UNIVERSITY OF GHANA

SUSTAINABLE WASTE TIRE MANAGEMENT THROUGH PYROLYSIS

ESTHER YOCHEBETH HARRISON (10869036)

AGYEI MICHAEL JUNIOR (10895494)

FINAL YEAR PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF MATERIALS SCIENCE & ENGINEERING IN PARTIAL FULFILMENT OF THE AWARD OF BACHELOR OF SCIENCE DEGREE IN MATERIALS SCIENCE & ENGINEERING

2024

SUPERVISED BY: PROF. DAVID DODOO-ARHIN

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DECLARATIONS

A. Candidates' Declaration

We hereby declare that this undergraduate thesis which has results of our own original research was prepared in accordance with the University of Ghana's academic regulations and that no part of it has been presented for another degree in this University.

CANDIDATE'S NAME**: ESTHER YOCHEBETH HARRISON** **STUDENT'S ID:10869036**

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B. Supervisor's Declaration

I hereby declare that the preparation and presentation of this report was supervised in accordance with the guidelines on supervision of project reports laid down by the University of Ghana.

NAME: **PROF. DAVID DODOO-ARHIN**

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DATE: ………………...……………….

C. Head of Department's Declaration

I hereby declare that the preparation and presentation of this report was accepted in accordance with the guidelines on supervision of project reports laid down by the University of Ghana.

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DATE: ………………………

ABSTRACT

Sustainable waste management is a global issue due to the continuously increasing number of discarded tires posing serious environmental problems. Therefore, effective and environmentally friendly disposal methods are needed to solve this problem. In this study, pyrolysis technology was used for the management of tire wastes. Pyrolysis is a thermochemical process which can be used to convert tire wastes into valuable products such as oil, gas and char. Liquid from tire samples was analyzed by using thermogravimetric analysis (TGA) and Fourier Transform Infrared Spectroscopy (FTIR) during this research. The obtained results showed that tire waste could be effectively converted into valuable materials through pyrolysis with minimum environmental pollution thus providing an innovative solution for the waste tire management.

ACKNOWLEDGEMENTS

We want to begin by thanking God for His constant guidance, strength and wisdom throughout this research endeavor.

Our deepest appreciation goes to Prof. David Dodoo-Arhin, our supervisor for his invaluable guidance and mentorship. We wouldn't have been able do this this project without his immerse encouragement and support.

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Finally, we want to say a big Thank You to our family and friends for their support both financially and emotionally.

DEDICATION

This research work is dedicated to our supervisor, Prof. Dodoo-Arhin whose encouragement have been our source of strength and inspiration throughout this journey, our mentors, family and all those committed to advancing knowledge, innovation and believe in the power of research to contribute to positive change in the world.

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LIST OF ACRONYMS/ABBREVIATIONS

NR- Natural rubber

SR- Synthetic rubber

NOx- Nitrogen oxides

CO- Carbon monoxide

BR-Butadiene rubber

SBR-Styrene-butadiene rubber

TGA - Thermogravimetric analysis

FTIR - Fourier transform infrared spectroscopy

VOCs- Volatile organic compounds

MSW- Municipal solid wastes

ELTs- End-of-life tires

WTO- Waste tire oil

RWTDC- Raw waste tire derived carbon

1.0 INTRODUCTION

1.1 Background information

Energy crisis and environmental degradation are currently one of the main problems in the world due to growing population and rapid industrialization.[1]

The use of both renewable sources and some other waste valorization processes is increasing, due to not only global warming as one of the most important factors, but also a high dependence of modern society on the fossil sources in both fuels and essential raw materials. [2] In addition, the number of vehicles in the world is continuously increasing and lack of both technical and economical mechanisms results in considering waste tires as one of very serious pollution problem associated with disposal.[3]

Approximately 1.5 billion tires are produced each year and hence removed from service at a rate that eventually make them the largest potential waste and environmental problem of modern society.[4] However, there is increasing interest in pyrolysis as a technology to thermally decompose the tires in order to produce valuable oil, char and gas products.[5]

In Ghana, from 2005 to 2015, the number of passenger cars and commercial vehicles has increased greatly from 159,000 to 890,000.[6] So it can be assumed that the amount of generated waste tire will increase rapidly in ten years. Waste tire is known as “black pollution”, because it is not easy to be degraded.[7] How to safely treat and recycle waste tire has always been the research focus and difficulty for rubber industries in the world.

Tires are made from natural rubber (NR) and synthetic rubber (SR). They consist of a basic body(carcass) and the tread. The carcass is usually composed of rubber-coated textile cords, which are mostly rayon and nylon, the belt, and the bead that is made from wires.[8] Generally, natural and synthetic rubber takes up approximately 47% (by weight) and steel makes up about 17% of tires. The material composition is different between tires of passenger cars, and tires of bigger commercial vehicles such as buses and trucks. Normally, bigger tires contain more steel as the steel content gets higher. For smaller tires, the content of textile cords gets higher. In production process, NR and SR are firstly mixed and then vulcanized. After vulcanization, the tire itself has a three-dimensional cross- linked chemical structure, which makes it difficult for the tire to biodegrade themselves and photochemically decompose under natural conditions. Tires have a high carbon content, and can be regarded as one type of high-calorific-value fuel(the calorific value is about 35MJ/kg),which is equivalent to the calorific value of coal.[9] Rubber materials, tires and various other products made from rubber are widely used all over the world thus a large amount of hard-to-decompose waste rubber is produced.[10] Improper handling of this material is likely to cause economic problems and environmental pollution. Improper disposal of tires does not only clog gutters and drainages, but provides a breeding ground for disease transmitted by rodents and insects The common practice of open burning produces hazardous substances, representing a threat to human health and the environment.

This issue has triggered the chase for different approaches to restoring waste tires and some these methods are discussed below

1.11 Landfill

The country discards tens of millions of tires every year. The disposal of waste tires is a difficult process because they are not biodegradable and tend to have long life. For a number of years, the conventional way to dispose waste tires in most countries have been stockpiling or illegally dumping wherever allowed and/or by landfilling which are all short-term solutions.[11] In Ghana, it is not illegal to dispose of waste tires in landfills. Tires landfilling is a significant problem, as tires migrate to the top of landfills and can damage caps and liners. Most countries do not like to have tires at landfills as they take up plenty of space in a rapidly filling hole and with 25% being there by volume, this goes about using valuable void. Most North American and European countries have prohibitions landfilling tires as whole or made recycling of scrap tire a compulsory condition.

A stockpile of tires is like an open invitation to mosquitoes, vermin and snakes. Semi-loads of unwanted tires can be dumped into a hole in the ground which is not only dangerous as it can lead to accidental fires that can rage for months releasing toxic fumes.

Figure 1.1-A stockpile of waste tires serving as breeding grounds for mosquitoes and snakes.

1.12 Burning of tires

Burning tires is often seen as an unstable and quite dangerous method where the disposal of waste tires is concerned. It poses a number of environmental risks and is hazardous to public health too but in some cases, burning tires can actually help with assisting in managing this type of waste.[12]

The burning of tires releases large amounts of toxic pollutants into the air. The criteria pollutants are sulfur dioxide (SO2), nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOCs) and particles which measured as particulate matter (PM10, PM5.0, PM2.5).[13] These pollutants can contribute to heavy smog formation which as a result, nearby communities can suffer from respiratory ailments.

There is a high chance of also creating tire fires that are intense and very difficult to contain. The fires burn with such intensity, as they create a dense smoke which makes it difficult for firefighters to combat the blazes. Certain tire fires have been known to occur for as long as fifteen years and during the course of that time all it does is instigate continuous movement of noxious elements and hazardous compounds.

Figure 1.2- Typical tire burning image

1.13 Retreading

Retread also known as a re-cap or recap is a remanufacturing process used to extend the life of worn out tires. Retreading is based on casings of used tires that are carefully checked and fixed.

Regrettably, it cannot keep being retreaded forever and soon would wind up in a landfill where it might come to endanger our environment.

Figure 1.3- Image of used tires becoming retread tires.

1.14 Pyrolysis

Pyrolysis or endothermic recycling technology is a process of decomposing materials to obtain liquid or oils, solid residue and high-temperature combustion gases without reactive atmosphere such as air or oxygen, through Thermal decomposition. Basically, pyrolysis is the destruction of organic matter through heating up to 500 °C or higher using solid waste. This process typically utilizes agricultural by-products, scrap tire, other rubber materials, municipal solid wastes (MSW), plastic material or certain types of wood waste as raw material sources.

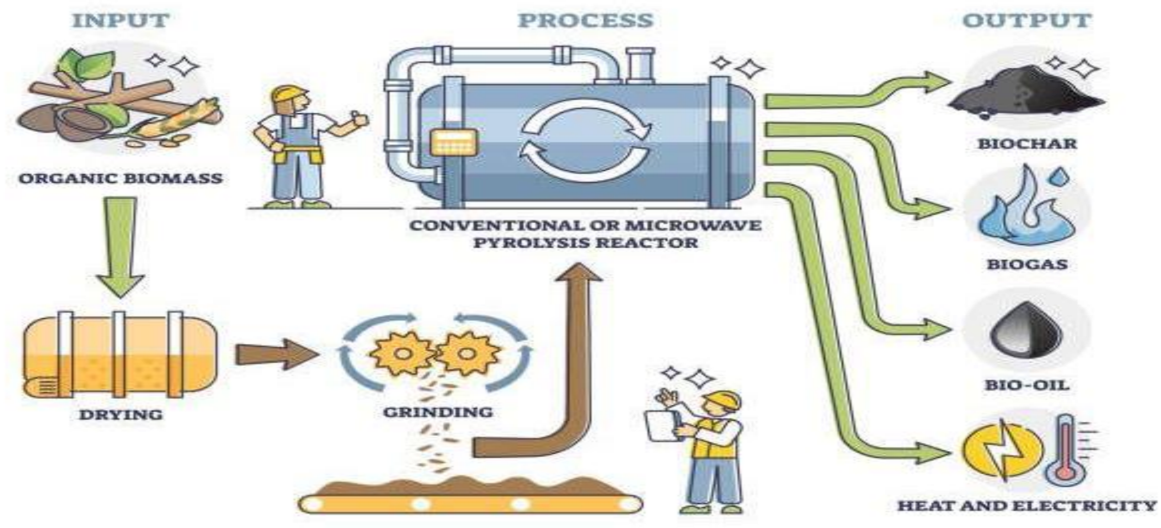


Figure 1.4 Pyrolysis Technology

1.15 Current Situation of waste tires in Ghana

Africa consumes at least 4 million tons of rubber and plastic annually, with waste tire dumps proving a daunting task to clear completely as efforts continue. Here are some key points:

It has become alarming in Ghana that the high number of vehicle imports corresponds to an increase in waste tires with poor littering and illegal dumpsites, leading to environmental degradation and health hazards hence blocking gutters which increases fire risks.[14]

A large proportion of the waste tires in Ghana at present are managed through informal practices predominantly by burning and landfilling. Both of these methods spew toxic pollutants into the air and soils around them creating ecosystems that are hazardous for both human health and environments.[15]

Regulatory Framework: The Ghanaian government in conjunction with numerous organizations are in the process of having an official, regulatory framework introduced for virtual asset business. Recently, the state of waste tires in Ghana looked really grim amidst a lot challenges with some efforts still underway to better manage and recycle them.

To answer that, the Ghanaian government has been issuing out frameworks in Agile alliance with other organizations.[16]

1.2 Significance of study

Pyrolysis of the waste has a great environmental significance as it gives a sustainable alternative for regaining valuable products such as pyrolysis liquid fuel, gas and char from discarded materials such tires. It reduces the wastes and also reduces fossil fuels dependency and with this efficient resource reuse it is an effective and clear example of a circular economy.[17]

1.21 Problems with waste tires and its management

Like any other garbage, used tires can also bring damage to our environment. They do not readily break down, so can contaminate the environment through agricultural soil and water if they are disposed of incorrectly. Tires, however, do not work as an effective method to landfill due to several reasons

Pollution: Landfilling can pollute the air, water and soil. Tires also release methane, a greenhouse gas pollutant, as they break down. The water percolating through the land filed tires, produce toxic liquid leachate.

Related emissions: Landfills emit greenhouse gases and particulate matter, which lead to smog (photochemical air pollution) that worsens respiratory disease

Unpleasant Aesthetics: Landfills are unsightly to look at and give off foul odors. Nobody wants to have a landfill next door, and property values in the area can go down because of it

1.22 The 3Rs and Why They Fall Short for Waste Tires

The waste management sector is in the habit of using the 3Rs as a promotional tool for waste reduction: Reduce, Reuse, and Recycle. However, this approach has limitations for waste tires

Reduction: Tire use is unlikely to decrease significantly, making reduction a non-viable primary solution.

Reuse: Reusing tires is limited as many become damaged or worn beyond safe use.

Recycling: While some tire recycling exists, it can be expensive.

A 4th R: Energy Recovery for Waste Tires

Many experts advocate for a 4th R - Energy Recovery. This involves converting waste tires into usable energy sources, such as liquid fuel. Pyrolysis, a thermal degradation process, is considered the most efficient and environmentally friendly method for this purpose [18]

1.3 THE PROBLEM STATEMENT

The increasing global production of waste tires is nearly at an alarming stage. Due to their composition and various additives, these tires cannot decompose naturally, resulting in the long existence within the surrounding environment creating potential threats towards human health and aquatic ecosystems and even everything that comes into direct contact with them. Traditional methods for tire garbage disposal have proved to be insufficient and out of date. Henceforth, it is necessary to explore other waste management alternatives among which would be ways of recycling or transforming this waste tire fraction into a useful energy source for several important applications.[19]

1.4 Aims and Objectives

Aim

- *We seek to use pyrolysis to convert waste tires into usable fuel, gases and char.*

Purpose(s) of Study

1. The project will be looking into waste tire pyrolysis and optimization of the process to obtain highest quality possible.

2. To provide a design guide and optimization framework for the output of waste pyrolysis systems in Ghana.

3. Production of petrochemical products or pyrolytic oil and characterization to identify the composition of the oils and products.

Objectives of Study

The study unfolded through three primary stages, namely:

1. We will study the thermal cracking and pinpoint the key factors that control the plastic pyrolysis and efficiency in product output. Additionally, we will examine other factors such as reactor and heating rate.

2. The second part of the study will concentrate on development of reactor performance and operational parameters in order to maximize the amount of pyrolytic oil and char produced.

3. Finally, testing will be undertaken on the outcome of the pyrolysis and its properties will be by use of characterization techniques.

Scope of study

The study covers waste tires from passenger cars and other small vehicles, trucks, buses. However, bicycle tires and motorcycle tires are not addressed in this scope of project.

Figure 1.4 Vehicles defined as passenger cars

2.0 **LITERATURE REVIEW**

2.1 *Waste Tires Statistics*

Every year, about one billion end-of-life tires (ELTs) are discarded globally, hence increasing the accumulation of waste tires in the environment [20]. The increasing popularity of tires is a result of the growing tire industry, mainly influenced by the increased manufacturing of new vehicles and the resulting higher demand for tires. These changes demonstrate how developments in the car industry impact the use of tires and the management of waste.

As car manufacturing is expected to reach 98.9 million vehicles per year by 2025, the problem of tire disposal becomes more evident [21]. By 2040, it is expected that there will be 2 billion cars and 790 million trucks globally, compared to the 294 million passenger cars and 41 million trucks in the European Union in 2020[22].

These numbers result in higher tire manufacturing to fulfill the demands of growing car fleets, continuing the issue of tire waste. Moreover, the need for fresh tires has increased in correlation with the rise in car production. A total of 4.2 million tons of tires were manufactured by the EU in 2020, with backing from a system of 93 tire production plants spread throughout the area [23]. Nevertheless, this strong manufacturing output has resulted in notable disparities in tire commerce, as considerable imports surpass exports in different tire types. Around 75% of used tires typically end up in landfills, causing increasing worries about the environmental and health dangers brought about by improper waste disposal practices. A jaw-dropping 317 million waste tires are thrown away annually in the United States, showing a shocking level of environmental influence [24]. This widespread problem emphasizes the immediate necessity to reconsider tire manufacturing methods and conform them to the principles of the circular economy, guaranteeing a more sustainable future for tire use and disposal globally.

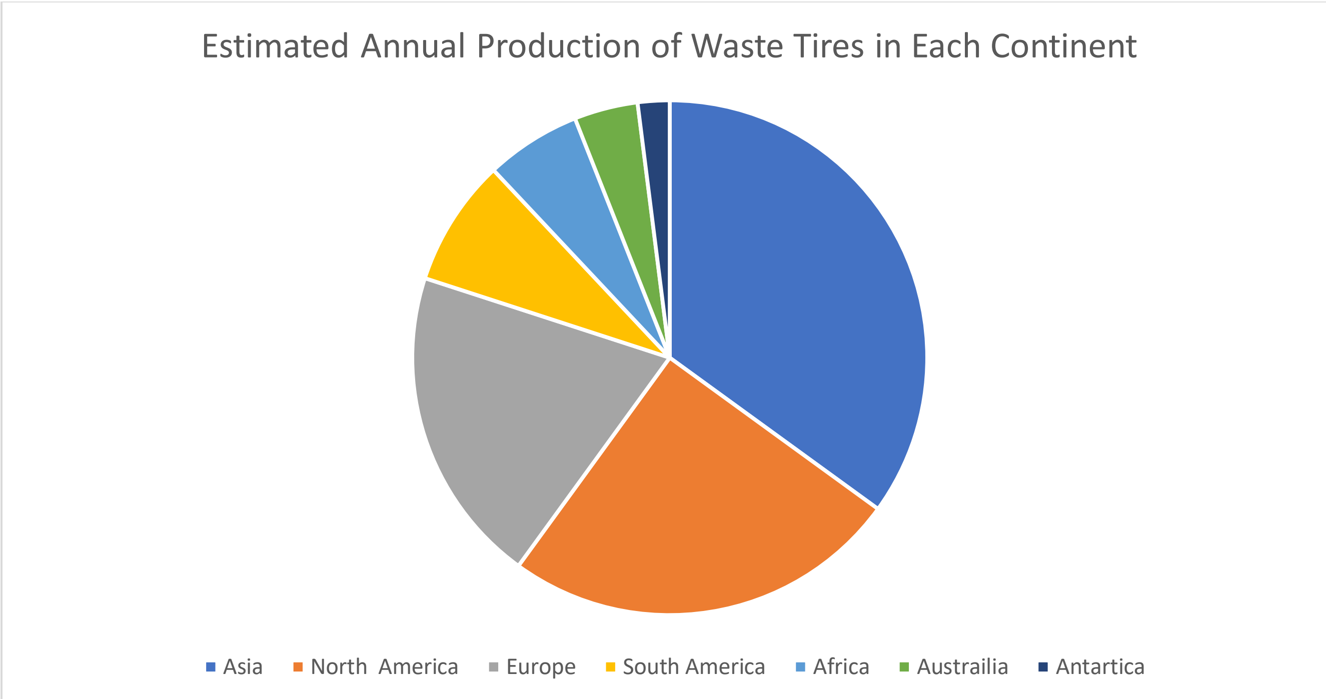


Figure 2.1 Estimated annual production of waste tires in each continent

2.2 Composition of Tires

Tires are mainly made of rubber, carbon black, and different organic and inorganic substances like plasticizers, anti-aging agents, and sulfur. The mixture typically consists of natural rubber (20-25%), SBR (30-50%), and BR (up to 30%), along with roughly 30% carbon black, 1-2.5% sulfur, and small amounts of other additives. The precise ratios differ based on the purpose for which they are being used. During tire manufacturing, a precise combination of natural rubber and synthetic rubber is mixed together in specific proportions and bonded with sulfur to create a strong three-dimensional chemical configuration that is essential for supporting weight, absorbing shock, and enduring wear.

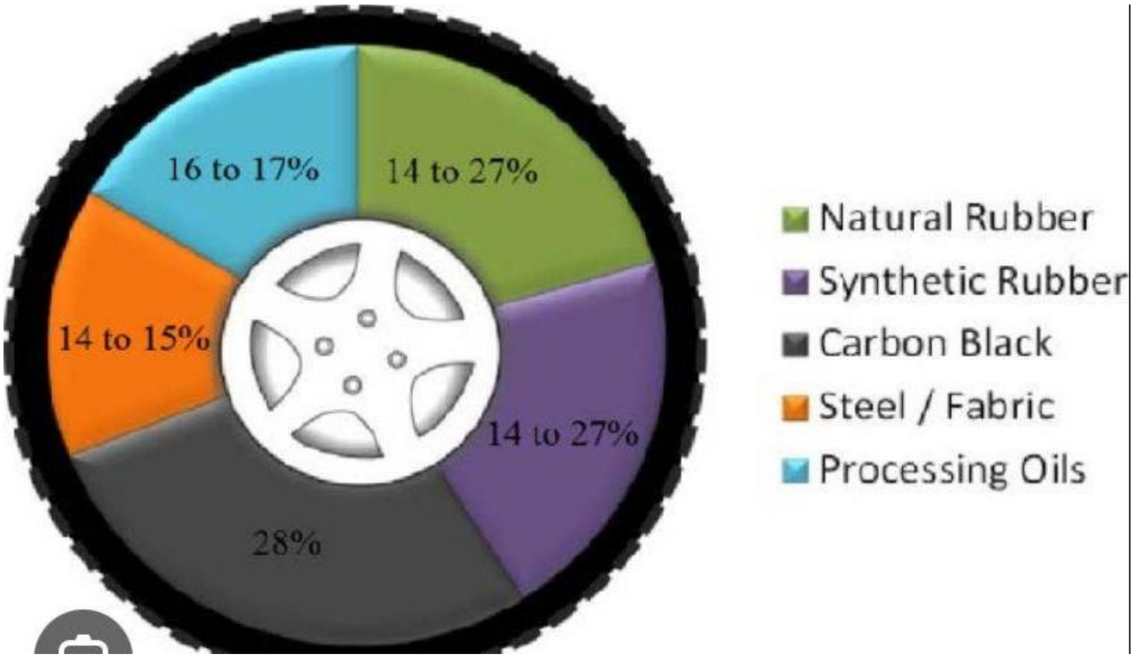


Figure 2.2 Various components of a car tire

2.3 Pyrolysis Mechanism

Pyrolysis is now seen as a promising method for handling waste tires, as it can convert them into valuable resources. The pyrolysis method includes heating organic substances like discarded tires without oxygen to decompose them into gases, solids, and liquid remnants. Throughout pyrolysis, the waste tire experiences both physical and chemical alterations as a result of the elevated temperature, causing the decomposition of intricate molecules into char, fuel, and gas.

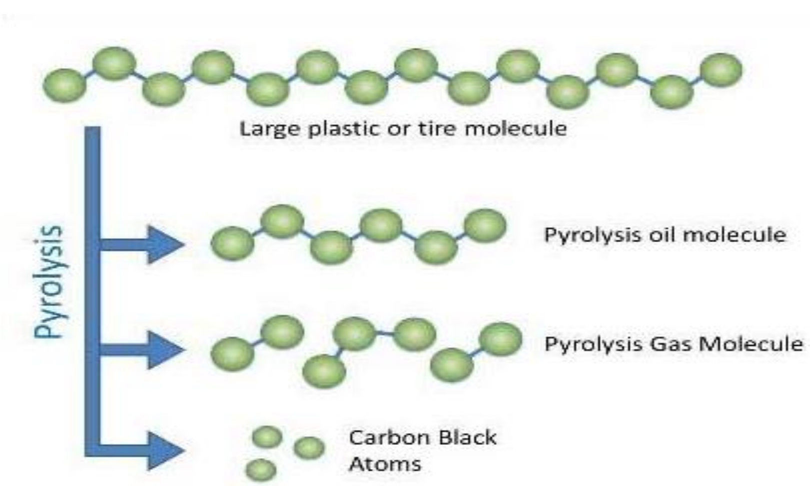


Figure 2.3 Pyrolysis process

2.4 Pyrolysis techniques

Mainly, pyrolysis techniques type can be separated into two. Slow pyrolysis and fast pyrolysis.

2.4.1 Slow Pyrolysis

This is where the scrap tires are first heated at low temperatures between 400–600 degrees Celsius without oxygen. It is heated up slowly so that complex organic compounds in tires are broken down into simpler molecules without combustion, resulting in valuable end products. The char and fuel produced from slow pyrolysis are of a higher quality as compared to that of fast pyrolysis, which is an important characteristic for many applications.[25] However, slow pyrolysis is very slow process and might even take a whole day or sometimes days to finish. It is very costly, and it further requires a lot of energy to maintain the high temperature needed for this process.

2.4.2 Fast Pyrolysis

This method of pyrolysis involves a fast heating up technique used to heat the waste tires at 800–1000 degrees Celsius. [26] Slow pyrolysis takes longer time to accomplish and produces more fuel than this technique. On the other hand, fast pyrolysis might create a less standard fuel compared to that of slow pyrolysis due to rapid heating.

In summary slow pyrolysis and fast pyrolysis can be sustainable way to address the tire waste problem for development of value-added products, but each has concerning trade-offs between quality, duration and costs while selecting a method.

2.5 *Factors influencing pyrolysis process and product yield*

Temperature- The above pyrolysis techniques mentioned how temperature is a major factor when it comes to the product yield. Temperatures of over 500 degrees Celsius result in waste tire decomposition levels that are considerably higher and hence more pyrolysis oil and gas.[27] Higher temperature will also result in thermal cracking, an undesired by- product which should be prevented to achieve higher quality end product. Low-temperature < 500 °C on the other hand produce high quality pyrolysis fuel and gases of low impurity with slower reaction rates but have lower product yield.

Detailed knowledge about the outcome of high and low-temperature conditions on waste tire pyrolysis enables you can adjust process parameters for ideal results.

Catalysts: The use of catalysts serves to alter the reaction pathways in order reduce production costs, increase overall product yield, reduce labor and also increases fossil oil concentration. This might reduce the activation energy required for the pyrolysis reaction to take place which in turn will increase production rates and decomposition kinetics, thus favoring the synthesis of desired products such as bio-oil or char. [28] It can also guide the process to form one product or another. They can similarly increase or lower the temperature, which is beneficial in terms of efficiency.

Heating Rate: The rate at which the waste tires are heated during pyrolysis can influence the product yield. Faster heating rates, as seen in fast pyrolysis, can result in higher fuel yields but may impact the quality of the products.[29]

2.6 Reviewed Experiments

Abdul Gani Abdul Jameel et al in their work carried out a process unit operation study experiment of pyrolysis and oxidation with waste tire oil (WTO). [30] Waste tires were pyrolyzed using an electric heating furnace at 500–550 °C under oxygen-free conditions, and the researchers came to a grim conclusion. For this purpose, they further studied the evolved gases during oxidation and showed how it influences thermal degradation pathways through thermogravimetric analysis. According to the study, volatile components were released as temperature rose and there was a sequence of compound emissions based on the boiling point. Furthermore, the oxidation of WTO in ambient oxygen was investigated showing a combination reaction sequences (low (∼750–950 K)- ["LTO"] and mid [∼1000-1100 K]-temperature oxidation phases [(MTOP)]) as well high temperature removal process in O2 involving most likely tungsten evaporation from WSxOy with subsequent condensation. The functional groups and gases that evolve during pyrolysis can be further analyzed to design effective, low-emission energy production systems such as gasifiers and combustors.

The study conducted by Galvagno, S. Casu et al involved a pyrolysis experimental survey at the ENEA—Trisaia Research Centre using a rotary kiln reactor. [31] The results showed high carbon content due to elastomer (SBR) and lamp-black, significant Sulphur content from rubber vulcanization processes, and ash content with zinc as a main component. Proximate analysis revealed organic material distribution into volatile and solid residue. Elemental analysis at 1000 °C and proximate analysis at 750 °C were performed, showing slight differences. Process temperature between 550-680 °C impacts volatile fraction distribution, with higher temperatures leading to increased gas production and near-complete material conversion. The study concluded that pyrolyzing scrap tires produces solid residue (char), liquid fraction (oil), and gaseous fraction (syngas) which has high energy value that can help to cover production costs. The purified pyrolysis oil can used as fuel with the advantage of practically ash-free combustion, as most of the inorganic components from the scrap tires are retained in the solid

Researchers Shen Boxiong, Wu Chunfei, Liang Cai, and their team investigated how the ratio of catalyst to tire material affects the yield and quality of derived oils. [32] They used shredded tire pieces from recycled cars, processed to remove steel and achieve a uniform size. The team employed a USY catalyst and a quartz reactor to pyrolyze the tire material at temperatures ranging from 400 to 500°C. The resulting gases were then cooled and condensed to produce oil. By varying the catalyst-to-tire ratio, the researchers aimed to understand its impact on the oil's concentration and properties.

A review by Martínez JD, Puy N et al. talks about how different factors affect the yield of products from waste tire pyrolysis. [33] They mention that the temperature is crucial as it can impact the production of oil. The optimal temperature for oil production is between 425 °C to 720 °C, with yields ranging from 38% to 60%. Factors like heating rate, gas residence time, reactor type, tire mass flow rate, and tire particle size also influence the outcome. Smaller tire particles tend to result in higher oil yields compared to larger particles due to more uniform heating. However, increasing the residence time for larger particles can achieve similar results but may increase costs.

An experiment conducted by Chang, Bouvier et al., and Kaminsky focused on studying how temperature affects the pyrolysis process and the resulting products. [34] They found that as the temperature increases, the volatilization reaction's conversion degree also increases. This is reflected in higher graphitization degree and fixed carbon content at higher temperatures. The hydrogen/carbon ratio decreases with temperature, indicating more aromatization and carbon-like structure in the char. The analysis of gases at different temperatures showed an increase in carbon content and a decrease in hydrogen content, with the gas containing more organic volatile compounds as the temperature rises. The calorific value of the gas also increases with temperature. Secondary reactions at higher temperatures lead to more non-condensable fractions and an increase in methane, C2, and C3 compounds.

3.0 **MATERIALS AND METHODOLOGY**

3.1 *Materials Used*

- Shredded waste car tires
- Liquefied Petroleum Gas (LPG)

3.2 *Equipment Used*

- *Reactor*
- *Furnace*
- *Condenser*
- *Collectors*
- *Thermocouple*
- *Fiber Glass*
- *Weighing scale*
- *Pressure Gauge*

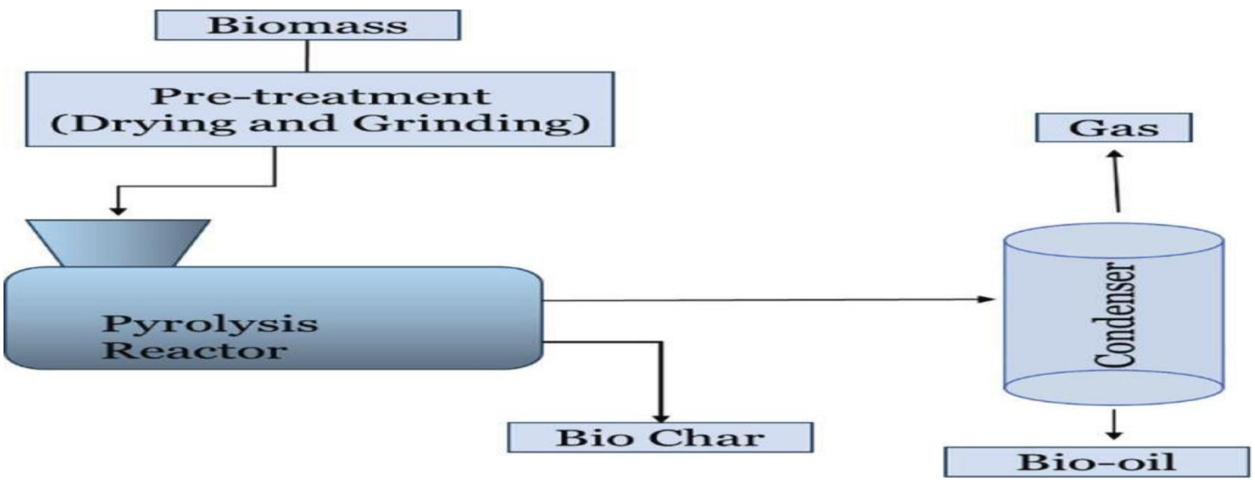


Figure 3.1 Flow chart of pyrolysis process

3.3 *Preparation of Waste Tires*

The waste tires collected were cut into pieces using a grinding machine in order to reduce their size and increase surface area for better pyrolysis efficiency. The cut tires were then washed to remove contaminants and dried to remove moisture.

Figure 3.2 Cutting of waste tires

Figure 3.3 Washing of cut tires

Figure 3.4 Drying of washed tire samples

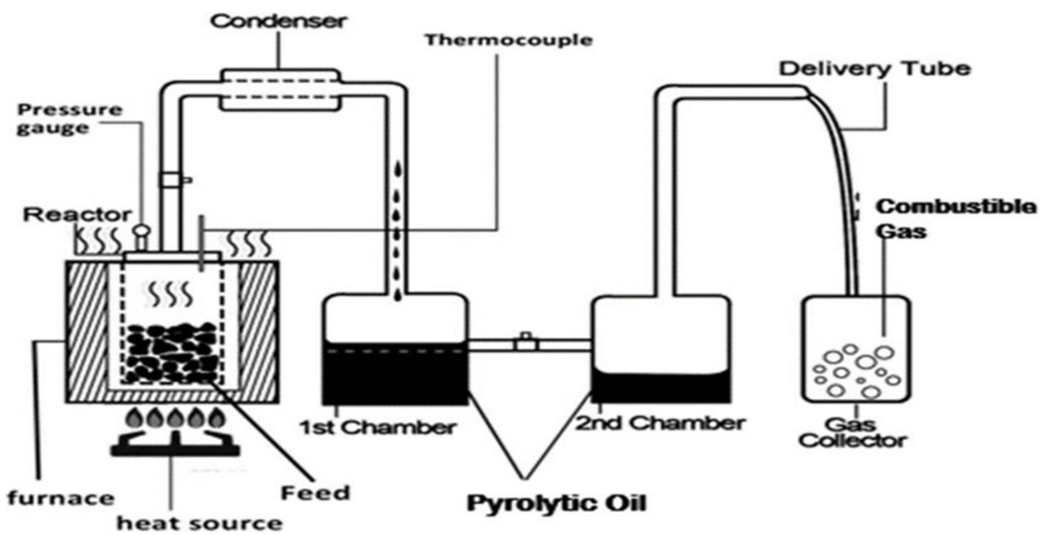


Figure 3.5 A schematic diagram of the pyrolysis process

3.4 The Pyrolysis Process

The cut waste tires were measured and fed into the reactor which was closed afterwards making sure it was airtight to prevent oxygen from entering. The reactor was then supplied with heat form the LPG gas to start the pyrolysis process. The pressure and temperature of the reaction was monitored with a pressure gauge and thermocouple respectively. The total duration of the process was also recorded.

3.5 Experiments with respective conditions

3.5.1 Test 1:

- 5kg of waste tires
- Maximum heating temperature of 550°C
- Total duration of 120 minutes

3.5.2. Test 2:

- 5kg of waste tires

- Maximum heating temperature of 580°C
- Total duration of 95 minutes

3.5.3. Test 3:

- 10kg of waste tires
- Maximum heating temperature of 550°C
- Total duration of 170 minutes

Figure 3.6 The complete pyrolysis set-up used

Figure 3.7 Putting waste tire sample into reactor

Figure 3.8 Reactor closed tightly to prevent air from penetrating

Figure 3.9 Collection of fuel from chambers

Figure 3.10 Gas collected in tube

4.0 RESULTS AND DISCUSSIONS

After pyrolysis of waste tires, the end products obtained were:

- Pyrolytic oil
- Combustible gas
- Carbon black

Figure 4.1 Pyrolytic oil collected from chamber 1 and chamber 2

Figure 4.2 Combustible gas

Figure 4.3 Carbon black obtained

A TABLE SHOWING THE PROPORTIONS OF FUEL, GAS AND CHAR OBTAINED

EXPERIMENT	MASS	LIQUID FUEL	GAS	SOLID RESIDUE
1	5 Kg	1.56Kg = 31.2%	1.3Kg =26%	2.1Kg =42%
2	5 Kg	1.51Kg =30.2%	1.19Kg =23.8%	2.3Kg =46%
3	10 Kg	3.14Kg =31%	2.06Kg =20.6%	4.8Kg =48%

Table 4.1

A TABLE SHOWING THE DENSITY OF LIQUID FUEL OBTAINED

1ST Experiment

SAMPLE	MASS	VOLUME	DENSITY
1st Chamber	1.38kg	1.2L	1.15Kg/L
2nd Chamber	0.18Kg	0.2L	0.9Kg/L

Table 4.21

2nd Experiment

SAMPLE	MASS	VOLUME	DENSITY
1st Chamber	1.35Kg	1.15L	1.17Kg/L
2nd Chamber	0.16Kg	0.19L	0.84Kg/L

Table 4.22

3rd Experiment

SAMPLE	MASS	VOLUME	DENSITY
1st Chamber	2.75Kg	2.38L	1.16Kg/L
2nd Chamber	0.39Kg	0.38L	1.02Kg/L

Table 4.23

The tables above show that the density of the pyrolysis fuel obtained from the car tires are slightly higher than that of the commercial diesel (0.82-0.86 Kg/L). This difference is as a result of heavy compounds present in the pyrolysis fuel.

FTIR and TGA characterizations were performed on some of the end products in order to get more information on their properties, functional groups, thermal stability etc.

4.1. Fourier Transform Infrared Spectroscopy (FTIR)

The pyrolysis oils obtained from both chambers and char were examined to identify the functional groups present. The spectrum revealed several characteristic absorption peaks that correspond to different molecular vibrations.

4.1.1. FTIR – fuel from 1st Chamber

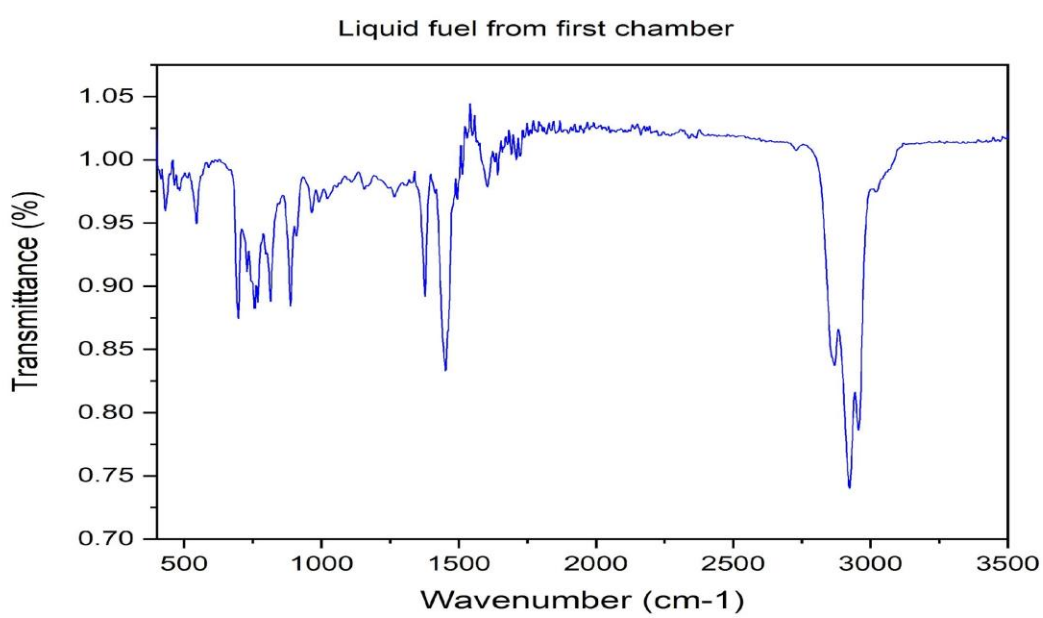


Figure 4.4- FTIR spectrum of liquid fuel obtained from first chamber

The above figure shows the FTIR spectrum of fuels collected from waste tires pyrolysis from the first chamber. The spectrum showed characteristic absorption peaks that correspond to different molecular vibrations. The strong absorption peaks were shown at 2995.75.cm, 2922.47cm and 2867cm showing the presence of C-H bonds corresponding to the presence of alkanes.

Alkanes are significant in fuel because they have high energy density meaning they can release a significant amount of energy when burned.

They are also combustible and help maintain fuel stability by preventing premature ignition. The peaks at 1605.14cm and 1452.19cm shows the presence of C=C bonds which correspond to the presence of the alkenes.

Alkenes are octane boosters; they are used to increase the octane ratings reducing engine knocking. Alkenes also help in the blending of fuels to create a balanced fuel mixture.

At 1357.39cm, it shows the presence S=O bonds. The presence of Sulphur is as result of the tire undergoing vulcanization. At 896.79cm, it shows the presence of benzene derivatives which also serve as an octane booster to increase octane ratings and also prevent sludge formation in fuels.

4.1.2. FTIR – fuel from 2nd Chamber

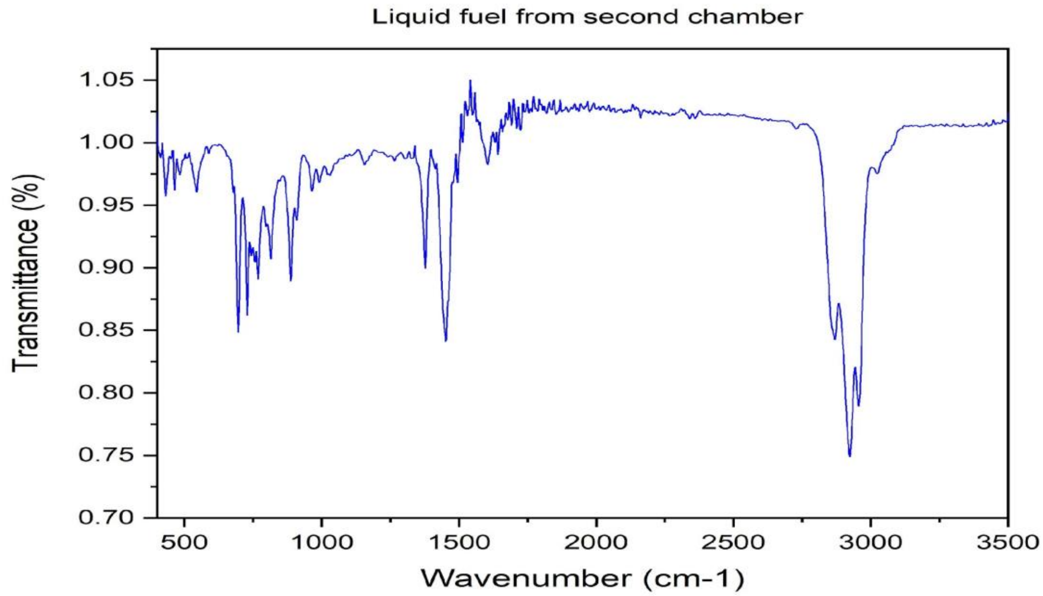
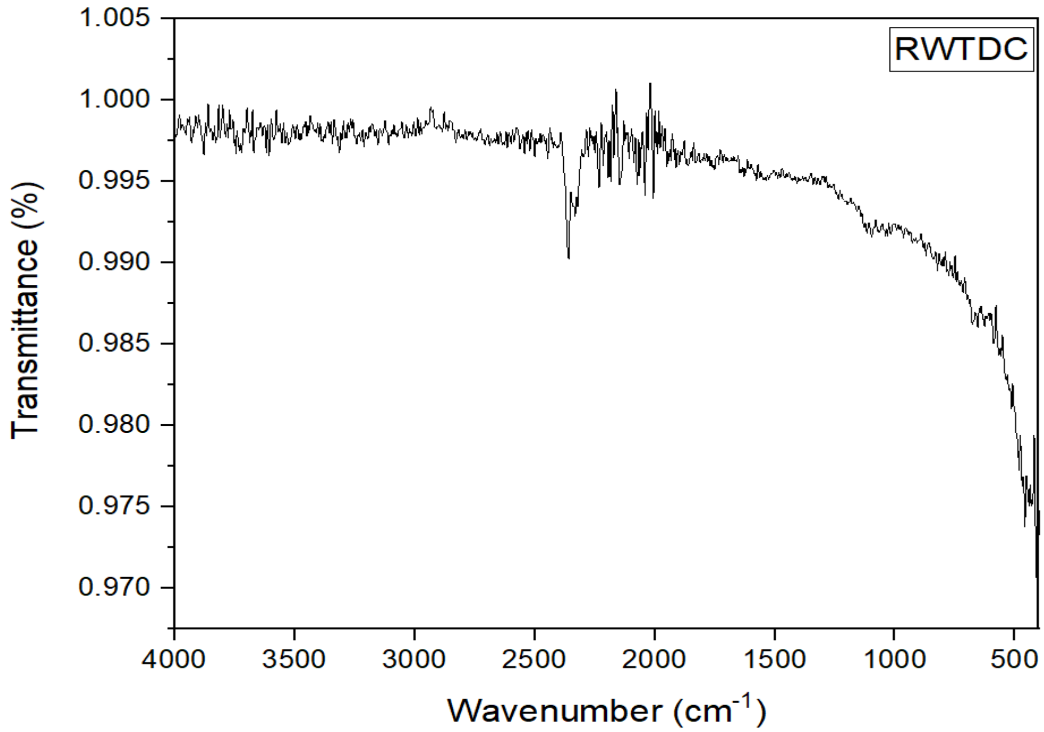


Figure 4.5- FTIR spectrum of liquid fuel obtained from second chamber

The figure above shows the FTIR spectrum of fuels obtained from waste tires pyrolysis from the second chamber. The spectrum showed significant absorption peaks that corresponds to different molecular vibrations. The strong absorption peaks were shown at 2955.79cm, 2924.96, 2869.64 showing the presence of C-H stretching bonds corresponding to the presence of alkanes.

The peaks at 1604.14cm and 1451.91cm shows the presence of C=C bonds corresponding to the presence of alkenes. At 1375.24cm it corresponds to the presence of S=O bonds. The peaks at 695.83cm and 543.24cm shows the presence of benzene derivatives which may result from the addictives added during manufacturing of the tire

4.1.3. FTIR – char obtained



In the broad region between 1000 and 1500 cm^{-1}, it is observed that there are subtle differences in the transmittance curve of the raw char. This is due to the presence of C-O, C-C, and C-H bond vibrations.

The 500-1000 cm^{-1} region range generally corresponds to bending vibrations of C-H.

In the higher wave number region between 3000-4000 cm^{-1}, there's a small broad absorption in the region, which is typical for O-H stretching (hydroxyl groups). This suggests the presence of some surface moisture or free hydroxyl groups present in the raw waste tire char.

4.2. Thermogravimetric Analysis (TGA)

TGA was performed on the pyrolysis oil and the raw material to determine its properties, composition, thermal stability etc.

Pyrolysis conditions were ensured in the furnace with nitrogen to ensure that all air and oxygen in the furnace were displaced to prevent oxidation of the samples.

4.2.1 TGA-Raw material

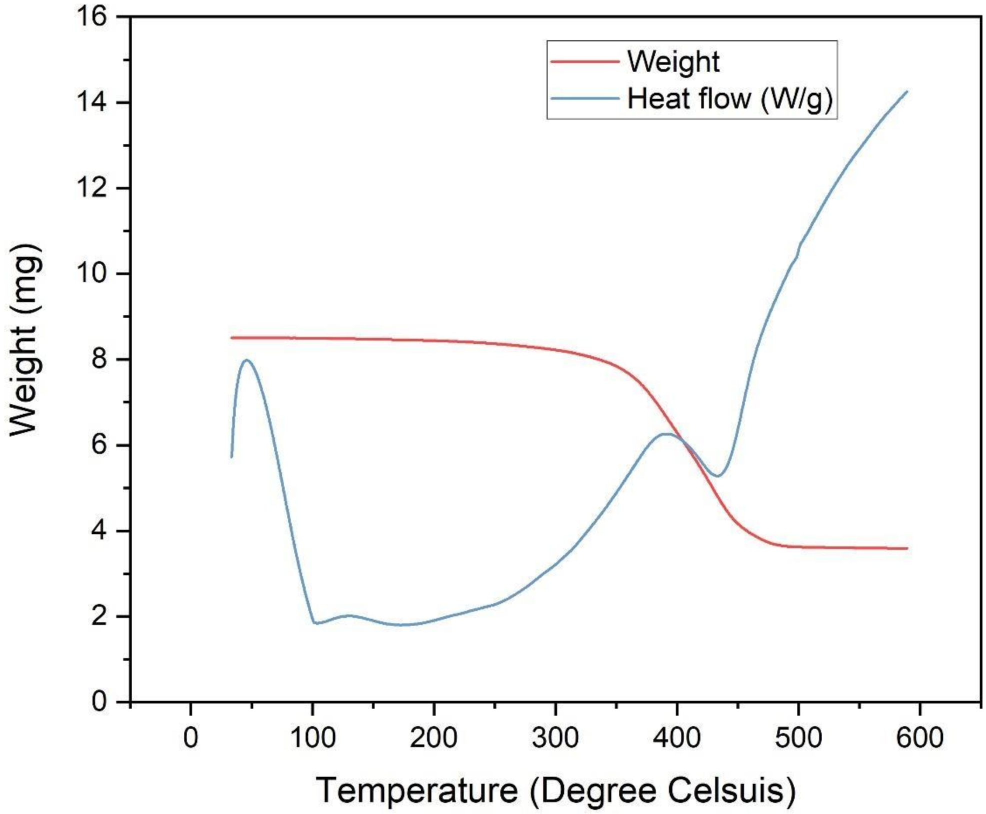


Figure 4.6 - TGA of raw material (car tire)

From the graph, it is observed that from 0-100°C, there is a slight weight decrease which is as a result of moisture evaporating and the presence of volatile compounds in the char. From 100°C to 300°C, the curve stabilizes, showing no significant weight loss, suggesting thermal stability. From 300°C and 500°C, there is a significant weight drop and this shows the breakdown of organic matter, such as hydrocarbons and polymers. Beyond 500°C, more weight loss is observed, indicating the degradation of more stable components. An endothermic peak around 100°C is also observed which corresponds to moisture evaporation, indicated by a dip in the heat flow curve due to heat absorption. Another large exothermic region from 300°C to 400°C represents the decomposition and oxidation of carbonaceous material, releasing heat during the breakdown of hydrocarbons and organic compounds. The sharp exothermic peak above 400°C indicates the combustion or oxidation of the remaining fixed carbon, releasing heat during this process.

4.2.2.TGA-pyrolysis fuel

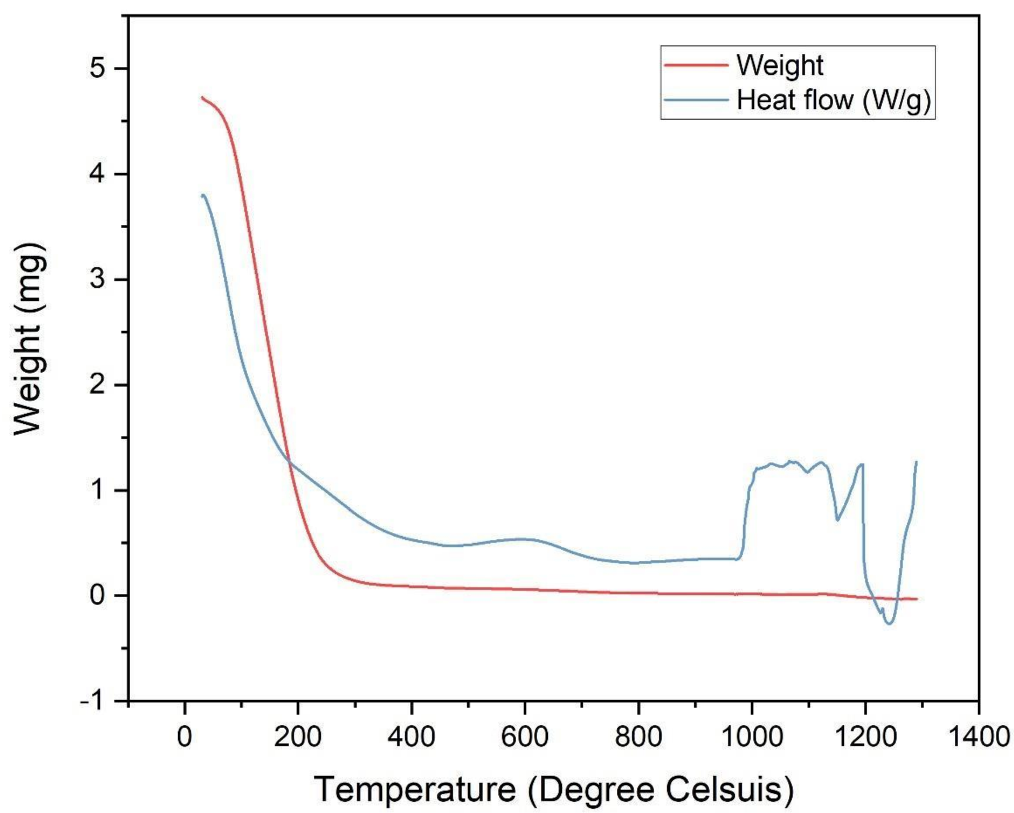


Figure 4.7 - TGA of pyrolysis fuel

From the TGA graph above, it is observed that there is an initial weight loss from 0-96°C due to moisture evaporation from fuel. As the temperature increases from 96-250°C, there is a significant drop in weight 0f about 20-40% and this is due to the release of volatile compounds and heavy ends decomposition. From 250-1200°C, the curve stabilizes showing no significant weight loss and hence thermal stability.

The heat flow curve also shows an endothermic peak around 150-200°C, indicating the energy absorbed during the release of volatile compounds. A small exothermic peak is also observed around 500-620°C showing the energy released during heavy ends decomposition. Around 1000-1120°C an exothermic peak is observed showing the energy released during char formation.

5.0 CONCLUSION AND RECOMMENDATIONS

The research on pyrolysis technology for sustainable waste management of tire wastes has demonstrated encouraging outcomes in turning discarded tires into useful products like pyrolysis oil, gas, and char. This study showed that tire waste can be effectively managed by pyrolysis, which is also an environmentally friendly method. The feasibility of this procedure was proven by analyzing the pyrolysis liquid produced by the pyrolysis process using Fourier Transform

Infrared Spectroscopy (FTIR) and thermogravimetric analysis (TGA). Through testing and characterization methods applied to the pyrolysis liquid suggests that it can potentially serve as an alternative energy source or even replace conventional fuels in the future

Future research in this field is advised to investigate further ways to improve the yield by optimizing some parameters like temperature, pressure and adding catalyst to the sample and also to treat the pyrolysis oil to remove the Sulphur content.

Additionally, examining the economic feasibility and scalability of deploying pyrolysis technology on a broader scale could provide insights into its practical application in real-world waste management circumstances. Working together with legislators and industry partners to include pyrolysis technology into waste management procedures could speed up the shift to a more ecologically responsible and sustainable method of handling waste tires.

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