بسم الله الرحمن الرحيم

Sudan University of Science
and Technology
College of Engineering
Mechanical Engineering Department
(Power)

Experimental Study to generate Useful Fuel from Waste Plastic in Khartoum

التجربة العملية لإستخلاص وقود صالح للإستخدام من المخلفات البلاستكية

Thesis Submitted in partial fulfillments for the degree of B.Eng (Honors) in Mechanical Engineering (Power)

Prepared by:

- **Alrumytha Taha Musa Fadlelmwla**
- **Omer Khair Allah Mohammed Hajana**
- **Tarek Anwer Ali Alnour**

Supervised by:
Dr. A.A.A.Abuelnuor

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الأية

قال تعالى :

﴿وَعَلَّمَ آدَمَ الْأَسْمَاءَ كُلَّهَا ثُمَّ عَرَضَهُمْ عَلَى الْمَلَائِكَةِ فَقَالَ أَنْبِئُونِي بِأَسْمَاءِ هَؤُلَاءِ إِنْ كُنْتُمْ صَادِقِينَ (31) قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ﴾

صدق الله العظيم

Dedication

To our parents who guide us through our life with their love and care and to the soul of the lately deceased our father (Taha Musa Fadlelmwla) .

To our brothers and sisters, whom never stopped giving us all supports, and trust that we needed to go on. To our friends whom helped us to accomplish our duties and for being there for us, and to our deer supervisor (Dr. A.A.A.Abuelnuor) . Wishing them good health and luck in their life's.

Thank you all

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We greatly appreciate the efforts of all my colleagues in school of mechanical who have played different roles in our support and facilitated for us all the possible resource to complete this research work.

Abstract

Recently the world suffer from depletion of energy recourse, especially fossil fuel. WTE is one of the methods to solve this problem. Today plastic wastes disposal represents great challenge in both developed and developing Countries. In this this study converting plastic waste into use fuel, has been studied experimentally. This fuel had been examined in laboratory and obtained that it has a high colorific value.

المستخلص

مؤخرا أصبح العالم يعاني من نقص كبير في مصادر الطاقة، وبالأخص مصادر الوقود الأحفوري.تحويل المخلفات إلى طاقة هى إحدى الطرق لحل هذه المشكلة.

في الوقت الحالي، التخلص من المخلفات البلاستيكية، أصبح مشكلة في الدول النامية والدول المتقدمة. في هذه الدراسة تحويل المخلفات البلاستيكية إلى وقود صالح للإستخدام, قد تم التوصل إليه بالتجربة, والوقود المتحصل عليه أختبر في المعمل, وكان ذو سعة حرارية عالية.

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Abbreviations

RIC	Resin Identification Code
EVOH	Ethylene-Vinyl alcohol
TGA	Thermo Gravimetric Analysis
SPI	Society of Plastic Industry
PI	Post Industrial waste
PC	Post-Consumer waste
PU	Poly-Urethane
EEE	Electrical and Electronic Equipment
PMMA	Poly methyl Methacrylate
EPA	Environmental Protection Agency
WTE	Waste-to-Energy
CO_2	Carbon dioxide
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
KSA	Kingdom of Saudi Arabia
HHV	High Heating Value
MPW	Municipal Plastic Waste
MSW	Municipal Solid Waste
NOx	Oxides of Nitrogen
PE	Polyethylene
PS	Polystyrene
PTF	Plastic-to-Fuel
PVC	Polyvinyl Chloride

Symbols

T	°C
Φ	%
μ	Cst
P	Atm
□	g/ml
c.v	Kj/kg

CHAPTER ONE

Introduction

1.1 Background:

Energy is a necessity for economic development and life quality improvement, and yet it is mainly produced from fossil fuels that are in contrast with sustainability [1]. With increasing energy demand globally coupled with depletion of the earth's fossil energy resources and growing problem of disposal of non-biodegradable waste such as plastic [2].

The world at present is confronted with the twin crisis of fossil fuel depletion and environmental degradation. Rapid depletion of conventional fossil fuel resources, their rising prices and environmental issues are the major concern of alternative fuels mainly derived from renewable or from wastes [3]. Recently biomass utilization has received more attention because of the environmental problems of global warming and the depletion of fossil fuel. Biomass is an abundant and renewable energy resource, which can replace fossil fuel [4].

Human activities create waste and these wastes are handled, stored, collected and disposed of, which can pose risks to the environment and to public health [5]. Due to a massive increase in volume and diversity of plastic waste materials generated by human and industrial activity, statistics show that more than over 260 million tons of plastics were produced in the world [6].

On the other hand waste plastics cause a very serious environmental dispute because of their disposal problems . Waste plastics are one of the promising factors for fuel production because of their high heat of combustion and their increasing availability in local communities[5].

Plastic waste can be transformed into an alternate fuel with the aid of Pyrolysis, which studied over the last few decades with the objective of producing useful liquid and gaseous fuels or chemicals from low value polymeric waste [5]. So Plastic is a potential ingredient to be converted into fuel by a pyrolysis process [7].

1.2 problem statement:

Recently in the last three decades the use of plastic increased Intentionally. that causes waste accumulation and this has a negative environmental impact because plastic wastes are un degradable material. There are several MPW disposal methods such as: (landfilling, recycling, Incineration, Gasification, and pyrolysis). Pyrolysis is the process used to convert plastic solid wastes into a useful fuel .

1.3 Research objective :

The objective of this study are :

i. To Design and fabricate test rig pyrolysis for MPW.
ii. To study experimentally emission from waste plastic.
iii. To investigate experimentally the plastic as a fuel.

1.4 scope of study:

To do this research there are many subjects had been covered such as: thermodynamics, fluid mechanics, material, and environmental science.

1.5 Significance of study:

Solve the problem of waste plastic disposal and to find an alternative fuel source.

CHAPTER TWO

Literature Review

2.1 Introductions:

The start of civilization, rapid migration of rural populations to urban centers, in search of better opportunities of livelihood, has resulted in race generating waste [8]. The level of MSW generation is directly related to economic development, rate of industrialization, and public practices of the region. It has been proven that a higher advancement in economic will result in a higher amount of MSW production [1, 9]. Low income regions have the highest fraction of organic waste, around 64 %, compared to high income regions where it is around 27 %. High-income regions have instead larger fractions of paper, metal and glass, which are smaller in low-income regions [9].In high-income countries, landfilling and WTE are the most common methods of MSW disposal [10]. So management of the solid wastes generated is a substantial challenge [11]. Municipal waste combustion (MWC) residues are generated at several points in the process of burning municipal solid waste (MSW) [12]. This has led to negative in affected the Planet Earth, so Global warming, diminishing energy supplies, and Disposal of wastes are a major concern [13].

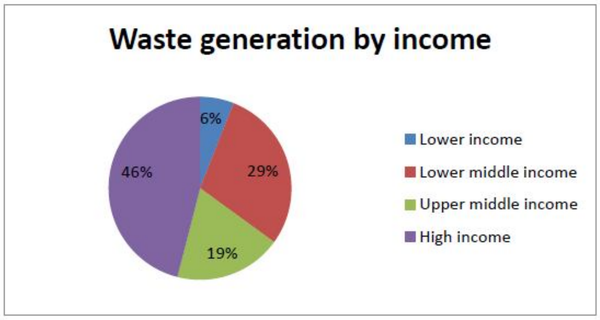


Figure 2. 1: Waste generation by income [8].

2.2 Municipal Solid wastes:

Municipal Solid Waste (MSW), commonly called “trash” or “garbage,” includes wastes such as durable goods (e.g., tires, furniture), nondurable goods (e.g., newspapers, plastic plates/cups), containers and packaging (e.g., milk cartons, plastic wrap), and other wastes (e.g., yard waste, food). This category of waste generally refers to common household waste, as well as office and retail wastes, but excludes industrial, hazardous, and construction wastes [14].

Municipal wastes are generated due to municipal services such as Street sweeping, and dead animals, market waste and abandoned vehicles or parts; also includes already mentioned domestic wastes, institutional wastes and commercial wastes [8]. The management of municipal solid waste (MSW) has been identified as one of the global challenges [15], for their handling to minimize their environmental impact. Traditional methods of waste management such as landfills and burning have a negative environmental impact, and societies are trying to minimize their use [16].

2.3Types of Solid Waste:

2.3.1 Medical Waste:

It refers to the waste materials generated at health care facilities, such as hospitals, clinics, physician's offices, dental practices, blood banks, and veterinary hospitals/clinics, as well as medical research facilities and laboratories.

The Medical waste is defined as "any solid waste that is generated in the diagnosis, treatment, or immunization of human beings or animals, in related research, or in the production or testing of biological." For example, the following trash constitutes medical waste: blood-soaked bandages, culture dishes and other glassware, discarded surgical gloves, discarded surgical instruments, discarded needles used to give shots or draw blood, cultures, stocks, swabs used to inoculate cultures, removed body organs (e.g., tonsils, appendices, limbs), and discarded lancets [8]. Plastic needles also will facilitate medical waste disposal by removing metal from the waste stream, hence making it easier to recycle [17].

Figure 2.2: Medical Waste

2.3.2 Hazardous waste:

Hazardous waste has dangerous properties and exerts a harmful effect on human health or the environment. Management of hazardous wastes is one of the major environmental issues [18].

The waste that is dangerous or potentially harmful to human health or the environment is called hazardous waste which can be in the form of liquids, solids, gases, or sludge. The discarded commercial products like cleaning fluids or pesticides, or the by-products of manufacturing processes can also be hazardous [8]. Hazardous waste sites are a potential threat mainly to groundwater and drinking water [19].

2.3.3 Industrial wastes:

These are non-hazardous solid material discarded from manufacturing processes and industrial operations, and are not considered as municipal wastes. However, solid wastes from small industrial plants and ash from power plants are frequently disposed of at municipal landfills [8].

Figure 2.3: Industrial wastes

2.3.4 organic waste:

includes animal and vegetable wastes due to various activities like storage, preparation and sale, cooking and serving; these are biodegradable [8].

Figure 2.4: organic waste

2.3.5 Domestic wastes:

Are generated by household activities such as cooking, cleaning, repairs, interior decoration, and used products such as empty glass/ plastic/ metal containers, packaging stuff, clothing, old books, newspapers, old furnishings, etc. [8].

Figure 2.5: Domestic wastes

2.3.6 Electronic waste(E-waste):

referred to the end-of-life electronic and telecommunication equipment and consumer electronics; to be specific, computers, laptops, television sets, DVD players, mobile phones etc., which are to be disposed. The industrialized countries generate tremendous amounts of E-waste. Most of it is exported to developing countries for disposal [8]. The electrical and electronic equipment (EEE) is one of the most growing productions globally [20].

Figure 2.6: Electronic waste(E-waste)

2.3.7 Plastic:

The Environmental Protection Agency (EPA) estimates that plastic accounts for about 12% total solid waste [21]. Municipal plastic waste (MPW) has a considerable share in the composition of Municipal solid waste (MSW) in both developed and developing countries [22]. Plastic waste is now one of the major components of municipal solid waste (MSW) [23].

The word ‘plastic’ is derived from the Greek word “plastikos”, meaning that materials are pliable for moulding into required shapes. Plastics are polymers synthesized chemically via polymerization from petroleum products [24]. It made from petroleum derivatives and considered to be a pollutant (air, land and water) [25].

Plastic is a high molecular weight material that was invented by Alexander Parkas in 1862. Plastics are also called polymers. The term polymer means a molecule made up by repetition of simple unit. For example, the structure of polystyrene can be written in a form as shown in Figure 2.7 or in Figure 2.8 .

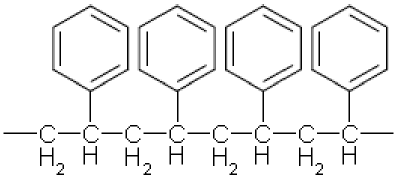


Figure 2.7: Common expression of polystyrene molecular structure [26].

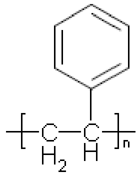


Figure 2.8: A simplified expression of polystyrene molecular structure [26].

The repeating unit of the polymer is in the brackets with a subscript, n, to represent the number of the unit in this polymer molecule [26].

Plastic consist of repeating long chains of carbon and other chemical elements. For example: ethylene (CH2=CH2) is the monomer of polyethylene (-CH2-CH2-).

In the polymerization process, monomers bonds break down and then an open bond created in the monomer. So, the monomer can joint with other or same repeating unit and create long chain of the monomer. Such as:

Vinyl chloride (CH2=CHCl) is the monomer of PVC or poly vinyl chloride - [-CH2 - CHCl-] –

Or: - [-CH2-CHCl-]-[-CH2-CHCl-]-[-CH2-CHCl-]-[-CH2-CHCl-]-[-CH2-CHCl-]-[-CH2-CHCl-]- [27].

The invention of plastics is a major milestone that led to improvement in the quality of the lives of human beings. plastics have substituted many types of materials such as wood, metals and ceramics in production of consumer products, as they are light, durable, resistant to corrosion by most chemicals, diversity of applications, ease to processing and low cost. Other than the mentioned advantages of plastics, studies have shown that plastic based products are responsible for reduction in cost of production in different fields of human endeavor In transportation, for instance, the use of plastic in manufacturing vehicles components and accessories reduces the weight, hence the fuel consumption of vehicles [28]. Plastics are nowadays indispensable in agriculture. They are used for crop protection and shading, soil mulching, irrigation pipes, silage covering, harvesting and post-harvesting operations, this involves several benefits but it results in huge quantities of agricultural plastic waste to be disposed of [29]. Plastics have carbon and hydrogen in their polymer backbone, Most plastics are made from simple hydrocarbon molecules (monomers) derived from oil or gas [30]. The thermal degradation process at an elevated temperature with a long pyrolysis time leads to the production of significant amount of hydrocarbons gases [31]. Discarding of the waste plastics create an enormous risk to the surroundings, it takes nearly 8 years for degrading. Land filling is not a suitable option for disposing plastic wastes because of their slow degradation rates. The use of incinerator generates some pollutants to the air, which also cause environmental issues. Therefore, recycling and recovering method have been used to minimize the environmental impacts and to reduce the damage of plastic wastes [26].

2.4 Classification of plastic:

2.4.1 Thermoplastic:

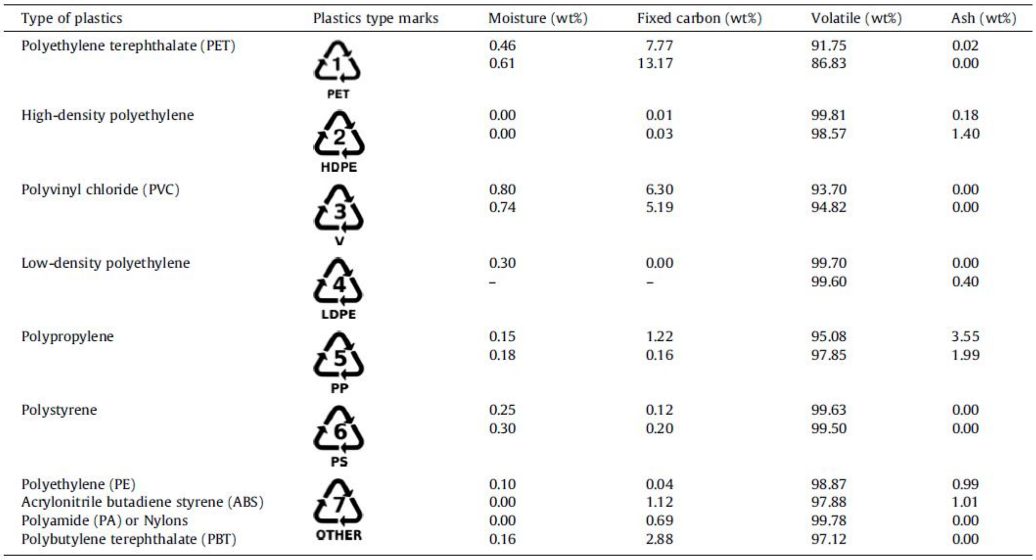
Thermoplastic made of long side chains. The bond between thermoplastics molecules are weak so they can be soften and harden through heating and cooling process repeatedly. And these changes do not make any kind of changes in their chemical structure. Thermoplastic have certain recycling capacity, it can be recycled after used. Most of the plastics products are made from thermoplastics [32]. 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 [26]:

- PET (Polyethylene Terephthalate)
- HDPE (High Density Polyethylene)
- PVC (Polyvinyl Chloride)
- LDPE (Low Density Polyethylene)
- PP (Polypropylene)
- PS (Polystyrene)
- Other

HDPE is characterized as a long linear polymer chain with high degree of crystallinity and low branching, which leads to high strength properties, So it's widely used in manufacturing of milk bottles, oil containers, toys and more [33]. Their application explain in Table (2.1) The above seven types of plastics are marked on various plastic products as follows in Figure (2.9), also Their application explained.

Figure 2.9: Marks of the seven types of plastics on various plastic products [26].

Table 2.1: Proximate analysis of plastics [33].



Type of plastics	Plastics type marks	Moisture (wt%)	Fixed carbon (wt%)	Volatile (wt%)	Ash (wt%)
Polyethylene terephthalate (PET)	1 PET	0.46	7.77	91.75	0.02
		0.61	13.17	86.83	0.00
High-density polyethylene	2 HDPE	0.00	0.01	99.81	0.18
		0.00	0.03	98.57	1.40
Polyvinyl chloride (PVC)	3 V	0.80	6.30	93.70	0.00
		0.74	5.19	94.82	0.00
Low-density polyethylene	4 LDPE	0.30	0.00	99.70	0.00
		–	–	99.60	0.40
Polypropylene	5 PP	0.15	1.22	95.08	3.55
		0.18	0.16	97.85	1.99
Polystyrene	6 PS	0.25	0.12	99.63	0.00
		0.30	0.20	99.50	0.00
Polyethylene (PE)	7 OTHER	0.10	0.04	98.87	0.99
Acrylonitrile butadiene styrene (ABS)		0.00	1.12	97.88	1.01
Polyamide (PA) or Nylons		0.00	0.69	99.78	0.00
Polybutylene terephthalate (PBT)		0.16	2.88	97.12	0.00

2.4.2 Thermosetting plastic:

It formed a cross-linked structure during processing so they cannot be reshaped or recycled. The bond between the molecules is very strong [32]. Thermo-setting plastics cannot be modified or re-softened [34]. For example polyurethane (PU): used in coatings, finishes, mattresses and vehicle seating, epoxy : used in adhesives, boats, sporting equipment, electrical and automotive components. And phenolic : used in ovens, toasters, automotive parts and circuit boards [30].

Table 2.2: Different available plastic polymers and their applications.

Thermoplastic	Application	Thermosetting	Application
PVC (Polyvinyl chloride)	Construction, Medical, Electrical, Automobile, Packaging, etc.	Bakelite	Electrical systems, non-conducting parts of telephones, radios and other electrical devices, including bases and sockets for light bulbs and electron tubes, supports for any type of electrical components, automobile distributor caps, insulators, billiard balls
PET (poly ethylene terephthalate)	Packaging film, PET Bottle, Carpet yarn, Engineering plastic, Filaments, Nonwoven, Packaging stripes, Staple fiber.	Epoxy	Coatings, adhesives and composite materials
Polypropylene	Bi axially oriented polypropylene (BOPP), clear bags, carpets, rugs and mats	Melamine	Formica, melamine dinnerware, laminate flooring, and dry erase boards
LDPE(low Density polyethylene)	Packaging for computer hardware, such as hard disk drives, screen cards, and optical disc drives, Trays and general purpose containers.	Polyester	Staple fiber (PSF), Bottles for CSD, water, beer, juice, detergents, Technical yarn and tire cord
HDPE(high density polyethylene)	Toys, utensils, films, bottles, pipe and processing equipment. Wire and cable insulations	Polyurethane	Building insulation, Refrigerators and freezers, Furniture and bedding, Footwear, Automotive. Coatings and adhesives.

During the manufacturing process, plastic waste can be classified in two types. First type of solid plastic waste (SPW) is generated: postindustrial (PI) waste, which never makes it to the consumer. Typically PI waste has the distinct advantages that it is clean and the composition of the polymer is known. In terms of recycling, these are often the higher-quality grades of polymer waste. At end-of-life, the product is disposed and becomes postconsumer (PC) waste. Depending on the country, PC plastic waste is collected separately or not. Typically, PC plastic waste consists of mixed plastics of unknown composition and is potentially contaminated by organic fractions (such as food remains) or non-polymer inorganic fractions (such as paper), which makes it a more complex stream to recycle than PI waste [35].

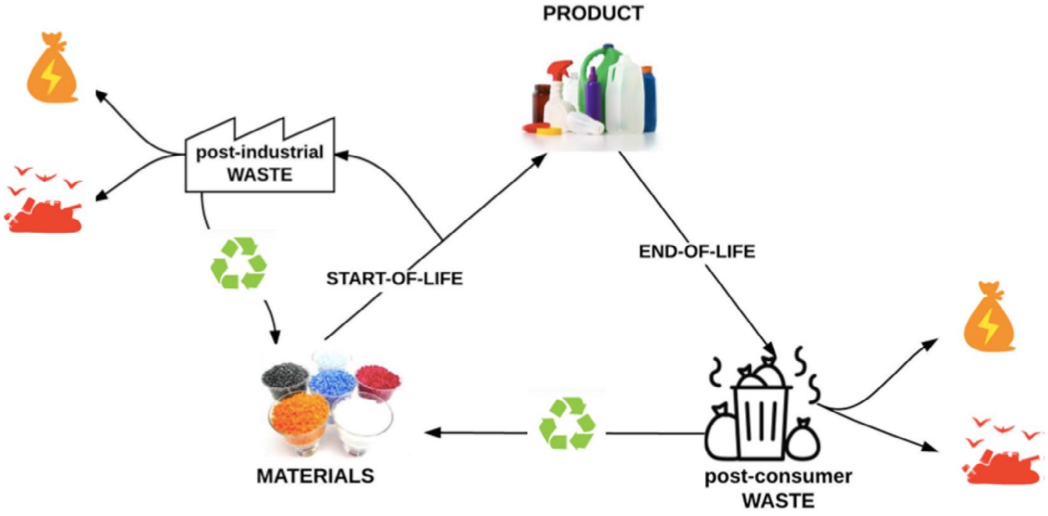


Figure 2.10: Life cycle of polymer material on chosen route, polymers will end up in recycling, energy recovery, and landfill [35].

2.5 Alternative Waste Disposal Methods:

Waste plastics disposal is an ever-increasing menace for global environment [36].

2.5.1 Recycling:

Recycling is one of the primary option available to reduce environmental Impacts associated with the disposal of plastics, reducing carbon dioxide ($CO2$) emissions, fossil fuel use and minimizing landfill deposition.

Recycling is not the complete solution for the disposal of waste plastic; because recycling into the same product with the same quality is not possible because the process alters the chemical properties of the original material. Recycling of plastics results in shortening of the polymer chains, with weakened strength and durability, making it unsuitable for use [37]. Thermosetting plastic is one of the basic categories of plastic which cannot be recycled again such as: Bakelite, Epoxy, Melamine, Polyester, Polyurethane and Urea –Formaldehyde. After third or fourth, recycling the plastic is unfit for reuse and hence ultimately it ends up in land filling [32].

2.5.2 Land Filling:

Land filling is the most convenient approach for waste management, but space constraints in developed countries and countries with high population densities limits this management practice. Most plastic packaging and non-recyclable plastics are disposed-off in landfills [38]. Landfills represent the dominant disposal practice for municipal solid waste (MSW) in the United States as well as in many other countries [39]. Disposal of MSW, industrial and agricultural waste at landfills produce significant amounts of methane gases $CH4$. The methane is produced during anaerobic digestion of organic material. In additional to the methane gas landfills also produce carbon dioxide $CO2$, and smaller amounts of nitrous oxide NOx [9].

Waste plastic materials are dumped for land filling and they become mummified after decades. Major drawbacks to waste management of plastics in landfills, are toxic adversely affecting soil microbial flora, leading to soil infertility and water supply contamination [40].

Plastic is not a biodegradable material that cause severe environmental hazard such as degradation of soil fertility, pollution of surface and subsoil water [32]. It also presents a risk to human health and exacerbates the problem of global warming since GHG, such as methane, are constantly released to the atmosphere [41].

2.5.3 Incineration:

Incineration is a common management practice for plastics, mainly applied to reduce the footprint of landfill facilities. The process is very expensive and dangerous.

Plastic incineration generates greenhouse gases (**GHGs**) such as methane (**CH4**) and (**CO2**), which are thought to lead to worldwide climate change [34].

Due to environmental footprint incineration is not a best option for managing plastics [34]. Incineration could recover energy from plastic waste by producing high pressure and temperature steam for power generation via steam turbine generator. However, it would need large amount of daily waste as well as a huge capital investment for construction work; hence this method of plastic waste management is generally not preferred, especially in developing countries [22].

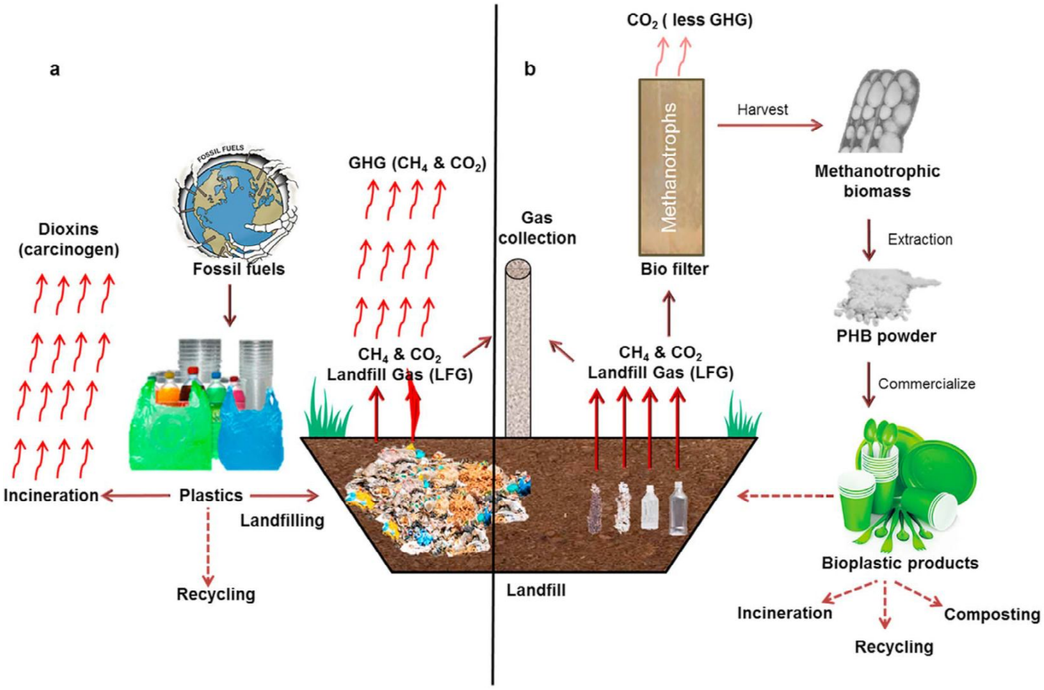


Figure 2.11: End of life landfill degradation of a) plastics and b) bio-plastics [34].

2.5.4 Blast Furnace:

Waste plastic may be used in place of coke, after forming into particles of the required size, and subsequently injected into the blast furnace.

The injected plastic is broken down to form reducer gas (CO+ H2), which rises through the raw material in the furnace and reacts with the iron ore.

The injection of chlorine-contained plastics such as poly vinyl chloride in the blast furnace generates hydrogen chloride.

Limestone used in the blast furnace to control the composition of the slag neutralist the hydrogen chloride in the furnace and decrease its concentration. substitution of coke with plastic is limited to approximately 40 % by weight only [34].

2.5.5 Gasification:

Gasification, unlike pyrolysis, is the process of conversion of carbonaceous materials (coal, petroleum, biofuel, biomass, or solid waste) into a combustible gas in the presence of a controlled amount of oxygen or air. Gasification is a partial oxidation with lower oxygen supply than that required for complete stoichiometric combustion. The operating temperature is generally within the range of 800–1200°C, depending on the type of reactor and the feedstock composition [16]. The resulting combustible gas is called synthesis gas (or syngas), and consists of carbon monoxide and hydrogen, carbon dioxide and methane, hydrocarbon oils, char and ash.

Gasification is an endothermic thermal conversion technology for extracting energy from different types of organic materials. The from a gasification plant include nitrogen oxides, sulphur dioxide, particulate matter, hydrogen chloride, hydrogen fluoride, ammonia, heavy metals, dioxins and furans.

The advantage of gasification is that using the syngas is potentially more efficient (than direct combustion of the original fuel) because it can be combusted at higher temperatures. Syngas may be burned directly in internal combustion engines (IC engines) or used to produce methanol and hydrogen, or converted via the Fischer-Tropsch process into synthetic fuel [8].

Gasification is essentially thermal decomposition of organic matter under inert atmospheric conditions or in a limited supply of air. If the feed contains chlorinated compound like PVC, gasification at lower temperature is the best option to remove chlorine, then the temperature is raised to convert higher hydrocarbons. However there are problems in controlling the combustion temperature and the quantity of unburned gases.

2.5.6 Pyrolysis process:

The word “paralysis” comes from the Greek word “πυρ” (pyr) which means fire and the Greek word “λύσις” (lysis) which means breakdown and separation emphasizing the disintegration of matter due to heat. Paralysis

or cracking is a thermal degradation process in the absence of oxygen, performed to obtain WPO by using silica alumina as a catalyst or without catalyst [26]. and typically at temperatures ranging between 300°C and 650°C [16]. Pyrolysis is an interesting technology for plastic waste feeds that are difficult to depolymerize and that are currently not (mechanically) recycled but incinerated and/or dumped to landfill such as mixed PE/PP/PS. The pyrolysis products of SPW can be decomposed into three fractions: gas, liquid and solid residue[35]. in different proportions just by the variation of operating parameters such as temperature or heating rate. It also gives possibility to transforms materials of low-energy density into bio-fuels of high-energy density [42].

In the pyrolysis process (heating in an oxygen-free atmosphere), the organic components of the decomposed material generate liquid and gaseous products, which can be used as fuels and/or a source of chemicals. The process is influenced by some important parameters such as temperature and time. Some papers report that the pyrolysis process happened at the temperatures of 350°C, 460°C, 500°C, 520°C, 600oC, 650°C, 685°C, 730°C, 780°C, 850°C, 900°C and within the duration of 15 minutes, 30 minutes, 60 minutes, or 120 minutes. Temperature distribution is important to be recorded because it can estimate the area in which thermal cracking occurs. Thermal cracking is the most important step in paralysis of plastic to produce fuel [43].

It is the most commonly used process to produce clean, high calorific value fuel from waste plastics. In this method hydrocarbon content of the waste plastics converted into fuel or gas with a high calorific value and produce char which has the industrial value as a resource of energy.

This technology has the operational advantages, environmental advantages and financial benefits. It is possible to convert around 80-90% of waste plastics into fuel or gas and could be easily marketed. It is the alternative solution for the land filling problem and reduced CO2 emission in the environment.

A catalyst (acid zeolites or transition metal oxides) can be added during the pyrolysis or to the liquid product for upgrading into synthetic fuels [44], The amount of catalyst used was 10% (w/w) relative to the amount of plastics feedstock used [33], Some of the inorganic components in MSW can also act as catalysts during pyrolysis, which can also have a significant influence on the products generated [45].

Now a day's paralysis technology gained a lot of attentions since it could convert plastic waste into oil that could be used as crude oil for further upgrading, distillation, or directly utilized with other conventional fossil fuels. This technology is adaptable at a community scale and requires significantly lower amount of budget compared to the incineration [22].

Studies have been started from analyzing the characteristics of liquid fuel produced from different type of plastics, up till the usage of catalysts in order to upgrade the liquid quality. In terms of quantity, most researchers reported high amount of liquid yield more than 80 wt.% could be produced in pyrolysis of individual plastic, which was higher than the pyrolysis of wood-based biomass in general. As for the quality, the obtained liquid also had high calorific value around 40 MJ/kg. With the addition of catalyst, the impurities contained in plastic waste could be removed, besides reducing the water content in liquid fuel. Only 21 wt.% liquid oil was obtained in the pyrolysis of plastic mixtures collected from the municipal solid waste (MSW). The parameters included temperature, ratio of plastic component, types of plastic waste, different bed material and type of fluidizing gas. Besides temperature, ratio also played an important role in determining the liquid product characteristics produced from pyrolysis of plastic mixtures [46]. Pyrolysis for the production of char as an energy carrier is not a new concept. It has been extensively used to produce charcoal and coke from biomass and coal [16]. The pyrolysis of MPW is a promising WTE or PTF technology for the sustainable management of plastic waste along with production of liquid oil as a source of energy and char and gases as value added products. pyrolysis process depends on series of factors such as temperature, residence time, heating rates, feedstock composition and presence of moisture or toxic elements [23]. Pyrolysis conditions are usually optimized in order to maximize the liquid and gas products; however a solid fraction named as pyrolytic char also are produced [42].

2.6 Current study on pyrolysis :

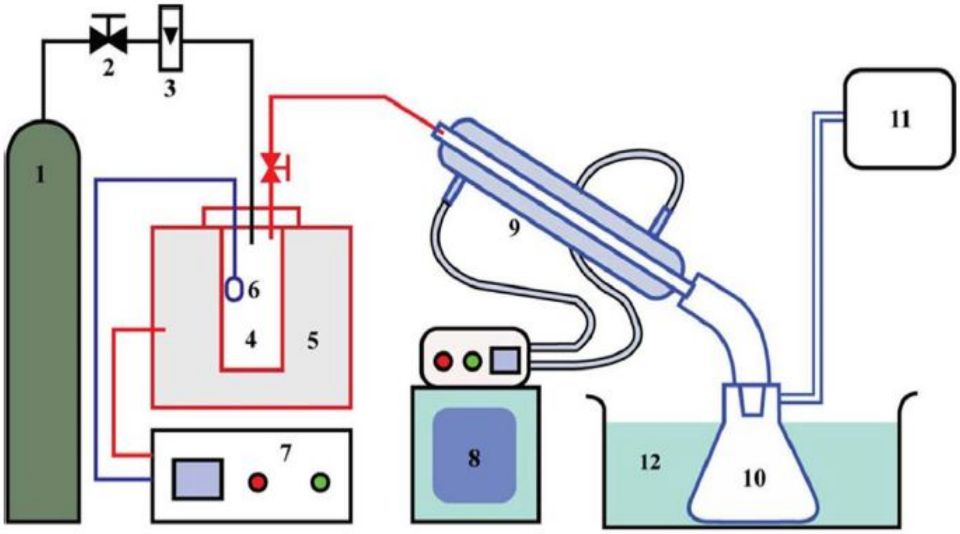
Virgin LDPE, HDPE, and PP were procured from Haldia Petrochemicals Limited, India. Physical properties of these plastics are reported In Table 2.3

Table 2.3: Physical properties of the materials

Plastics	**Density (kg/m^3)**	**Melting point (°C)**
LDPE	934	111±2
HDPE	950	132±1
PP	900	168±1

Materials collected were cleaned and segregated according to their resin identification code. Dry samples were cut manually into small pieces of size 1–2 cm for the paralysis. Segregated samples were mixed together in the proportion of 30 wt.% LDPE, 30 wt.% HDPE and 40 wt.% PP. Thermal degradation study was carried out for individual plastics using TGA (NETZSCH 209 F1 TG) equipment in inert environment (N2 gas) with a flow rate of 60 ml/min (40 ml/min as purge and 20 ml/min as protective gas) at a heating rate of 10 °C/min. TGA analysis was carried out to determine the temperature range at which degradation occurs.

Thermochemical conversion of plastics to plastic derived oil (PDO) were conducted in a semi-batch tubular reactor (SS 316) having a capacity of 1000 ml, heated externally by a tubular electrical furnace. Based on the TGA data, three pyrolysis temperatures (350, 375 and 400 °C) were selected for all the experiments except for the pyrolysis of PP (325, 350 and 375 °C) as the degradation range of PP is lower than LDPE and HDPE. The following processing sequence was adopted: samples were heated at a rate of 20 °C/min and subsequently held at the final temperature for 8 h. 50 g sample was taken for each run. N2 gas was purged continuously at a flow rate of 200 ml/min to maintain the inert environment inside the reactor and to sweep out the pyrolysis vapor products.

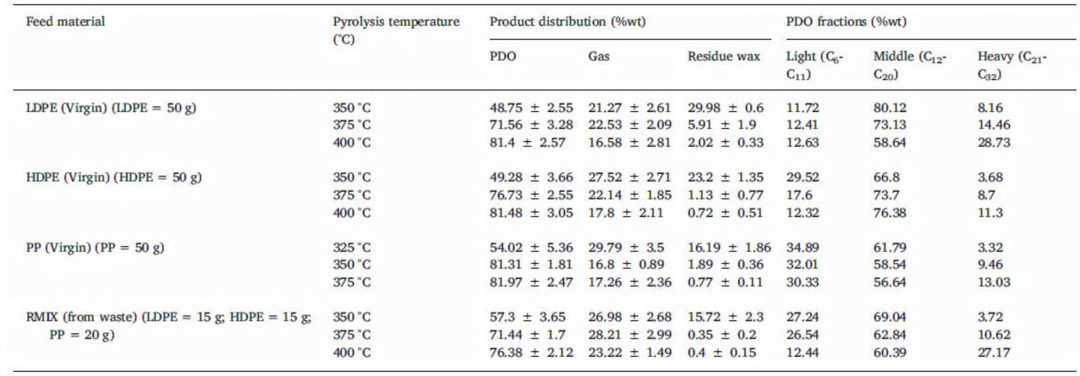


1.Nitrogen cylinder, 2. Regulator valve, 3. Rotameter, 4. Pyrolysis reactor,
5. Tubular furnace, 6. Thermocouple, 7. PID controller, 8. Water circulator,
9. Condenser 10. Conical flash to collect liquid, 11. Tedlar bag, 12. Ice bath

Figure 2.12: semi-batch tubular reactor [31].

The yields of three main products obtained from the lab scale pyrolysis experiments; plastic derived oil (PDO), gas and residue are summarized in Table 2.4 Oil yield was found maximum a higher reaction temperature and, the pyrolysis of PP produced the highest amount of PDO compared to other individual plastics.

Table 2.4: Pyrolysis yield from individual and mix plastic and the PDO fractions obtained from SimDist analysis.



Feed material	Pyrolysis temperature (°C)	Product distribution (%wt)			PDO fractions (%wt)		
		PDO	Gas	Residue wax	Light (C_6-C_{11})	Middle (C_{12}-C_{20})	Heavy (C_{21}-C_{32})
LDPE (Virgin) (LDPE = 50 g)	350 °C	48.75 ± 2.55	21.27 ± 2.61	29.98 ± 0.6	11.72	80.12	8.16
	375 °C	71.56 ± 3.28	22.53 ± 2.09	5.91 ± 1.9	12.41	73.13	14.46
	400 °C	81.4 ± 2.57	16.58 ± 2.81	2.02 ± 0.33	12.63	58.64	28.73
HDPE (Virgin) (HDPE = 50 g)	350 °C	49.28 ± 3.66	27.52 ± 2.71	23.2 ± 1.35	29.52	66.8	3.68
	375 °C	76.73 ± 2.55	22.14 ± 1.85	1.13 ± 0.77	17.6	73.7	8.7
	400 °C	81.48 ± 3.05	17.8 ± 2.11	0.72 ± 0.51	12.32	76.38	11.3
PP (Virgin) (PP = 50 g)	325 °C	54.02 ± 5.36	29.79 ± 3.5	16.19 ± 1.86	34.89	61.79	3.32
	350 °C	81.31 ± 1.81	16.8 ± 0.89	1.89 ± 0.36	32.01	58.54	9.46
	375 °C	81.97 ± 2.47	17.26 ± 2.36	0.77 ± 0.11	30.33	56.64	13.03
RMIX (from waste) (LDPE = 15 g; HDPE = 15 g; PP = 20 g)	350 °C	57.3 ± 3.65	26.98 ± 2.68	15.72 ± 2.3	27.24	69.04	3.72
	375 °C	71.44 ± 1.7	28.21 ± 2.99	0.35 ± 0.2	26.54	62.84	10.62
	400 °C	76.38 ± 2.12	23.22 ± 1.49	0.4 ± 0.15	12.44	60.39	27.17

Plastics have carbon and hydrogen in their polymer backbone, so the thermal degradation process at an elevated temperature with a long paralysis time leads to the production of significant amount of hydrocarbons gases [31].

The pyrolysis process takes place at high temperatures (500 °C, 1–2 atm) in absence of oxygen. Fig. 2.13 shows the implementation of a novel vortex reactor technology in a classical plastic waste pyrolysis plant, design equipped with a conventional separation section. the presence of certain impurities can substantially affect the product distribution and make that the obtained product lose a substantial part of its value, for example certain oxygenates that lead to the formation of methanol or formaldehyde, Catalytic cracking increases the oil yield as shown in Fig. 2.14 [35].

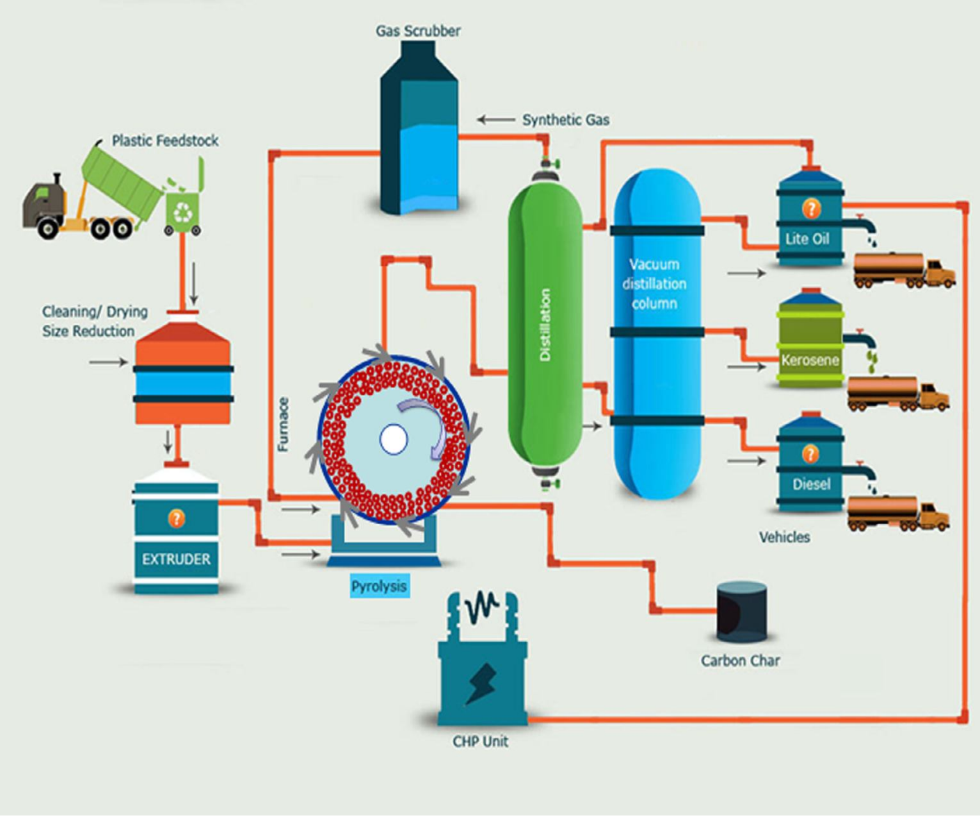


Figure 2.13: Process Flow Diagram of a classical pyrolysis plant with a novel vortex reactor technology [35].

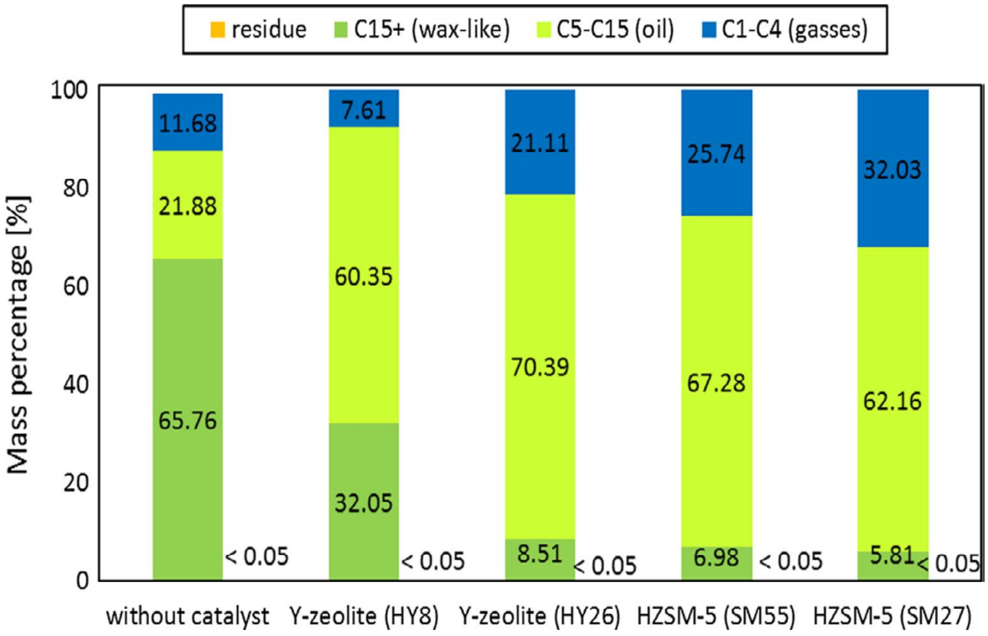


Figure 2.14: Products yields of various catalysts at 440 °C [35].

Plastic samples of PET, PVC, high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP) and PS were obtained from the post-consumer polymer waste stream in Malaysia [46]. Studies also showed that the formation of some undesired inorganic by-products containing Cl, Br, and S could be reduced with the use of catalysts [16].

The pyrolysis process was performed at 500 C with a heating rate of 20 C/min by using the electrical furnace. Each experiment was performed at 30 min reaction time, Nitrogen was used as carrier gas with flow rate of 200 ml/min to remove the products from the reaction site and minimize the secondary reaction of vapors that would reduce the yield of liquid oil, and then improve the liquid quality. Each experiment was repeated three times to take the average of the results.

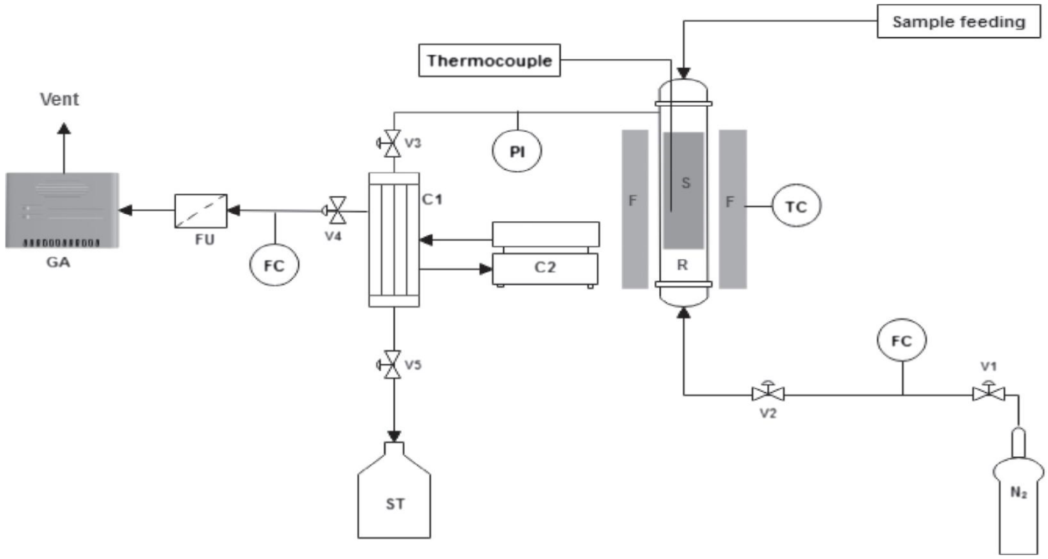


Figure 2.15: F: Furnace, R: Reactor, S: Sample, TC: Temperature controller, FC: Flow controller, V: Valve, C1: Condenser, C2: Chiller, ST: Storage tank, FU: Filter unit, GA: Gas analyzer [46].

Based on the proximate analysis results, the moisture content of all plastics were very low except for PET which was slightly high compared to others. No fixed carbon was found in all plastics except PET and PVC.

The oxygen content of PET was determined to be very high around 31.49 wt% where as high chlorine content was found in PVC around 57.61 wt%. The high oxygen content indicated that PET had lower calorific values while the high chlorine content made the liquid produced from pyrolysis of PVC not suitable to be used as fuel. The results showed that all plastics started to degrade at 300 C and completed the degradation at 500 C except PVC. From Fig. (2.16) it can be concluded that 500 C was selected as the most effective temperature for pyrolysis since all type of plastics have completed their decompositions when reaching this temperature [46].

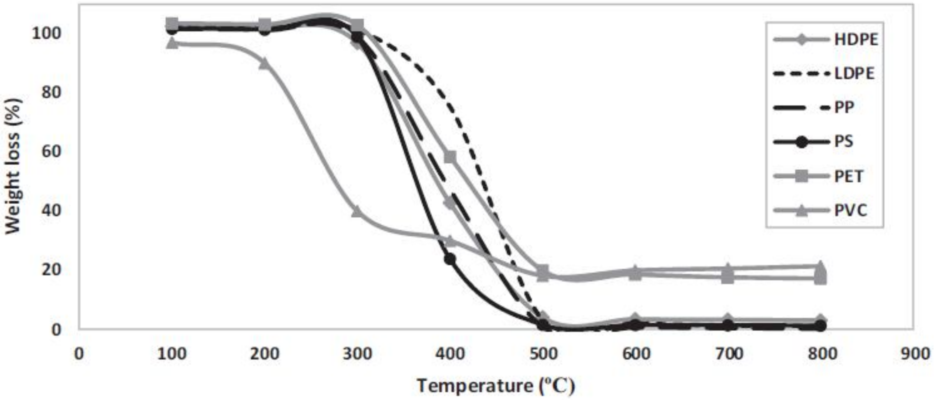


Figure 2.16 TGA thermographs of different type of plastics [46].

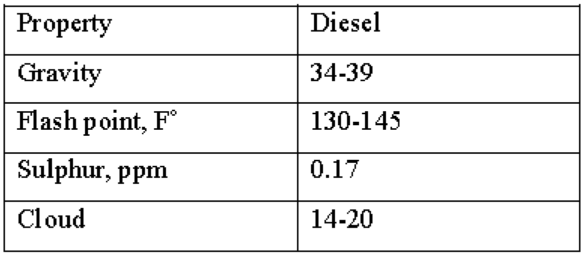
Williams and Williams conducted the pyrolysis of plastic waste (high- and low-density polyethylene, polypropylene, and PVC using a fixed-bed reactor at temperatures between 500°C and 700°C. The study showed that increased temperature led to a dramatic increase in the yield of gas. It was also found that higher temperatures enhanced the yield of aromatic compounds in the liquid product. pyrolysis at high temperatures will remove volatiles in the thermoplastic phase, which increase the pore size, resulting in a nonselective type of char. This type of char has properties similar to commercial activated carbon and has good adsorption capacity [16].

The increased residence time could lead to enhanced higher gas yields. However, long residence times could reduce the processing efficiency in terms of the capacity of MSW treatment. Heating rates for MSW pyrolysis reported in literature varied from approximately 10°C/min in slow pyrolysis to 600°C/s in flash pyrolysis. It was commonly recognized that high heating rate could lead to a higher yield of volatile products and lower char yield. Di Blasi has reported on the influence of particle size on MSW pyrolysis and concluded that reduced particle size in general resulted in increasing heating rate and consequently higher yield of the liquid product. Another study, showed that the influence of particle size on the yield of the liquid product was minor when the temperature was sufficiently high. Additionally, operating pressure is also an influencing factor. High pressure pyrolysis increases the yield of char, although practically it may be difficult to operate.

A study compared the behavior of heavy metals in MSW pyrolysis with that in incineration and showed that the release of heavy metal in rapid-heating combustion generally exceeded that observed in pyrolysis. The volatilities of some heavy metals, e.g., Zn and Pp., were reduced in pyrolysis compared to those in combustion. It was concluded from that study that pyrolysis is a better choice for MSW treatment in terms of controlling heavy metal contamination [16].

Green Diesel factory in Bangladesh, will use HDPE, LDPE, LLDPE, and PP. mixed waste plastics as its feedstock. During this process additive such as lubricant and antioxidant has to add. Finally at certain temperature level diesel is collection from the distillation chamber. produced better version of diesel with less than 0.17 ppm of sulphur. This means that better diesel quality. Green Diesel's diesel is new, ultra clean, don´t need to recycle, cheaper and moreover has the same efficiency as local diesel [47].

Table 2.5: explain the properties of green diesel.



Property	Diesel
Gravity	34-39
Flash point, F°	130-145
Sulphur, ppm	0.17
Cloud	14-20

In Kingdom of Saudi Arabia (KSA), 1 kg of feedstock for each plastic type was used in the pyrolysis reactor individually and in mixture form. The reactor was heated from room temperature to 450 C using a heating rate of 10 C/min. The effect of plastic types on pyrolysis product yields, especially on the liquid oils is shown in Fig.(2.17) PS showed maximum conversion of feedstock into liquid oil (80.8%) along with least gases (13%) and char (6.2%) in comparison to other plastic waste types. Also reported similar results that PS produced maximum fraction of liquid oil in comparison to PE and PP plastic types, this maximum degradation of PS was due to its simple structure in comparison to other plastic types. Thermal pyrolysis of PP produced relatively less amounts of liquid oil (42%) and char (3.5%) along with high yield of gases %(54.6).

However, the slow pyrolysis of PP waste increased the liquid oil yield as compared to gases yield. In the present study, the large amount of gases production can be attributed to the fast pyrolysis, since the experiments were carried out at high heating rate of 10 C/min. Pyrolysis of mixed plastic was also carried out with different ratios Table2.6 . The results showed that addition of PS with PP further reduced the liquid oil yield down to 25% from their individual yields of 80.8 and 42% respectively. Similarly, mixing of PS with PE reduced the liquid yield in comparison to individual PS pyrolysis. The GC-MS results of produced liquid oil from mixing of PS with PE also showed the presence of some aliphatic and olefins compounds that is the characteristics of PE liquid oil. The mixing of PP with PE increased the gases (51.2%) and char (24.8%) yields with a decrease in liquid oil yield (24%). also reported the similar trend of high gases yield from the pyrolysis of PE with PP. Furthermore addition of PS and PP with PE at a ratio of 50/25/25% has slightly increased the liquid oil yield (49%) along with gases (47.2%) and char (3.9%). However, no wax was produced from this mixture as compared to only PE pyrolysis. Moreover mixing of PS with PET, PP and PE at a ratio of 40/20/20/20% decreased the liquid yields down to 40%, while gases (42%) and char (18%) yields were increased. Moreover, addition of PET increased the production of halogenated compounds in the produced liquid oil. TGA was carried out for each type of plastic waste individually to find out its optimum temperature for thermal degradation under control conditions Fig (2.19).

Figure 2.17: Small pilot scale Batch Pyrolyzer Reactor [23].

Table 2.6: Experimental scheme.

Feedstock types	Quantity (kg)	Ratio (%)	Retention time (min)	Temperature (°C)	Heating rate (°C/ min)
PS	1	100	75	450	10
PE	1	100	75	450	10
PP	1	100	75	450	10
PS/PP	1	50/50	75	450	10
PS/PE	1	50/50	75	450	10
PP/PE	1	50/50	75	450	10
PS/PE/PP	1	50/25/25	75	450	10
PS/PE/PP/PET	1	40/20/20/20	75	450	10

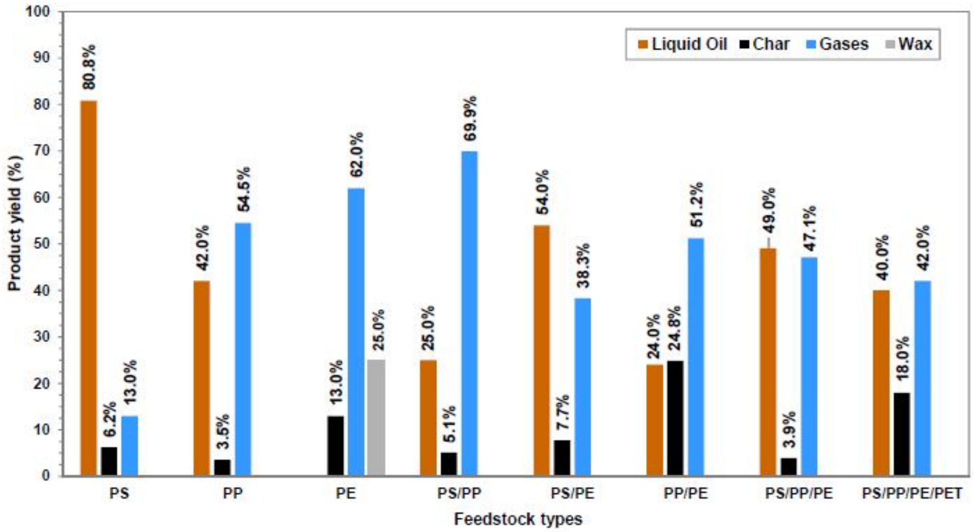


Figure 2.18: Effect of plastic waste types on pyrolysis yield [23].

TGA was carried out for each type of plastic waste individually to find out its optimum temperature for thermal degradation under control conditions [23].

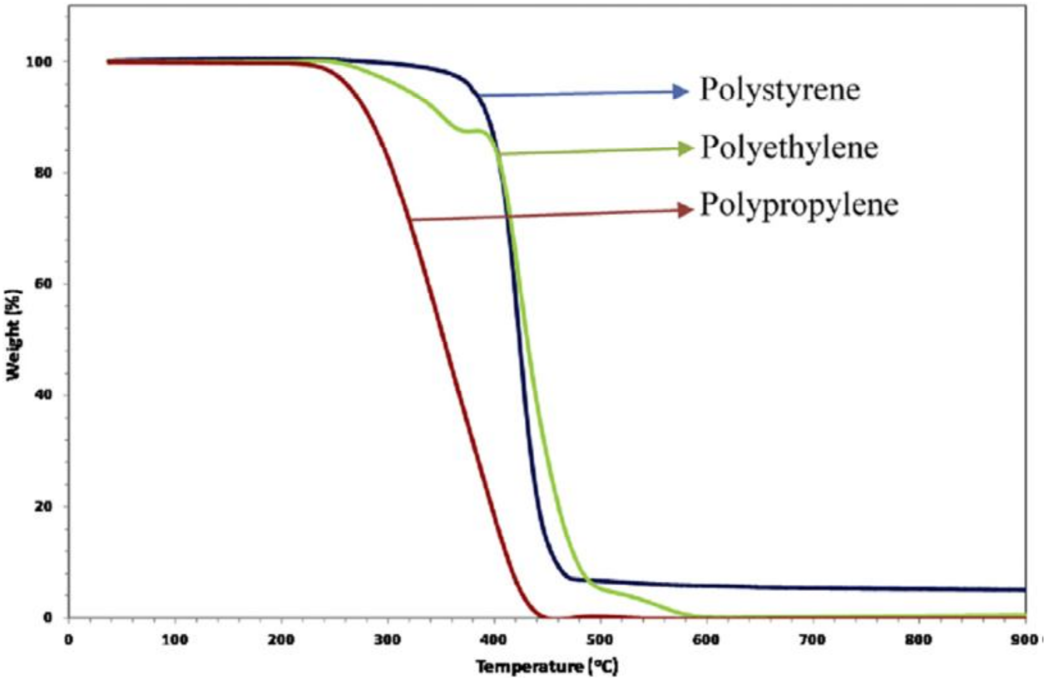


Figure 2.19: Thermogravematric analysis (TGA) of PS, PE and PP plastic types [23].

Sampling of municipal plastic waste (MPW) was done at the Nongkhaem transfer station in Bangkok, Thailand. The classification of plastic type was performed according to the Resin Identification Code (RIC) system designed for material recycling and recovery by the Society of the Plastics Industry namely, (1) Polyethylene terephthalate (PET), (2) High-density polyethylene (HDPE), (3)Polyvinyl chlorine (PVC), (4) Low-density polyethylene (LDPE), (5)Polypropylene (PP), (6) Polystyrene (PS), and (7) OTHER (acrylic, nylon, polycarbonate, polylactic acid). The flow rate of nitrogen gas was set at 200 ml/min. The heating rate of the pyrolsis test was 50□C/min. The temperature was 600 □C and the residence time for each paralysis test was 30 min excluding heating period. LDPE would give highest energy recovery due to its highest yield and energy density. Implementation, mixture of HDPE and LDPE, energy recovery should be reduced.

Figure 2.20: Experimental Setup [48].

The oil produced from the mixture of plastics is slightly viscous. It is about mixed consistency and homogeneous products resulted that was entirely liquid at room temperature [48].

Figure 2.21: Condensed oil and char obtained [48].

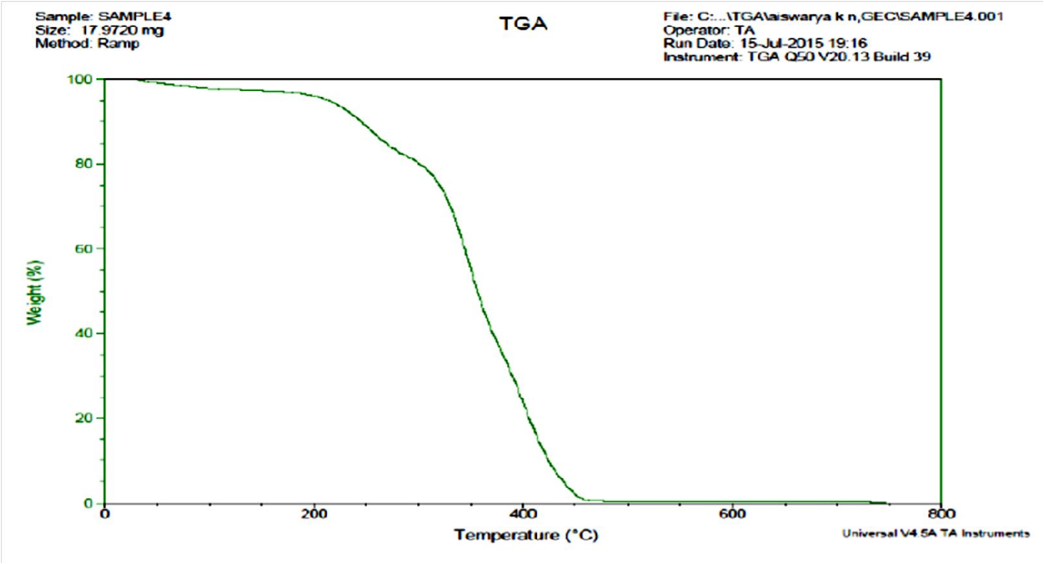
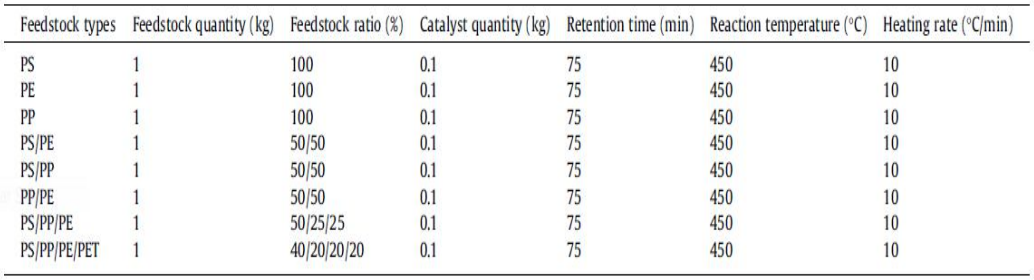


Figure 2.22: TGA of pyrolysis oil of mixture [48].

In KSA The feedstock consisted of PS, PE, PP and PET plastics respectively. For catalytic pyrolysis, the catalyst was mixed with the feedstock to examine its catalytic effect on the quantity and quality of products, in particular on the liquid oil. The effect of catalysts on the pyrolysis products yield at 450 □C, and 75 min, by using natural and synthetic zeolite catalysts. The catalytic pyrolysis of PS with natural zeolite resulted in higher liquid oil (54%) yield along with char (33.2%) and gases (12.8%) yields as compared to synthetic zeolite pyrolysis yields of liquid oil (50%), char (27.2%) and gases (22.8%). The catalytic pyrolysis of mixed plastic wastes in different ratios was conducted with both natural and synthetic zeolite catalysts separately in Table 2.7. Mixing of PS with other plastic wastes showed reduced liquid oil yields as compared to single PS feedstock.

Table 2.7 :Experimental scheme of catalytic pyrolysis, each experiment with natural and synthetic zeolite catalysts separately.



Feedstock types	Feedstock quantity (kg)	Feedstock ratio (%)	Catalyst quantity (kg)	Retention time (min)	Reaction temperature (°C)	Heating rate (°C/min)
PS	1	100	0.1	75	450	10
PE	1	100	0.1	75	450	10
PP	1	100	0.1	75	450	10
PS/PE	1	50/50	0.1	75	450	10
PS/PP	1	50/50	0.1	75	450	10
PP/PE	1	50/50	0.1	75	450	10
PS/PP/PE	1	50/25/25	0.1	75	450	10
PS/PP/PE/PET	1	40/20/20/20	0.1	75	450	10

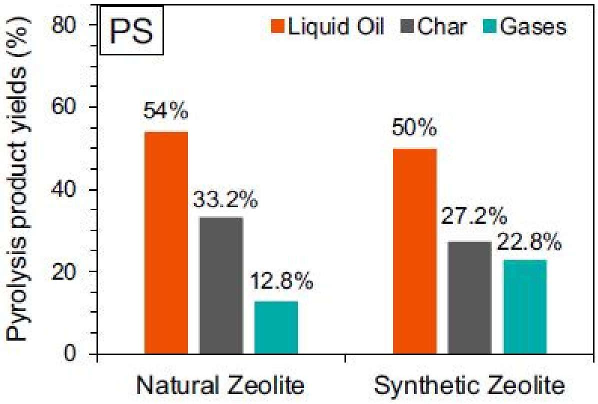


Figure 2.23: Pyrolysis product yields (%) with addition of catalysts [23].

The study showed the potential of Saudi Arabian natural zeolite as an alternative promising cheap catalyst in pyrolysis technology [23].

CHAPTER THREE

Methodology

3.1 Introduction:

In this chapter experiment's materials, apparatus or equipment that are used, and explained experimental method,.

3.2 Flow chart:

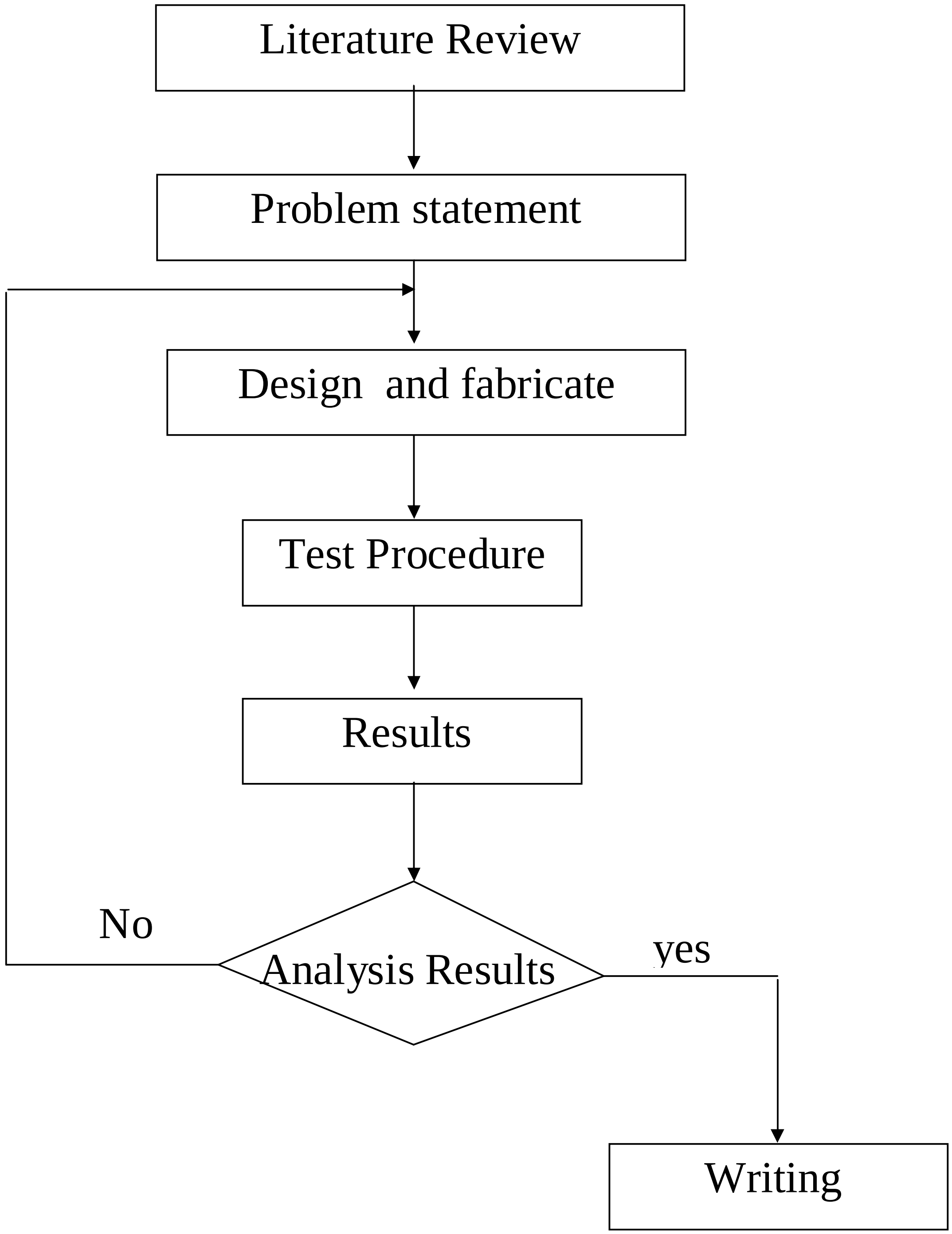


Figure 3.1: Experiment's Flow chart

3.3 Design and fabricate:

3.3.1 Apparatus or equipment:

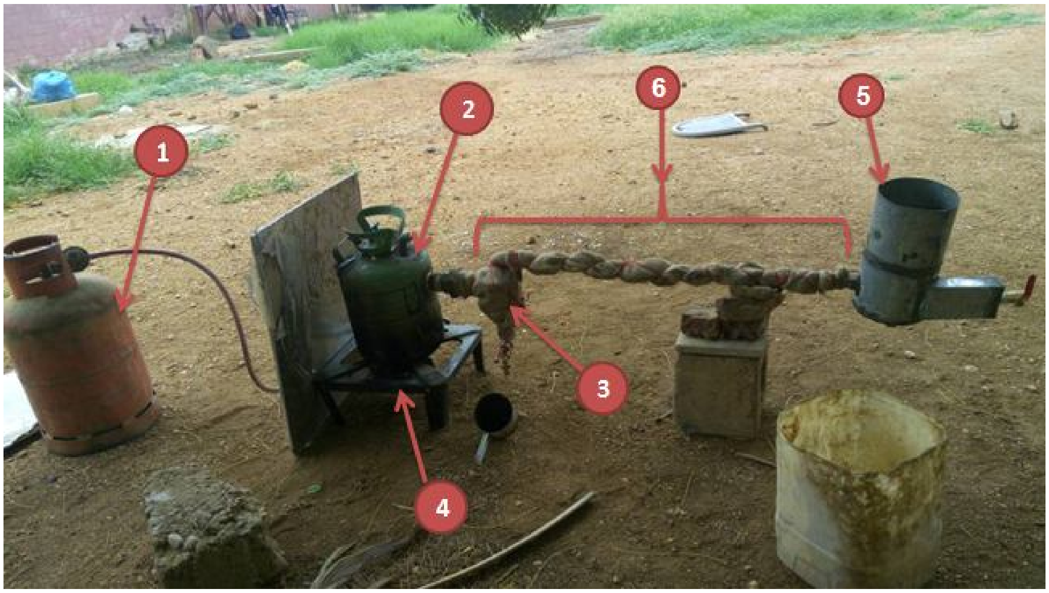


Figure 3.2: The paralysis reactor

Device parts :

1- Fuel cylinder (LPG).
2- Pyrolysis reactor; where reaction occurs.
3- Collector.
4- Heat source.
5- Exhaust system.
6- Cooling system

3.4 Waste plastic sample:

The plastic used is mixed of bag made of **LDPE** and polyethylene terephthalate or **PET**, both weighing 1000 grams.

Figure 3.3: plastic sample

3.5 Measuring device:

3.5.1 Gas analyzer:

Use this device to measure different types of non-condensable gases from pyrolysis reactor after experiment. Such as :carbon monoxide(**CO**),un burnt hydrocarbons (**HC**), and carbon dioxide (**CO2**). All measured and calculated parameters can be printed on the optional infrared printer or saved to the analyzer’s memory.

Figure 3.4: Gas analyzer

3.5.2 Thermocouple:

A thermocouple is a temperature sensor, used in wide range of temperature measurement process. Made from two dissimilar metals, which join together to create a junction. When the junction experiences, a very small voltage was created responsible for temperature reading.

Figure 3.6: Thermocouple

3.6 Sample preparation:

Plastic bags (**LDPE**) and opaque plastic (**PET**), are used as samples in experiment. First separate plastic, clean it, and cut it into small pieces Weight **1000 grams** of prepared plastic, and feed it into paralysis reactor.

3.7 Experiment Method:

At the beginning of the experiment plastic’s sample feed into pyrolysis reactor at certain temperature, which by thermocouple. After condensate system, liquid was separated, and collected in collector, and weighted at the end of the experiment.

The non-condensable gases from paralysis were analyzed, by using gas analyzer. The liquid collected in collector, were tested in laboratory; to check all fuel properties. Also the char remaindered at reactor, weighted and tested; to view its analyticities.

CHAPTER FOUR

Results And Discussion

4.1 Introduction:

This chapter presents the results of plastic waste pyrolysis. All data presented in this studies were an average value taken from five repeated experiments, at the same conditions.

4.2 Experimental results and discussion:

The design and fabricate of test rig, was done, as shown in figure 3.2.1. Figure 4.1 show In Y axis concentration of CO and CO2, and **X** axis show temperature. From this figure concludes that, whenever temperature has increased, emissions were also increased; because in high temperature degrees, hydrocarbon dissociation into carbon and hydrogen, also moisture content (H2O) in plastic dissociation into hydrogen and oxygen, this atoms formation CO and CO2. This result was agreed with previous study [16].

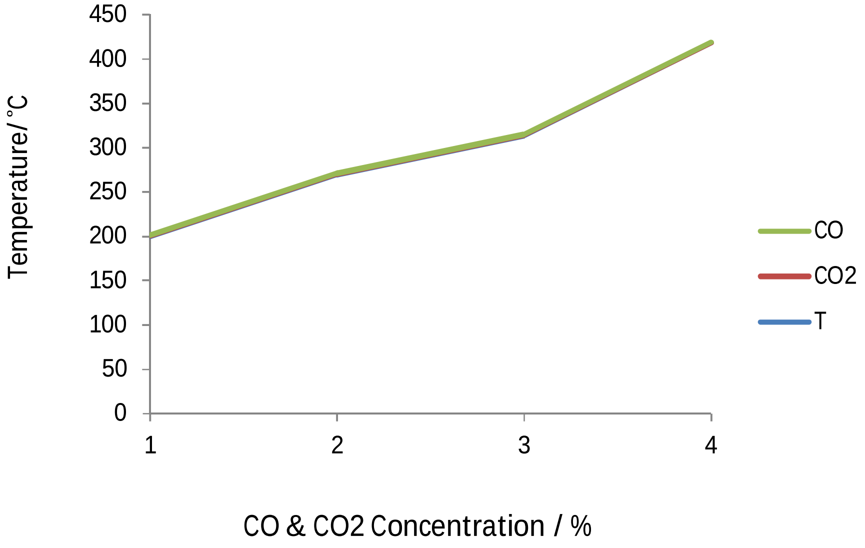


Figure 4.1: Temperature with CO & CO2 concentration.

Figure 4.2 show In Y axis concentration of HC**,** In **X** axis show temperature. Plastics have carbon and hydrogen in their polymer backbone, so the thermal degradation process at an elevated temperature with a long paralysis time leads to the production of significant amount of hydrocarbons gases. This result was agreed with previous study [31].

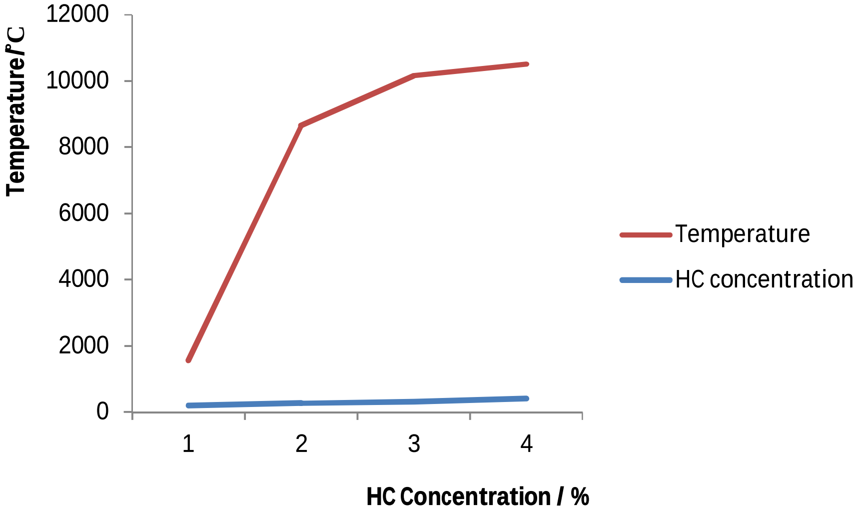


Figure 4.2: Temperature with HC concentration.

4.3 Analysis of bio fuel:

Table 4.1 and Fig 4.3 shows the WPO properties, from this table calorific value is very high. Flash point is high, that means it can use as a fuel. WPO is lightly viscous, and entirely liquid at room temperature, this results was agreed with previous study [48].

Figure 4.3: WPO produced from pyrolysis experiment

Table 4.1: WPO properties.

NO	Test	Test Method	Results	Unit
Test conditions: T= 29 □ C & Φ= 19%				
1	Density@ 15□ C	ASTM D 4052	0.77823	g/ml
2	Cross calorific value	Calculated value	46590.5	Kj/kg
Test conditions: T= 27.3 □ C & Φ= 24%				
3	Viscosity at 40 □C	ASTM D 445	1.904	cSt
4	Flash point	AS TM D92	50	□ C

4.4 Visual Inspection:

Figure 4.4 show combustion of WPO as a bio-fuel, that means its hydrocarbon content is high.

Figure 4.4:bio-fuel combustion.

CHAPTER FIVE

Conclusion and Recommendations

5.1 Conclusion:

Design is complete, and find that plastic's calorific value is high; So WPO can be used as fuel. Presence of emissions, due to plastic pyrolysis, which is derivative from petrol.

5.2 Recommendations:

1. Using catalytic such as: natural zeolite, and synthetic zeolite, in pyrolysis; to accelerate the function.
2. Using devices more accurate than gas analyzer, able to detect the non-condensable gases, produced while pyrolysis.

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