures. Increased usage of plastic and absence of an efficient system to address its non-degradability has become a serious issue threatening the human life. On the other hand, increased fossil fuel consumption which led to their depletion necessitates the search for an alternative that could replace the conventional fuels and alongside abate the emissions. Both the non- degradability of plastic and need for an alternative fuel can be addressed by converting the waste plastic to useful energy. The present article reviews about pyrolysis, a chemical treatment to convert waste plastic to energy. It also focuses on its functional feasibility as a fuel in a compression ignition engine.

Thermal processes can be used to convert plastics into hydrocarbon fuels such as gasoline, diesel, aviation / jet fuel, which have unlimited applications in airline industries, helicopter, heavy transportation, and electricity generation. Nowadays Recycling waste plastic in the way of thermal pyrolysis becomes more and more popular. Through pyrolysis, we can extract fuel oil from plastic waste and this kind of fuel oil can be used as industrial heating energy. The proposed methodology renders a promising alternative diesel fuel. The plastic waste pyrolysis oil's properties are superior to those of biomass pyrolysis oil (bio-oil), which is characterized by high water content and is highly acidic, and those of scrap tire pyrolysis oil (STPO), which has high sulfur, nitrogen, and metals (Na, Ca, Ti, Fe, Cu, Al, Zn, Pb, and Cr) content.

The project shows some light on the possibility of manufacturing liquid fuels which could be used as feed stock refinery for further modification or commercial use. By using this technology we could solve the waste plastic problem and also significantly reduce the landfills-which are the cause of infertility of agriculture

land. Waste plastics can also become a very good source of energy and an alternative to fossil fuel which have caused an environment imbalance.

The fuel oil from plastic waste is a kind of heavy oil which has heating value

>10000kcal/L, even higher than some diesel, so you can well take the advantage of its high heating value, and use it for boilers, cement factory, steel mill and glass factory, etc as the diesel, coal as well as wood substitute. For e.g. a steel mill will consume hundreds tons of fuel oil from plastic waste.

However, there are also disadvantages of fuel oil from plastic waste. Fuel oil from plastic waste has higher sulfur content than normal diesel, but no need to worry about this, because many industries are equipped with environment protection devices to scrubber the smoke produced in the heating process. Besides, the other disadvantage of fuel oil from plastic waste is lower flash point. The flash point of fuel oil from plastic waste is <40 degrees, and flash point of normal diesel is about 50 degrees. Flash point mainly influence on the fuel oil transportation, but fuel oil transportation is not a problem. Actually the disadvantages of fuel oil from plastic waste can be improved a lot through our waste oil distillation plant. After process of distillation, oil color & odor removal as well as filtering, diesel-like fuel can be extracted from plastic fuel oil. Reportedly, waste plastic oil when used in a diesel engine yields lesser thermal efficiency, higher brake specific fuel consumption, increased emissions of carbon monoxides, and oxides of nitrogen and unburnt hydrocarbons. Irrespective of its disadvantages, it is worthwhile to note that it is waste plastic which is converted to useful energy. However, not much work on the technical feasibility and functional efficacy of waste plastic oil as a fuel in a diesel engine is reported, and hence, research in this application seems to gain its focus in near future.

APPENDIX

Appendix A

Abbreviations

BPSD	Barrels per Stream Day
CCR	Conradson Carbon Residue
EP	End Point
HSD	High-Speed Diesel
IBP	Initial Boiling Point
LDO	Light Diesel Oil
MMTY	Metric Tons per Year
MT	Metric Ton
MTD	Metric Tons per Day
TBP	True Boiling Point
VGO	Vacuum Gas-Oil

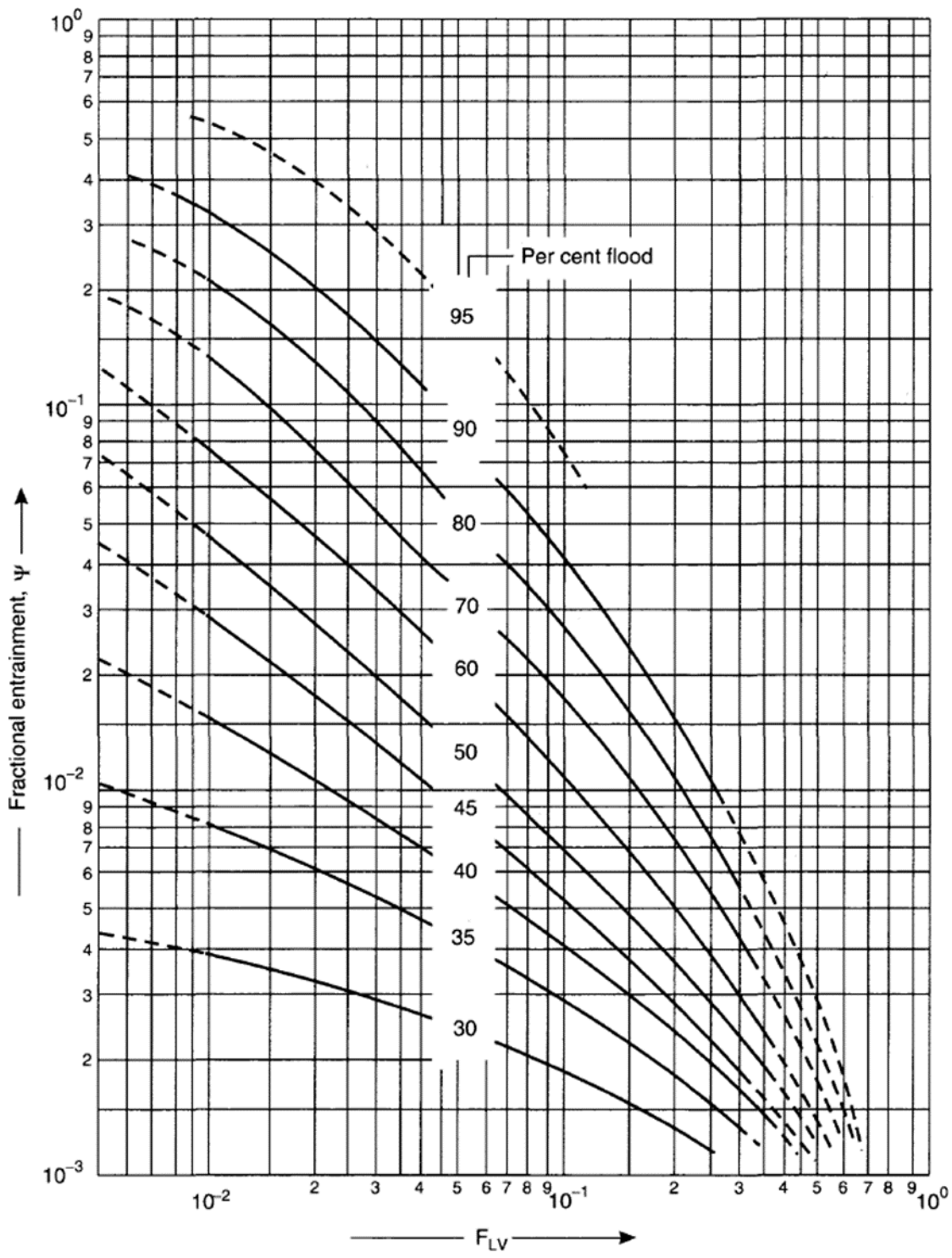


Figure 1

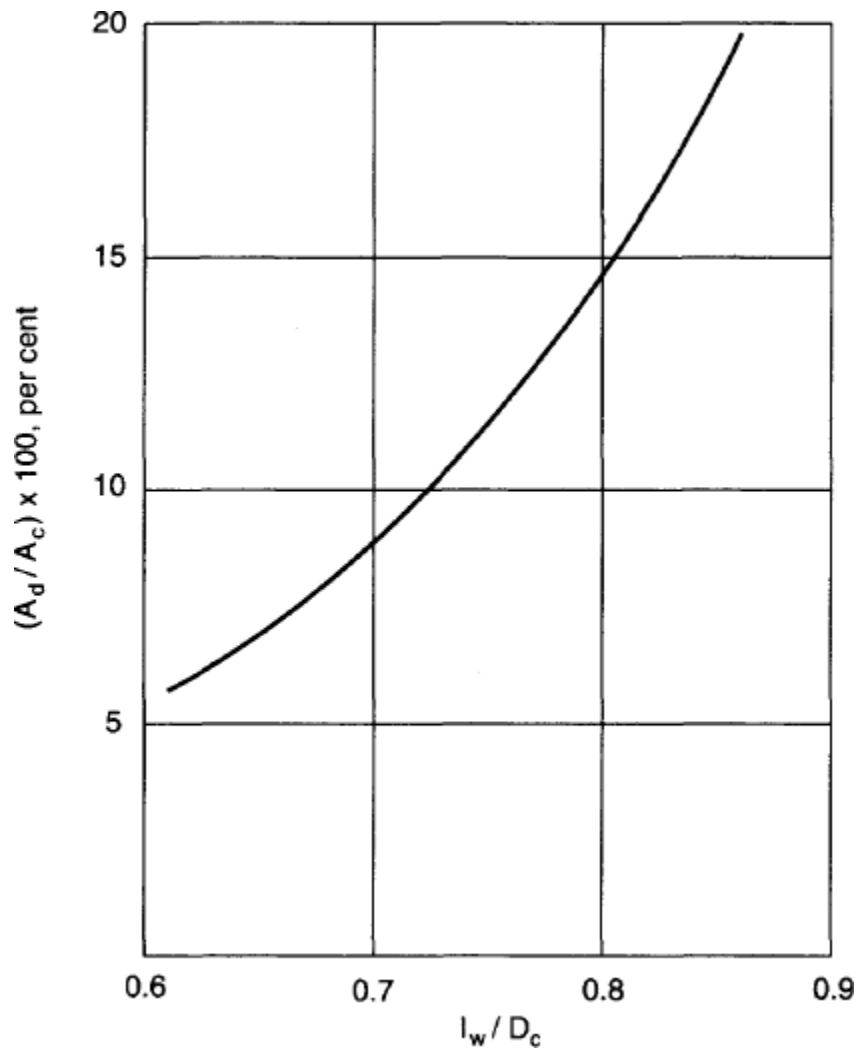


Figure 2

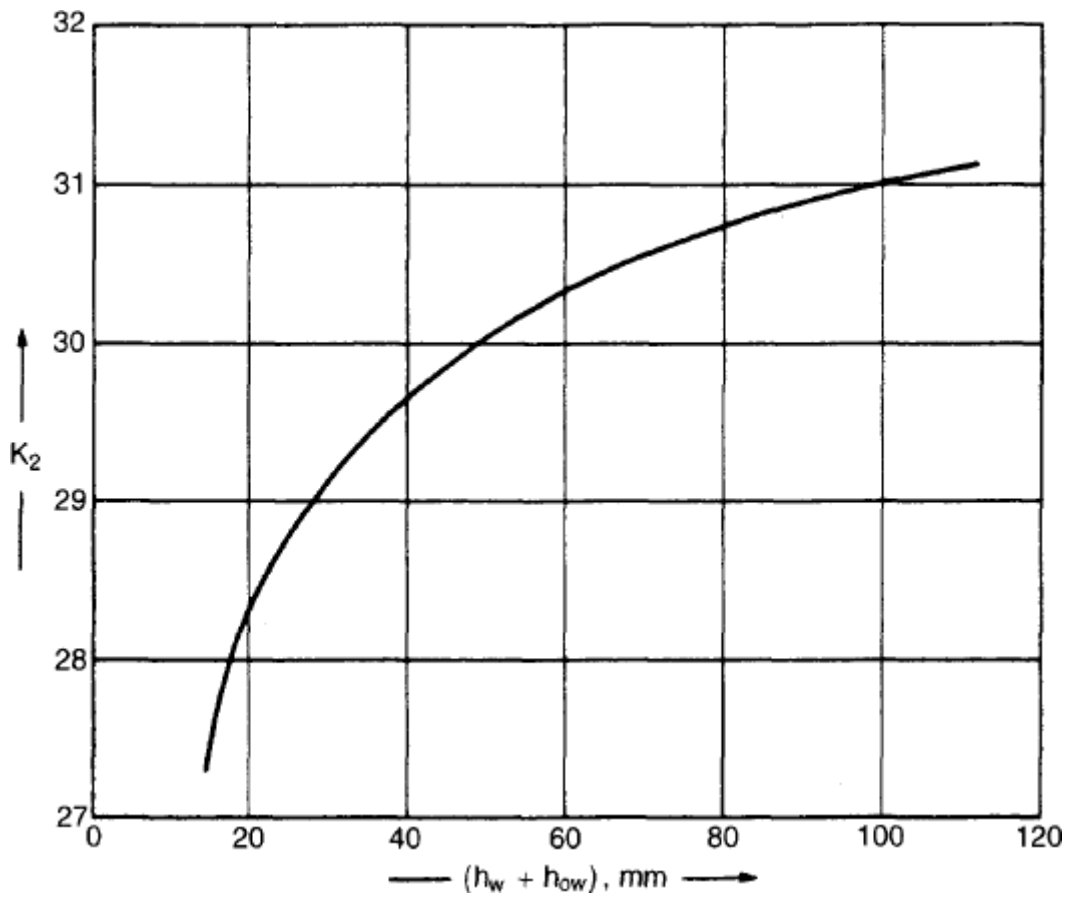


Figure 3

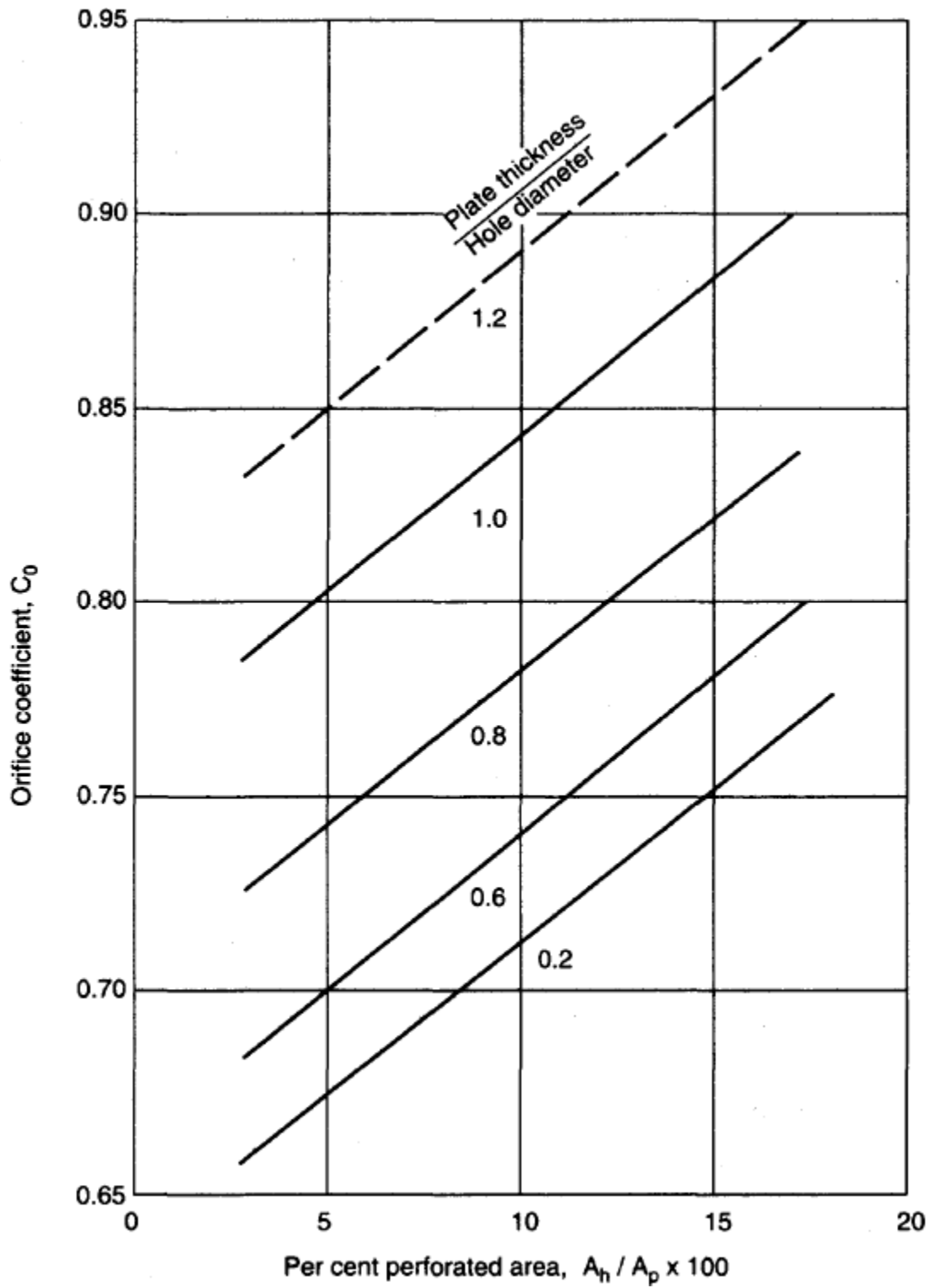


Figure 4

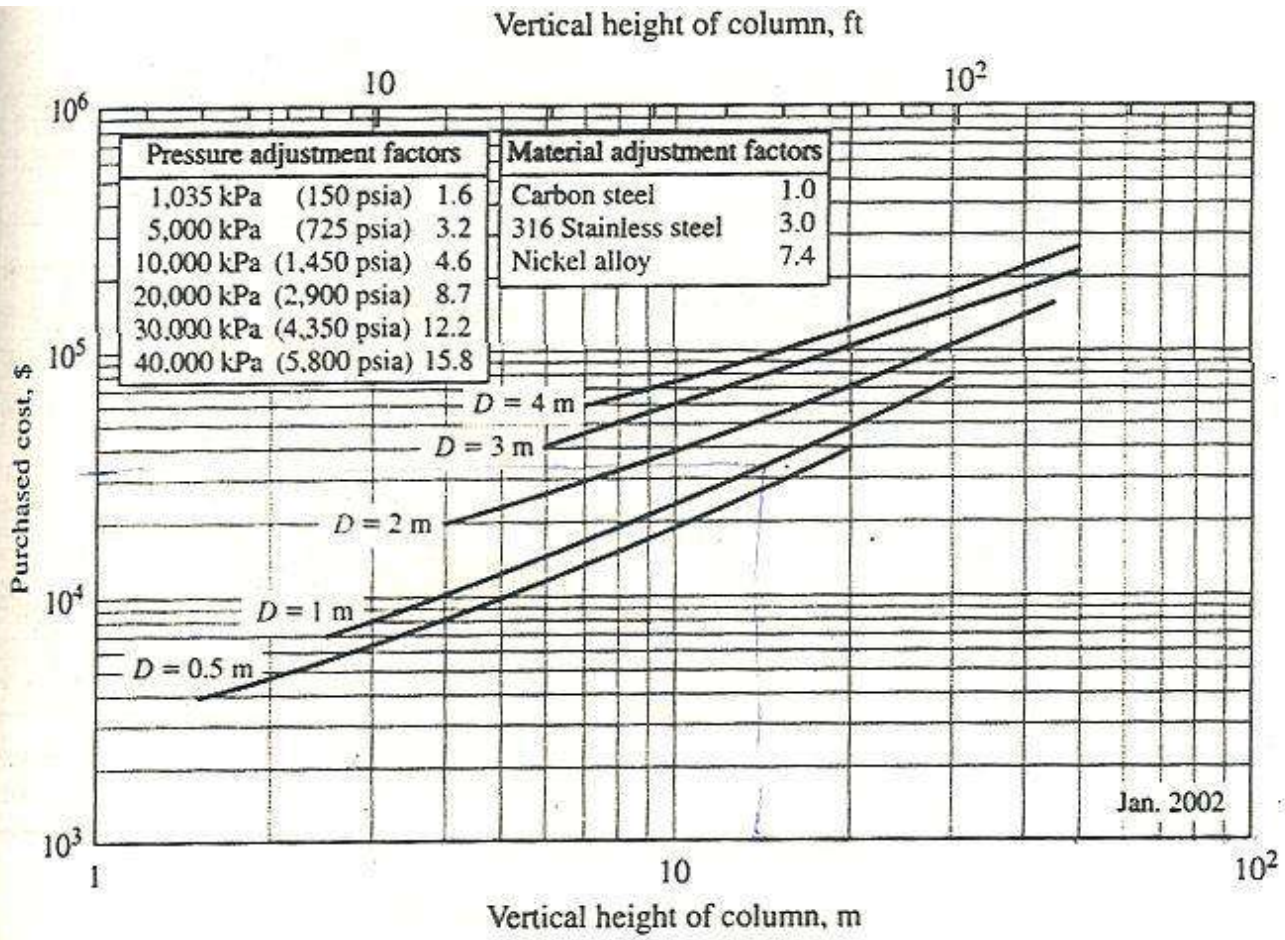


Figure 5

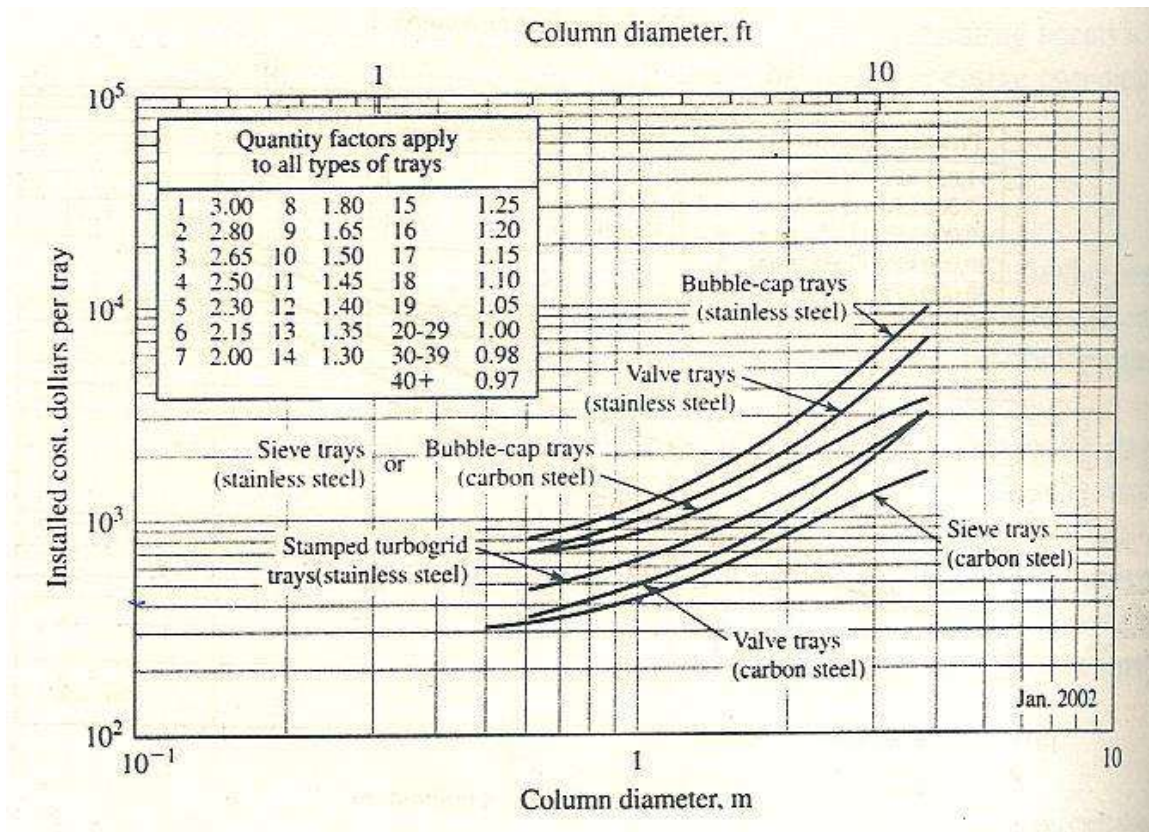


Figure 6

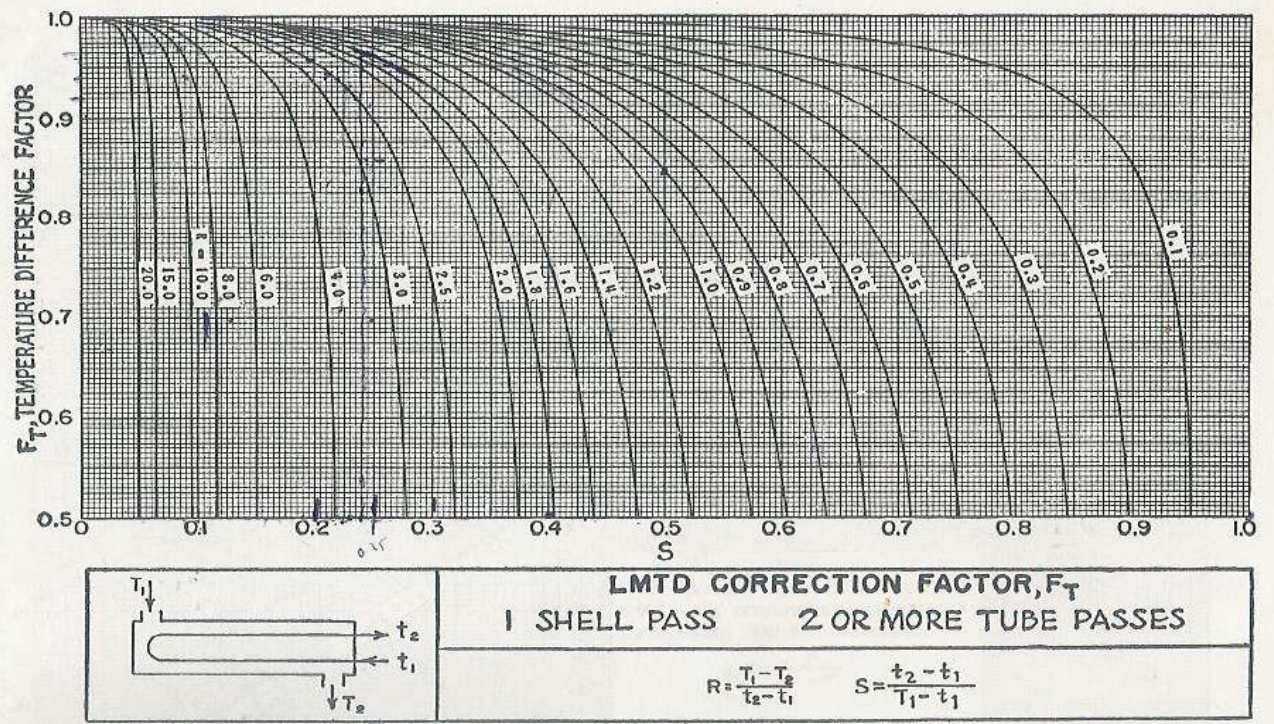


Fig. 18. LMTD correction factors for 1-2 exchangers. (Standards of Tubular Exchanger Manufacturers Association, 2d ed., New York, 1949.)

Figure 7

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