Extraction Of Bio-Fuel Through Pyrolysis.

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APPROVAL

The thesis entitled **"Extraction Of Bio-Fuel Through Pyrolysis"** has been accepted as satisfactory for science in Mechanical Engineering approved as to it's style and contents.

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“We should try to leave the world a better place than when we entered it. As individuals, we can make a difference, whether it is to probe the secrets of Nature,to clean up the environment and work for peace and social justice, or to nurture the inquisitive, vibrant spirit of the young by being a mentor and a guide.”

– Michio Kaku

COMMON ABBREVIATIONS USED

SPI	Society of Plastic Industry
PE	Polyethylene
HDPE	High density polyethylene
LDPE	Low density polyethylene
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
PET	Polyethylene Terephthalate
GC	Gas chromatography
MS	Mass spectrometry
TGA	Thermo gravimetric analysis
LPG	Liquefied petroleum gases
MW	Molecular weight
Micro-GC	Micro gas chromatography
SEM	Scanning electron microscope
EDS	Energy-dispersive x-ray spectrometer
ZAF	A Standard less method for SEM-EDS
CV	Calorific value

ABSTRACT

Energy is the key of globalization. As the world population and economy grow, higher consumption results in higher waste packaging ,plastic and paper residues. Pyrolysis offers a way to recover fuels and other chemical from this fraction. By applying heat to these feedstock into more valuable products in the forms of gas, liquid and char.

The main objective of this study were to understand and optimize the processes of waste plastic and rice husk pyrolysis. Pyrolysis of polyethylene (PE), polypropylene (PE), polystyrene (PS), cellulose, lignin, silica and moisture has been investigated both theoretically and experimentally in a pyrolysis reactor. The key factor have been investigated and identified. The cranking temperature for the PE and PP in the pyrolysis is at 450 degree C, but that of PS is lower at 320 degree C, cellusole is 410 degree C, lignin is 405 degree C and silica is 700-1100 degree C. High reaction temperature and heating rate can significantly promote the production of light hydrocarbons. Long residence time also favours the yield of the light hydrocarbon products. The effects of other factors like type of reactor, catalyst, pressure and reflux rate have also been investigated in the literature review.

ACKNOWLEDMENT

This is to place on record our appreciation and deep gratitude to the faculty members, without whose support this project would have not ever seen the light of the day. We have immense pleasure in expressing our gratitude to our supervisor, Md. Sojib Kaisar, Assistant Professor, Department of the Mechanical Engineering, his guidance, insightful suggestions encouragement, and for all facilities to complete this project. We express their profound thanks to him for everything he done.

We also like to thanks the lab assistants from Heat Transfer Lab" at Sonargaon University, for their assistance in setting up the project work and lending their time and expertise to finish our experiment.

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CHAPTER-1 INTRODUCTION

1.1 Introduction

Pyrolysis is a process by which a solid (or a liquid) undergoes thermal degradation into smaller volatile molecules, without interacting with oxygen or any other oxidants. Pyrolysis of wood is one of the first chemical processes adopted by humans. Starting from the 12th century, it was widely used in Russia for the production of pine resin (used for tarring wooden ships and impregnating ropes), this process was called smolokurenie.

It is believed that in Sweden in the 16th century, the first application of pyrolysis technology on an industrial scale began. The Swedes used the technology of impregnation of ship's wood with tanning pine resins obtained as a result of simple pyrolysis. Logs of coniferous wood were laid in the copper VAT, the VAT was hermetically closed, which achieved the lack of air access inside. A VAT on an open flame was heated to a temperature of 400°C-500°C, and at the same time oily resins accumulated on the bottom, which were drained through a hole in the bottom. With the development of metallurgy, there was another industry based on the technology of pyrolysis of wood – coal burning. When wood was burned without air access, charcoal was produced.

Pyrolysis is a thermo chemical treatment, which can be applied to any organic (carbon-based) product. It can be done on pure products as well as mixtures. In this treatment, material is exposed to high temperature, and in the absence of oxygen goes through chemical and physical separation into different molecules. The decomposition takes place thanks to the limited thermal stability of chemical bonds of materials, which allows them to be disintegrated by using the heat. Thermal decomposition leads to the formation of new molecules. This allows to receive products with a different, often more superior character than original residue. Thanks to this feature, pyrolysis becomes increasingly important process for today industry – as it allows to bring far greater value to common materials and waste.

Pyrolysis is frequently associated with thermal treatment. But in contrary to combustion and gasification's processes, which involve entire or partial oxidation of material, pyrolysis bases on heating in the absence of air. This makes it mostly endothermic process that ensure high energy content in the product received

During the pyrolysis, a particle of material is heated up from the ambient to defined temperature (setup temperature of Biogreen equipment). The material remains inside the pyrolysis unit and is transported by screw conveyor at defined speed, until the completion of the process. Chosen temperature of pyrolysis defines the composition and yields of products (pyrolysis oil, gas and char).

1.2 Uses of Pyrolysis

- Utilization of renewable resources.
- Self-sustaining energy.
- Conversion of low energy in biomass into high energy density liquid fuels, potential to produce chemicals from bio-based resources.
- It is a simple, inexpensive technology that can help in processing a wide variety of feedstock's.
- It reduces waste going to landfills and greenhouse gas emissions.
- It reduces the risk of water pollution.
- It can reduce the country’s dependence on other energy resources by generating energy from domestic resources.

- Waste management done with the help of pyrolysis technology is inexpensive compared to disposal in landfills.
- The construction of a pyrolysis power plant is a fast process.
- It can create new jobs for low-income people based on the quantity of waste generated in the region, which in turn provides public health benefits through waste clean-up.

Pyrolysis is one of the sustainable solutions that are economically profitable on very large scales and can minimize environmental problems especially in terms of waste minimization.

1.3 Type Of Pyrolysis

There are generally three types of Pyrolysis:

1. Slow Pyrolysis
2. Fast Pyrolysis
3. Flash Pyrolysis

Slow Pyrolysis: It is characterized by lengthy solids and gas residence times, low temperatures, and slow biomass heating rates. It is used to modify the solid material and minimize the oil produced. On the other hand, fast pyrolysis and ultra-fast (flash) pyrolysis maximize the gases and oil produced.

Temperature: Med-high (400-500 °C)

Residence time: Long (5-30 min)

Fast Pyrolysis: It is a rapid thermal decomposition of carbon-containing materials in the absence of oxygen in moderate to high heating rates. It is the most common method used in research and in practical use. The major product is bio-oil. Pyrolysis is an endothermic process. Char is accumulated in very large quantities and is to be removed frequently.

Temperature: Med-high (400-650 °C)

Residence time: Long (0.5-2 s)

Flash Pyrolysis: It is a very rapid thermal decomposition pyrolysis process, the heating rate is also very high. The main products are gases and bio-oil. Flash pyrolysis produces a very less quantity of gas and tar as compared to slow pyrolysis.

Temperature: high (700-1000 °C)

Residence time: Long (less than 0.5 sec

1.4 Feedstock

- The feedstock subjected to pyrolysis is exposed to temperatures above its decomposition temperature. At this point, the chemical bonds holding the molecules of the feedstock together are broken down. This process results in the fragmentation of the molecules of the feedstock into smaller molecules.
- The process of pyrolysis is carried out in the absence of oxygen and water in some cases, a very small quantity of water and oxygen is allowed to enter the pyrolysis setup. This is done to facilitate other important processes such as combustion and hydrolysis, Certain chemical substances may also be mixed with the feedstock in order to obtain specific products from the pyrolysis process.

1.5 Applications of Pyrolysis:

- The heat-facilitated browning of sugar (also known as caramelization) is an example of the pyrolysis process.
- Destructive distillation is an important application of pyrolysis. In this process, unprocessed material (organic products) are subjected to large amounts of heat in relatively inert atmospheres to facilitate them breaking down into smaller molecules. The extraction of coke and coal ash from coal is achieved with the help of this technique.
- Many common cooking techniques involve pyrolysis like grilling, frying, toasting, and roasting.

- It is widely used in the chemical industry to produce methanol, activated carbon, charcoal, and other substances from wood.
- Synthetic gas produced by the conversion of waste materials using the pyrolysis process can be used in gas or steam turbines to produce electricity.
- A mixture of stone, ceramics, soil, and glass obtained from pyrolytic waste can be used as a building material or for filling landfill cover liners.
- It is also used in carbon-14 dating and mass spectrometry.
- Wood placed in tar kins and subjected to high temperatures in order to obtain tar is also an example of the pyrolysis process.
- This process is also used in several cooking procedures like grilling, frying, and baking.

1.6 Plastic

Plastic is a high molecular weight material that was invented by Alexander Parkes in 1862. Plastics are also called polymers. The term polymer means a molecule made up by repetition of simple unit. Plastic is one of the most commonly used materials in daily life which can be classified in many ways such as based on its chemical structure, synthesis process, density, and other properties. In order to assist recycling of the waste plastic, Society of Plastic Industry (SPI) defined a resin identification code system that divides plastics into the following seven groups based on the chemical structure and applications:

1. PET (Polyethylene Terephthalate)
2. HDPE (High Density Polyethylene)
3. PVC (Polyvinyl Chloride)
4. LDPE (Low Density Polyethylene)
5. PP (Polypropylene)
6. PS (Polystyrene)

   Others.

Due to the convenience to manufacturing and use, the world plastic production has been increasing since it was firstly commercially manufactured, from 1.5 million tons in 1950 to 260 million tons in 2007. One of the major concerns for extensive use of the plastics is the disposal of the waste plastic. In addition, the plastics are produced from non-sustainable oil or coal, and thus it is a non-sustainable product. There were 30.7 million tons of waste plastic generated in the U.S in 2007 which accounts for 12.1% of the total municipal solid wastes. In U.K., 4.9 million tons of plastics were consumed in 2007. Europe consumes about 25% of the global plastic production, which is equivalent to 60 million tons per year.

1.7 Economic Value Of The Community

The technology helps to save land resources by utilizing waste plastics to generate valuable energy. Currently, a majority of the waste plastic is land filled and it is not sustainable because waste plastic takes very long time to decay. However, it seems that Dhaka has no other choices but continues to do so in the foreseeable future. Dhaka is a populous city , the society as a whole has to pay increasing attention to the environmental sustainability for the next generations.

The world’s annual consumption of plastic which was five million tones in the 1950’s has skyrocketed to a global production of 245 million tones in 2008 and waste plastic generation is rapidly increasing. Plastic waste is the third largest contributor to municipal and industrial waste systems after food and paper. The New Zealand city of Christchurch produced 243054 tons of municipal refuse between July 2003 and Jun 2004 of which 15% was plastic waste. PE, PS and PP account for over 70% of this plastic waste according to the Christchurch City Council. Therefore, significant amount of energy can be produced with this technology. This could be an alternative energy resource for substituting fossil fuels. The Bangladesh government could reduce the reliance on the imported oils. The community may also reduce the reliance on the gas power generation.

The fuels produced from this process do not contain sulphur content because there is no sulphur in the waste plastic feedstock. This is an advantage compared with the classic fossil fuels such as diesel because sulphur content in the fuels could form SO2 after combustion. SO2 is a pollutant causing severe air pollutions, which affects people health and damages the concrete structure. Therefore, this technology is environmental friendly and has significant positive impaction the local government and community.

1.8 The Pyrolysis Of Plastic Materials

Pyrolysis is a thermal cracking reaction of the large molecular weight polymer carbon chains under an oxygen free environment and produces small molecular weight molecules. Traditional treatments for post-consumed plastics were landfills or incineration. However, landfill of the post-consumed plastics has potential problems because of limited land resource and high durability of plastics. Incomplete incineration may generate poisonous substances and causes serious health problems. Other methods like gasification and bioconversion are mainly used for organic materials.

HDPE, LDPE, PP and PS are all hydrocarbons consisting entirely of carbon and hydrogen, which are similar to hydrocarbon fuels such as liquefied petroleum gas (LPG), petrol and diesel. Plastics are derived from petroleum and have calorific values in a similar range as those of LPG, petrol and diesel.

Calorific Values For Various Metarials:

Material Calorific value (MJ/kg):

Polyethylene	46.3(MJ/kg)
Polypropylene	46.4(MJ/kg)
Polystyrene	41.4(MJ/kg)
Polyvinyl chloride	18.0(MJ/kg)
Coal	24.3(MJ/kg)
Liquefied petroleum gas	46.1(MJ/kg)
Petrol	44.0(MJ/kg)
Kerosene	43.4(MJ/kg)
Diesel	43.0(MJ/kg)
Light fuel oil	41.9(MJ/kg)
Heavy fuel oil	41.1(MJ/kg)

Some commercial plastic pyrolysis plants have been in operation in which all types of post-consumed plastics accepted need to be treated using hydrochloride scrubber which is for PVC cracking and is not preferable in the fuel product because chloride is not desirable in the fuels. Those plants are sophisticated and not suitable for relatively small scale production. In these plants, catalysts are also used to improve the quality of pyrolysis products in many existing equipments. Those equipments with catalysts have some weakness in terms of long material resistance time, undesired contact between plastics and catalysts, required high heat transfer rate, and cost of the catalysts.

1.9 Rice Husk

The rice husk, also called rice hull, is the coating on a seed or grain of rice. It is formed from hard materials, including silica and lignin, to protect the seed during the growing season. Each kg of milled white rice results in roughly 0.28 kg of rice husk as a by-product of rice production during milling. Common products from rice husk are: solid fuel carbonized rice husk produced after burning, and the remaining rice husk ash after combustion.

1.10 Characteristics Of Rice Husk

Rice husk is light in weight, yellowish in color and convex in shape, slightly larger than the rice grain. It is separated from the brown rice grain as part of the milling process, after which the rice is polished. Forming one fifth of the volume of paddy, it is bulky and hence difficult to store. Some of its distinctive features include:

- Husk makes for good insulation material since it does not burn easily till air is blown through it. It is highly resistant to the penetration of moisture and fungal decomposition.
- Rice husk decomposes slowly due to the rice silica content, and can therefore not be considered for use as fodder.
- When rice husk is burned, its ash content of 17 – 26 % is far higher than that of wood and coal. This explains the need for much larger volumes of husk when utilized for power generation.
- Its high calorific value makes it a good source of renewable energy.

1.11 Potentially Beneficial Uses Of Rice Husk

The sheer volume of rice husk makes it difficult to store and its removal a challenge. Burning it only pollutes the air though it yields rice husk ash, or carbonized rice husk if not completely burned. Some of the many uses of rice hus that have developed over time include:

- Use in horticulture for soil aeration – Rice husk is being added to soil on the recommendation of scientists to improve soil aeration. Husk with its rich reserves of potassium and silicon helps to amend the soil, improve its properties by decreasing soil bulk density, improve its fertility with the air pockets created underground, and works like a rice conditioner.
- For making animal bedding – one of the simpler uses of husk is to convert them into bales which provide cushioned animal bedding. Its anti-caking properties make it easier to clean and maintain. It also serves as a good insulator.
- Composites like particle boards- Composite materials are produced by combining two or more materials that serve to enhance the properties of the original. The silica intrinsically found in rice husk makes it an ideal addition to panel and particle boards to make them stronger and resilient while remaining light in weight.
- Using its silica – Husk contains three fourths of organic volatile matter and the balance is converted into RHA or rice husk ash. RHA contains nearly 90% of amorphous silica, that is excellent for reinforcing rubber tyres, can be used as an anti-caking agent, and for strengthening of building material.
- Renewable fuel – Rice husk is being increasingly used as biomass that fuels and co-fuels power plants. There are now a large number of power plants in Asia that are completely powered by ground rice husk.

- Insulation- Rice husk is considered to be a top class insulating material since it is difficult to burn and does not easily absorb moisture. It can be used as insulation powder in steel mills.
- Building material- The amorphous silica contained in rice husk ash helps to strengthen materials, and this is why there is a spiraling demand for it in the production of cement and concrete mixes, and low permeability concrete used for construction of bridges, nuclear plants, and in marine environments.
- Generating steam in rice mills- One of the most common uses is in the rice mills itself where husk is used as fuel to generate steam for the parboiling process of rice, which is consumed by the poorer sections of society.

1.12 Chemical Composition Of Rice Husk

Current rice production in the world is estimated to be 700 million tons. Rice husk constitutes about 20% of the weight of rice and its composition is as follows: cellulose (50%), lignin (25%–30%), silica (15%–20%), and moisture (10%–15%). Bulk density of rice husk is low and lies in the range 90–150 kg/m^3.

CHAPTER-2 LITERATURE REVIEW

2.1 Some Of Previous Research Works.

1. **Writer Information:** Nanta Sophonrat, Pyrolysis of mixed plastic and paper to produce fuels and other chemicals, Doctoral Dissertation, KTH Royal Institute of Technology, Stockholm, Sweden, 2019.

   Remarks: Were performed in the bench-scale fixed bed reactor, the products were collected and analyzed separately. Three types of fuel were extracted there, Liquid Fuel, Gases, Solid Fuel.
2. **Writer Information:** Katarzyna Ewa Kucharczyk, Catalytic Pyrolysis of Biomass,Nob-2019,TECNICO LISBOA.

   Remarks: In this work, a horizontal fixed-bed reactor was designed and constructed. The experiments used materials was 50%PE, 30%PP, 25%PS and total weight of that mixture was 10 gm. The extracted products of this experiment Non-Condensable Gas, Dark brown liquid, and yellow or brown wax.
3. **Writer Information:** Feng Gao, Pyrolysis of waste plastic into fuel, University of Canterbury, New Zealand-2010

   Remarks: In this work a horizontal fixed-bed batch reactor was designed and constructed. The used material was in this experiments are 50% PE, 30% PP and 20% PS in total 10gm (weight). The extracted products was in this experiment are non-condensable gas, dark brown liquid, yellow or brown wax and char.

2.2 Factors Affecting Plastic Pyrolysis

The major factors influencing the plastic pyrolysis process and pyrolysis product molecular distribution include chemical composition of the feedstock, cracking temperature and heating rate, operation pressure, reactor type, residence time and application of catalyst. These factors are summarized in this section as follows.

2.3 Chemical Composition Of Feedstock

The pyrolysis products are directly related to the chemical composition and chemical structure of the plastics to be pyrolyzed. In addition, the chemical composition of the feedstock also affects the pyrolysis processes. In reality, waste plastics are possibly contaminated before recycling which could also have effects on the pyrolysis process and products.

PE,PP and PS are most commonly used polymerichydro carbons and were selected as the investigated materials in this study. Polyethylene is formed from ethylene through chain polymerization.

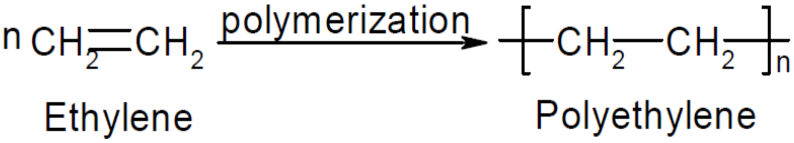

Fig:2.1:Chemical Composition of pollymerization

2.4 Cracking Temperature And Heating rate

Temperature is one of the most important operating variable, since the temperature dominates the cracking reaction of the polymer materials. Not all of the polymer materials can be cracked by increasing the temperature. Van der Waals force is the force between the molecules, which attracts molecules together and prevents the collapse of molecules. When the vibration of molecules is great enough, the molecules will evaporate from the surface of the object. However, the carbon chain will be broken if energy induced by van der Waals force along the polymer chains is greater than the enthalpy of the C-C bond in the chain. This is the reason why high molecular weight polymer is decomposed rather than is boiled when it is heated. In theory, the temperature of thermal breaking the C-C bonds should be constant for a given type of plastic (polymer). However, this temperature has been found to differ in different studies. For example, the temperature when PP starts cracking was reported at 380 ºC in Ciliz et al.'s result but it is measured to be 650 ºC in Demirbas's result. Both of them used similar batch process reactor and thermo gravimetric analysis. According to the provided schemes, the most likely reason is the difference in the temperature measurement location where the temperature sensors were located. There was significant temperature gradient along the apparatus in which the melted plastic at the bottom of a fix-bed batch reactor had much lower temperature than that on the top surface of the reactor. It was also found that the space temperature in the pyrolyzer was strongly influenced by the product vapour. Different locations of the temperature sensors in different studies are believed to be one of the most important factors on the different cracking temperature reported. Karaduman et al. investigated the temperature profile along a tube heated by external furnace. Large temperature variation was observed between the ends and the centre of the tube. Clearly, there wassignificant heat loss at both ends of the tube reactor.

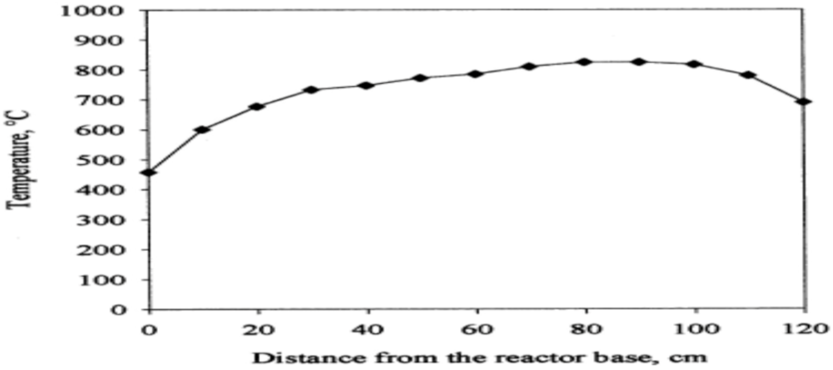

Fig:2.2:Cracking Relation Between Temperature And Distance.

2.5 Type Of Reactor

The reactor type for the plastic pyrolysis significantly influences on the heat transfer rate, mixing of plastics with pyrolysis products, residence time and the reflux level of the primary products. Reactors can be classified into batch, semi-batch and continuous or classified based on types of reactor bed.

2.5.1 Batch, Semi-Batch And Continuous Reactors

According to the feeding and product removal processes, the pyrolysis reactor is categorized into batch, semi-batch and continuous reactors. In the batch reactor, the materials are fed into the reactor in batches for pyrolysis either at the start of the process or after all of the fed materials are processed. In the continuous reactor, the feed materials are input from one part and the products are led out from the other part of the reactor. A semi-batch reactor removes the pyrolysis products continuously once they are generated but the feed materials are added initially before the pyrolysis process starts. Some semi-batch process uses inert carrier gas to help remove the pyrolysis products.

2.5.2 Fixed Bed, Fluidized Bed And Screw Kiln Reactors

Based on the heat transfer methods and flow patterns of the feedstock and products, the pyrolysis reactors can be classified into fixed bed reactor, fluidized bed reactor and screw kiln reactor. In the fixed bed reactor, the pyrolysis occurs on a stationary bed which is easy to design and operate. However, the irregular sizes and shape of the feedstock plastics may cause feeding problems in continuous process and the low thermal conductivity of the plastics results in large temperature gradient in batch process devices. In some systems, the fixed bed reactors are only used as the secondary pyrolysis reactor because the products from the primary pyrolysis are mainly in liquid and gaseous phase which can be easily fed into the fixed bed.

2.6 Residence Time

The definition of residence time differs in various studies. In fast pyrolysis or continuous pyrolysis process, it refers to the contact time of the plastic on the hot surface throughout the reactor. However in slow pyrolysis and batch process, the residence time means the duration from the time when feedstock plastic start to be heated to the time when the products are removed. Longer residence time favours a further conversion of the primary products thus yielding more thermal stable products such as light molecular weight hydrocarbons, non-condensable petroleum gases. In a slow pyrolysis, long residence time encourages the carbonization process and produces more tar and char intheproducts.The pyrolysis conditions, residence time and target products are given in Table 2.1.

Table: 2.1: Pyrolysis Processes And Target Products.

Process	Heating rate	Residence time	Temperature (°C)	Target Products
Slow carbonization	Very Slow	Days	450-600	Charcoal
Slow pyrolysis	10-100K/min	10-60 min	450-600	Gas,oil,char
Fast pyrolysis	Up to 1000K/s	0.5-5 s	550-650	Gas,oil,char
Flash pyrolysis	Up to 10000K/s	<1 s	450-900	Gas,oil,char

Except for the batch pyrolysis reactor in a closed system, residence time is difficult to be controlled directly but can be adjusted by altering other operation parameters such as feeding rate, carrier gas flow rate and product discharge rate. Residence time was, then, calculated for these controllable operation parameters. Secondary pyrolysis cracking occurs when residence time is long enough, which enhances the yield of gaseous product. Higher value of V/m represents longer residence time. The Y axis is the conversion of HDPE to gaseous product. There is a significant effect on the conversion when the residence time varies in a certain range during the non-catalyst thermal reaction.

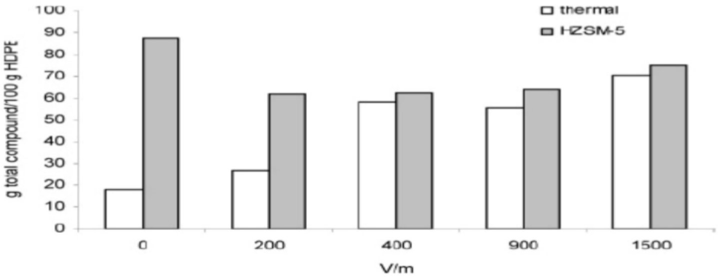

Fig:2.3: Influence of residence time on the production of gaseous products.

2.7 Use of catalyst

In order to optimize plastic pyrolysis reactions and modify the distribution of pyrolysis products, catalysts are widely used in research and industrial pyrolysis processes. Petroleum fuels, such as LPG, petrol, kerosene, and diesel, are hydrocarbons from C1 to C24 . The PE pyrolysis products are mainly straight hydrocarbons from C1 up to C80 , which contain much more heavier molecular weight components. One of the main purposes of using catalysts is to shorten the carbon chain length of the pyrolysis products and thus to decrease the boiling point of the products. Catalysts are found to be mainly applied to PE pyrolysis because the primary product from other plastics, such as PP and PS, are mainly light hydrocarbons, with similar carbon chain length to the range of commercial fuels. The products from non-catalytic PE pyrolysis contain high proportion of 1-alkenes and dialkenes. Some catalysts are applied specifically to reduce the unsaturated hydrocarbons and promote the yield of aromatics and naphthenic. This can significantly increase the stability and cetane number of the oil products. Moreover, it is reported that activation energies (Ea) measured in the PE pyrolysis with catalysts (such as HZSM-5, HY, and MCM-41) were much lower than those when no catalyst was added.

2.8 Pressure

Operating pressure has significantly effect on both the pyrolysis process and the products. The boiling points of the pyrolysis products are increased under higher pressure, therefore, under pressurised environment heavy hydrocarbons are further pyrolyzed instead of vaporized at given operation temperature. The effect of pressure on hydrocarbon number and their fractions in the pyrolysis products of PE. In effect, under pressurized pyrolysis, more energy is required for further hydrocarbon cracking. It was also found that high pressure increases the yield of non-condensable gases and decreases the yield of liquid products. The average molecular weight of gas product also decreases with the increase of pressure. The influence of pressure on the concentration of double bond, Components.

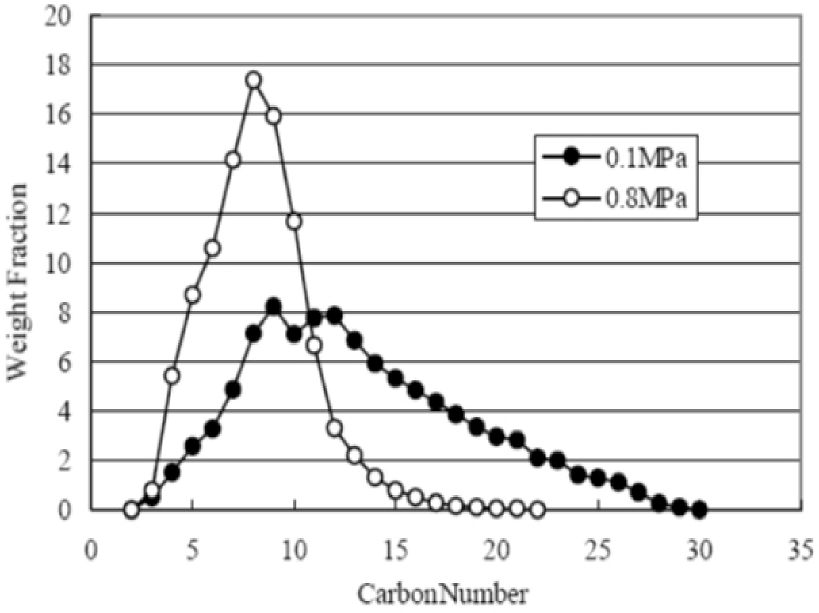

Fig:2.4: Effect of pressure on the distribution of PE pyrolysis products

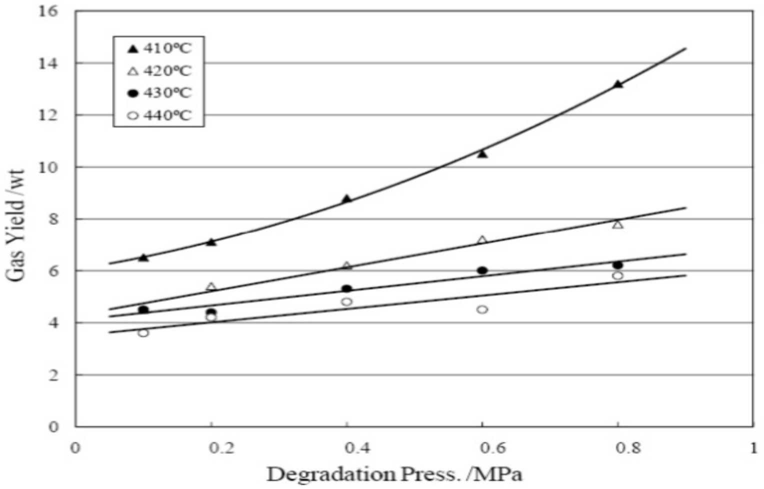

Fig:2.5: Effect of pressure on the yield of gas at different temperature.

2.9 Other Influencing Factors

There are a number of other factors which also affect pyrolysis process to a certain extent. For example, reactive additives such as air, oxygen, or hydrogen are sometimes present in the reaction for different purposes, which will interfere with the reactions and affect the quality of the products.

Further pyrolysis of the primary product occurs in most processes. Secondary cracking reactions were found in many reports which are enhanced by high pressure, long residence time, low heating rate and high refluxes. Although many researchers observed the impact of secondary cracking, few have investigated the influence of secondary cracking process on the yield and the quality of the products. Most secondary cracking occurred during the pyrolysis of PE and very limited cracking was found in PS pyrolysis. This is possibly due to the difference in their primary products. The primary products produced from PE pyrolysis contain large proportion of heavy hydrocarbons with carbon chain number up to 80. The average molecular weight of the primary products from PE is much higher than that of other plastics, PS, PP, PVC and PET. The secondary cracking is mainly effective for heavy hydrocarbons, hence, has less effect on the pyrolysis of PS, PVC, PET and other plastics. The importance of secondary cracking on PE pyrolysis has intensively been studied in this research.

2.10 Existing Commercial Plastic Pyrolysis Technologies and Processes

The waste plastic pyrolysis plants were developed and built in many countries. The selection of the process and the plant is determined mainly on the feedstock composition and the target products.

2.11 Feedstock Effects

According to a summary of existing processes and technologies reported by Arena and Mastellone, the most important property of plastic feedstock is whether it contains PVC. PVC pyrolysis has different the thermal cracking process and different products from those of other common waste plastics including PE, PP and PS. In the PVC pyrolysis, the products containing HCl are particularly hazardous for fuels.If the feedstock contains PVC, the plants must have re-treatment system to remove and a solvent scrubber to remove HCl from the pyrolysis products.

The other important property for some current processes is the size of feedstock. The requirement for the feedstock size is to avoid the feeding blockage and to enhance the heat transfer between the heating medium and the plastics particles.

It was found that in most cases, the feedstock is a mixture of various waste plastic in municipal slid wastes or industrial residues. In pyrolysis of the mixed plastics, interactive effects among the different plastic types may occur due to the difference in cracking temperatures and different products. . However, no report has been found where the pyrolysis technology is designed for a specific type of the waste plastic.

2.12 Technology

The selection of pyrolysis technology is based on the characteristics of the feedstock and the target products. In general, each pyrolysis technology consists of three parts: feeding system, pyrolysis reactor and separation system.

2.12.1 Feeding System

In most commercial processes, the raw materials are firstly heated and melted in the feeding system before flowing into the reactor. The air, moisture and other solid materials can be separated from the raw plastic materials in the feeding system. In addition, the pre-treatment may be required for cracking the PVC at 250 ºC. In some rotary kiln reactors, solid plastic particles with appropriate sizes can be extruded into the reactor directly. Most feeding systems move the highly viscous melted plastics into reactors by its gravity or by an extruder. However, a required temperature gradient should be maintained from the feeding system to the pyrolyzer although this may not be an issue for the rotary kiln reactors. The required temperature gradient is to prevent melted plastic cracking before entering the pyrolyzer. For example, the cracking temperature of PS is 420 ºC thus any over heating in the feeding system should be avoided. Free-fall feeding system is widely applied in fixed bed and fluidized bed reactors.

2.12.2 Pyrolysis Reactor Technology

Pyrolysis reactors are typically designed to maximize the production of liquids through fast rather than slow heating although increasing interest in biochar or black carbon is now shifting the preferred product mix. The reactor type for the plastic pyrolysis significantly influences on the heat transfer rate, mixing of plastics with pyrolysis products, residence time and the reflux level of the primary products. Reactors can be classified into batch, semi-batch and continuous or classified based on types of reactor bed.

2.12.3 Product separation and collection

The products from the plastic pyrolysis are mainly combustible gases and liquids. The liquids can be either combusted for power generation or for further refining to produce high quality fuels. In some plants, the pyrolysis products are simply separated into liquid, gas and solid whereas others have a more complete separation system by feeding the mixture of liquid and gas into distillation columns. Diesel range products can then be distilled out as in an oil refinery process. The non-condensable gases are mainly made of hydrocarbons, and a minor amount of hydrogen and carbon monoxide. The gases can be liquefied as fuels, or used as fuels to heat the pyrolysis reactor, or if the amount is insignificant, the non-condensable gases are sent to an incinerator flaring off with the air.Ash may present in the non-condensable gases so most commercial processes have a gas scrubber for cleaning the gases.

CHAPTER-3 EXPERIMENTAL SETUP & PROCEDURE

3.1 Experimental Setup

For the purpose of researching the pyrolysis process with waste plastic and rich husk, an experimental facility has been designed, build and put into operation. This chapter presents a thorough description of the experimental setup and methodology.

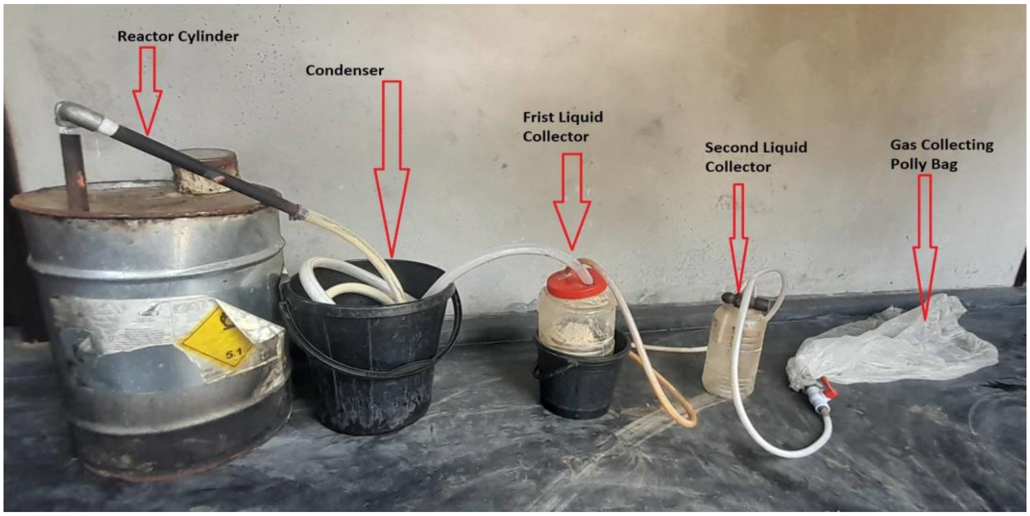

Fig:3.1: Experimental setup

3.2 Experimental Equipment

An experimental facility has been designed, fabricated and installed to collected data for this research. The detailed description of experimental apparatus and experimental procedure are presented in this chapter.

- Furnace
- Reactor Cylinder
- Thermocouple
- PVC Plastic Pipe
- Stainless Steel Pipe
- Hose Clamp
- Nitin Pipe
- Ball Valve
- Polly Bag / Gas Collector
- Condenser
- threat Tape
- Silicone Gel
- Insulating Foam

3.3 Furnace

Fig:3.2 Gallenkamp Electric Furnace

In the system, a M303PY Gallenkamp electronic furnace was applied to heat the reactor as an external heating resource as shown in figure:3.2. There are one heating sources in the furnace. That one was used for heating the reactor in this experiment, which has a maximum power output of 881W. The output power was dialled at Load 100 to provide its maximum power In this work.

3.4 Reactor Cylinder

Fig:3.3 Reactor Cylinder

A vertical fixed-bed batch reactor was designed and constructed as shown in figure:3.3.The goal for this experiment was to understand the process of the waste plastic and rich husk pyrolysis by monitoring and analyzing the temperature profile. The reactor was made of stainless steel with an inner diameter of 304.8 mm and thickness of 06 mm. The system also consists of nitrogen purging bottle and a water-cooling condenser, both of which are connected to the reactor. Connected to the condenser are a liquid collector and a gas collector.

3.5 Thermocouple

A thermocouple is simply a sensor that is used for measuring temperature. This design of sensor consists of two dissimilar metal wires which are joined together at one end, connected to an instrument that is capable of accepting a thermocouple input and measure the reading. In this system this is used to measured the centre space temperature in the reactor.

3.6 PVC Plastic Pipe

Fig:3.4 PVC Pipe

It's the white plastic pipe commonly used for plumbing and drainage. PVC stands for polyvinyl chloride, and it's become a common replacement for metal piping. PVC's strength, durability, easy installation, and low cost have made it one of the most widely used plastics in the world. In this system it is used to made a condenser.

3.7 Stainless steel

Fig:3.5 Stainless Steel

Stainless steel pipe is primarily used in piping systems for the transport of fluids or gases. We manufacture steel pipe from a steel alloy containing nickel as well as chromium, which give stainless steel its corrosion-resistant properties. Steel pipes are cylindrical tubes made from steel that are used many ways in manufacturing and infrastructure. They're the most utilized product made by the the steel industry. The primary use of pipe is in the transport of liquid or gas underground—including oil, gas, and water.

3.8 Hose Clamp

Fig:3.6 Hose Clamp

Hose clamp is a device used to attach and seal a hose onto a fitting such as a barb or nipple. Commonly, they're used in the automotive and agriculture industries. However, apart from their usual applications, it's not uncommon for people to use hose clamps for other purposes, such as for clamping lines during home emergency plumbing repairs and in this system hose clamp is used to fitting pipe of liquid collecting line.

3.9 Nitin Pipe

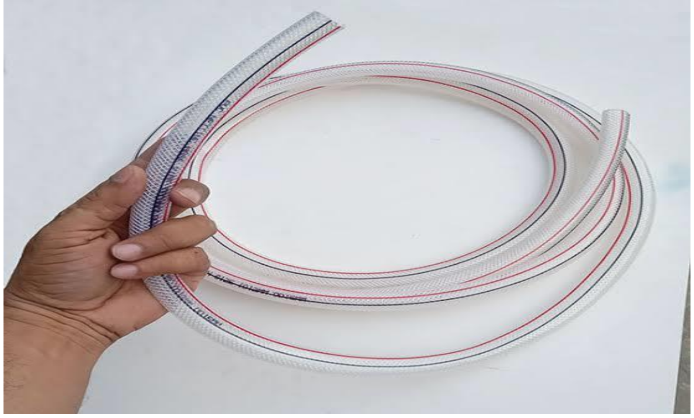

Fig:3.7 Nitin Pipe

3.10 Ball Valve

Fig:3.8 Ball Valve

Ball valve is the most used fluid shutoff valve in upstream oil and gas production facilities, both onshore and offshore. They are also used in fuel gas systems feeding furnaces. Plug valves present the following advantages: Resistance to high pressure. In this work ball valve is used to resistance to gas flow.

3.11 Polly Bag / Gas Collector

Fig:3.9 Polly Bag with Gas stored

A polly bag is a common shipping and packaging resource made of polymer material that is exceptionally durable, pliable, and customizable to fit any application. Made of polyethylene or polystyrene materials, poly bags are a precisely engineered and designed compact method for protecting and securing products, parts, and merchandise.In this case polly bag is used to storage.

3.12 Condenser

A condenser is a vessel or stage which turns a vapor into a liquid. A compressor is used to pump that vapor to a condenser, where the vapor turns back into a liquid, ready for reuse. Condensers are special heat exchangers that remove the heat of vaporization from steam. condenser's function is to allow high pressure and temperature refrigerant vapor to condense and eject heat. There are three main types: air-cooled, evaporative, and water-cooled condensers. In this work water cooled condenser is to reduced gas temperature.

3.13 Threat Tape

Fig:3.10 Threat Tape

Thread seal tape (also known as PTFE tape, Teflon tape, or plumber's tape) is a Polytetrafluoroethylene (PTFE) film tape commonly used in plumbing for sealing pipe threads. The tape is sold cut to specific widths and wound on a spool, making it easy to wind around pipe threads. Another alternative to thread seal tape is Valve packing, which is another form of Teflon. In this case it's used to in pipe fitting joint as like sealing. It's used as an alternative for

O-rings as it acts as a gasket or bushing, ideal for connections that come with large gaps or with a ridge.

3.14 Silicone Gel

Fig;3.11 Silicone Gel

Silicone gels are typically composed of a very lightly cross-linked silicone elastomeric whose polymer network has been swollen with silicone fluids or, less commonly, non silicone fluids, such as mineral oil. In this experiment silicone gel are used to sealing. A silicone gel sheet is a soft, flexible, self-adhesive dressing that is applied over scars. It contains silicone. Silicone can help to improve the color, height and texture of a scar. Silicone can also relieve itching and discomfort caused by a scar.

3.15 Insulation Foam

Fig:3.12 Insulating Foam

Expanding foam became a valuable form of insulation due to its thermal properties and resistance to heat flow, otherwise known as R-value. The higher the R-value, the more effective the insulation. In this experiment, insulating foam are used on reactor cylinder for resistance of heat.

3.16 Method Of Plastic Pyrolysis

This experiment is divided into two parts. The first step of pyrolysis used materials collected from some waste plastic storage which was a mixer of 50% PE, 25% PP, and 25% PS (weight) in the from of post-consumer plastic chips.

Fig:3.13 Used Waste Plastic

During the experiment 1.5 kg of the collected materials sample chips were placed in the centre of the combustion chamber inside the reactor cylinder that was for maintaining consistency of the sample location in the reactor cylinder.

Fig:3.14 Reactor Cylinder

The bottom section was at the heating zone of the furnace, which had the highest temperature in the process.

After the test plastic chips were placed in the reactor cylinder, the system was sealed. When the pyrolysis started and the plastic was heated and then decomposed once the temperature is high enough, the gases produce went through the water-cooling condenser and the temperature was reduced to about 35 degree "C' liquid and non-condensable gases were separately then collected separately.

Fig:3.15 Gas Collecting Polly Bag

The process ended when no more products came out and the space temperature raises above 500 degree "C". In the second phase of pyrolysis used materials is "Rich Husk" which was a mixer of cellulose (50%), lignin (25%-30%), silica (15%-20%) and moisture (10%-15%) (weight). During the experiment 1kg of the collected materials sample were placed in the combustion chamber inside the reactor cylinder that was for maintaining consistency of the sample location in the reactor cylinder.

Fig:3.16 Rich Husk

After the test plastic chips were placed in the reactor cylinder, the system was sealed. When the pyrolysis started and the plastic was heated and then decomposed once the temperature is high enough, the gases produce went through the water-cooling condenser and the temperature was reduced to about 35 degree "C' liquid and non-condensable gases were separately then collected separately. The process ended when no more products came out and the space temperature raises above 500 degree "C.

CHAPTER 4 - FUEL ANALYSIS AND DISCUSSIONS

4.1 Fuel Analysis And Discussions

The 1.5kg plastic mixture and other pyrolysis process 1kg rich husk was completely pyrolized and after the experiment some ash was left in the centre of the combustion chamber. The production collected included non-condensable gases in the gas collector, but non of the gases from the plastic and rich husks could be quantified.

Fig;4.1 Collected Ash After Pyrolized

The measured accumulated volume of non-condensable gas product was shown in figure 3.15 for plastic waste pyrolysis experiment. From the figure, it is found that the non condensable gas started to be generated when the combustion temperature reached a certain temperature, 450 degree "C", in all two runs. This start of gas generation indicated the corresponding star of plastic cranking. In the experiment, the test sample of plastic mixture was placed horizontally in the combustion boat. The plastic at the central zone of the boat would start cracking earlier than those at the ends because of the temperature gradient along the reactor length. Although it was unable to determine exactly the hottest spot in the combustion boat. It should be noted that the actual cranking temperature can be slightly different and likely to be lower than upside point in the combustion chamber.

Table 4.1 Product output from the experiment

Sl No:	Product	Material Volume(kg)	Extracted Volume(gm)			
			Liquid Oil	Semi-Solid Oil	Non-Condensable Gas	Ash
1	Waste Plastic	1.5	177	115	Not Measured	155
2	Rice Husk	1	162	-	Not Measured	137

The non-condensable gas, liquid, ash and semi-solid product collected in the experiment are given in table 4.1. In addition to the gas, ash and semi-solid product was also found in the combustion chamber (at the two end zones) after the pyrolysis process was complete.

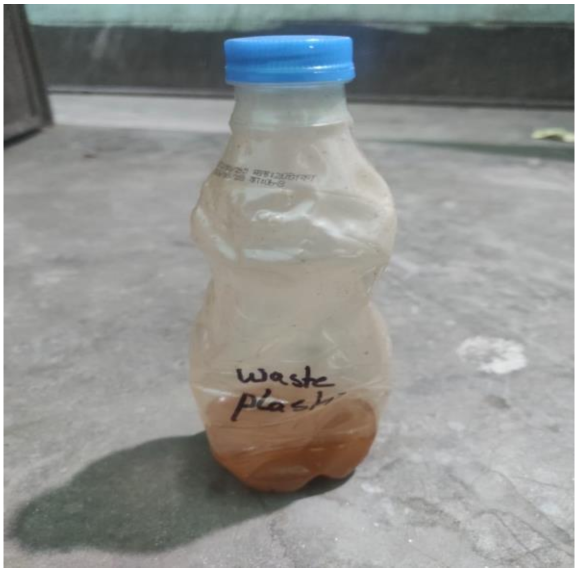

Fig:4.2 Final Liquid Product Collected From Waste Plastic Pyrolysis.

Fig.4.3 Final Liquid Product Collected From Rice Husk Pyrolysis.

Fig:4.3 Final Semi-Solid Product From Plastic pyrolysis.

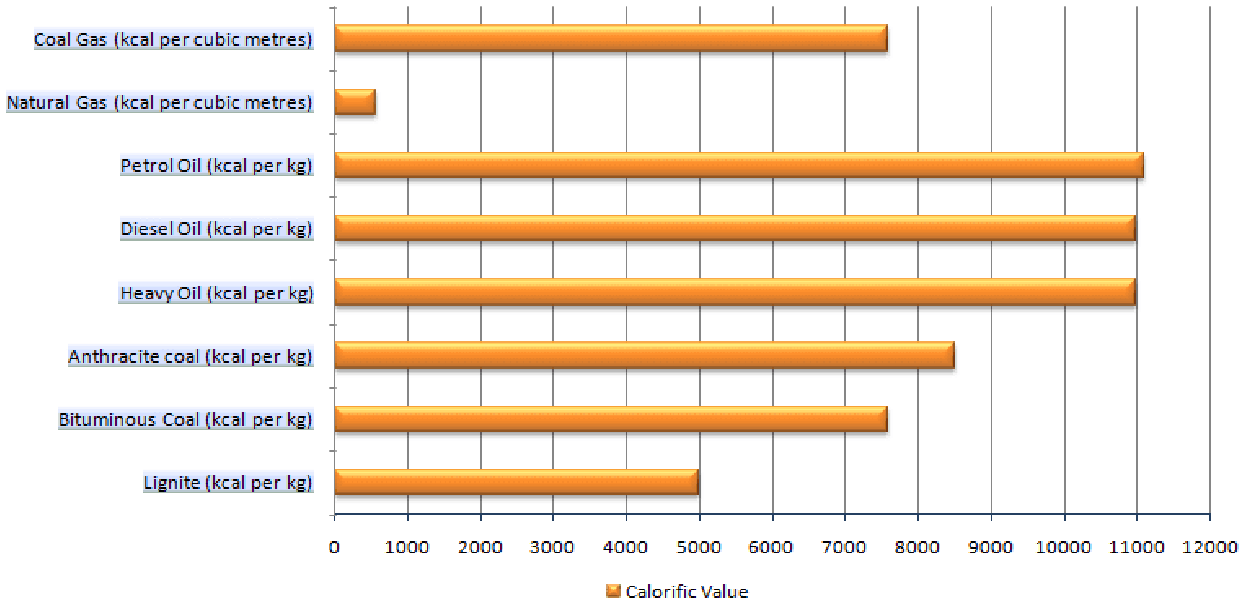

Fig:4.5 Calorific Value Of different Type of Fuel

Table. 4.2 Comparison Of Calorific Value Of Our Materials With Calorific Value Of Other Materials.

Reference-1 (Diesel Oil)	Reference-2 (Heavy Oil)	Our Extracted Product From Plastic Pyrolysis	Reference-3 (Bituminous Coal)	Reference-4 (Lignite Coal)
11000 Kcal/kg	11000 Kcal/kg	8151 Kcal/kg	8500 Kcal/kg	5000 Kcal/kg

In the figure 4.5 is shown the calorific value of different type of fuel. The extracted liquid and semi-solid products are sent to "Institute Of Fuel Research And Development" for calorific value testing. IFRD could not measured the calorific value of extracted liquid fuel of waste plastic and rice husk-derived liquid fuel due to water content. On the other hand the calorific value of fuel extracted from waste plastic was measured and the result was 8151 Kcal/kg. If we compared the calorific value of this semi-solid fuel to the calorific value of different type of fuel that shown in figure 4.5 so the CV of semi-solid fuel obtained from our pyrolysis process is lower than the "Anthracite Coal" and higher than the "Bituminous Coal"

CHAPTER-5 CONCLUSION

5.1 Conclusion

The aims of this part of experimental studies were to experimentally examine the effect of the pyrolysis process and the produced product. Non-condensable gas, liquid, ash and semi-solid were are the final products in the pyrolysis of waste plastic and the non-condensable gas, liquid and ash were are the final products in the pyrolysis of rich husk. The calorific value of the liquid fuels obtained from our experiments could not be measured due to their water content. Condensation system should be improved so that is no liquid content in the extracted product and care should be taken to ensure that is no liquid in the materials used. it was concluded that the rapid production of non-condensable gases were generated from random cracking at the beginning of the pyrolysis.

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