Production, Characterization and Performance Evaluation Diesel Engine Using Fuel from Waste Garage Oil and Tire and its blends

Simegn Mulugeta Damesa

A thesis Submitted to the Department of Mechanical Engineering
School of Mechanical, Chemical, and Materials science and Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of

Master of Science in Thermal Engineering

Office of Graduate Studies

Adama Science and Technology University

June, 2023

Adama, Ethiopia

Production, Characterization and Performance Evaluation Diesel Engine Using Fuel from Waste Garage Oil and Tire and its blends

Simegn Mulugeta Damesa

Advisor: Dr.Dawit Gudeta

A thesis Submitted to

The Department of Mechanical Engineering

School of Mechanical, Chemical, and Materials science and Engineering

Presented in partial fulfillment of the Requirement for the degree of

Master of Science in thermal Engineering

Office of Graduate Studies

Adama Science and Technology University

June, 2023

Adama, Ethiopia

Declaration

I hereby declare that this Master Thesis entitled "Production, Characterization and Performance Evaluation Diesel Engine Using Fuel from Waste Garage Oil and Tire and its blends'' is my own original work That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

Simegn Mulugeta Damesa _____ _____

Name of student Signature Date

Recommendation

I the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled “Production, Characterization and Performance Evaluation Diesel Engine Using Fuel from Waste Garage Oil and Tire and its blends” prepared under my guidance by Simegn Mulugeta submitted in partial fulfillment of the requirements for the degree of Master of Science in Thermal Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr.Dawit Gudeta _____ _____

Advisor Signature Date

Approval page

I, the advisors of the thesis entitled "Production, Characterization and Performance Evaluation Diesel Engine Using Fuel from Waste Garage Oil and Tire and its blends'' developed by Simegn Mulugeta, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr: Dawit Gudeta _____ _____

Advisor Signature Date

We, the undersigned, members of the Board of Examiners of the thesis by Simegn Mulugeta have read and evaluated the thesis entitled "Production, Characterization and Performance Evaluation Diesel Engine Using Fuel from Waste Garage Oil and Tire and its blends'' and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Thermal Engineering.

_____ _____ _____

Chairperson Signature Date

_____ _____ _____

Internal Examiner Signature Date

_____ _____ _____

External Examiner Signature Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

_____ _____ _____

Department Head Signature Date

_____ _____ _____

School Dean Signature Date

_____ _____ _____

Office of Postgraduate Studies, Dean Signature Date

ACKNOWLEDGMENT

First and for most, I want to thank the Almighty God who is at my side, gives me patient, strength, courage and wisdom to complete this thesis. Next, I would like to express my deepest thanks to my advisor Dr. Dawit Gudeta for his guidance, intellectual support, and invaluable advice throughout this thesis. I also like to express my special thanks go to the lab assistants of Thermal and Aerospace engineering, Automotive Engineering and manufacturing Engineering and also Addis Ababa science and technology. I would like to thanks all my best friends for their encouragement, suggestion, and assistance, and gave a worthy comment on my work and through the process of researching. My heartfelt and deepest gratitude goes to all of my family who was always on my side persistently throughout my entire academic life.

TABLE OF CONTENTS

CONTENTS **PAGE**

LIST OF TABLES

TABLES **PAGES**

LIST OF FIGURES

FIGURES **PAGE**

LIST OF ACRONYMS AND NOMENCLATURE

Acronyms

ASTM	American Society Testing Materials
bsfc	Brake Specific Fuel Consumption
CO	Carbon Monoxide
CO2	Carbon Dioxide
HC	Hydrocarbons
IC	Internal Combustion
Kg	kilogram
kW	kilo Watt
kWh	kilo per Watt-hour
Tb	Brake torque
LPG	Liquefied Petroleum Gas
Pb	Brake power
ppm	Parts per Million
UHC	Unburned hydrocarbon
WPO	Waste pyrolysis Oil
WTEO	waste tire and engine oil
WEO	waste engine oil
WT	waste tire
BFBR	Batch fixed bed reactor
CFBR	Conic fixed bed reactor
BTX	Benzene, toluene and xylene

Nomenclature

B0	pure diesel
B20	20% WTEO and 80% pure diesel
B30	30% WTEO and 70% pure diesel
B40	40% WTEO and 60% pure diesel
m^3	Cubic meter
min	Minute
ml	Milli Liter
ρ_f	Density of fuel

ABSTRACT

This study makes an effort to analyze the procedures involved in converting garage waste into more value items like fuel. The key technique the researcher employed, among others, to recycle spent such like waste is the pyrolysis process. Different experimental procedures were used in this work to get the desired result. The experiment system covered the conversion of waste into a fuel product through pyrolysis and chemical treatment. Additionally, the process's energy source is thermal energy, which was used in a furnace composed of a material with limited thermal conductivity. The fuel with various characteristics is produced after experimental study using several techniques. The results of this experimental study showed that the fuel that can be recovered from garage waste and has the following properties: 838 kg/m^3 density, 2.1 mm^2/s kinematic viscosity, -21 ^{o}C cloud point, and 62 ^{o}C flash point. This study looked at whether using garage waste as an alternative fuel for diesel engines was appropriate and what impact blending garage waste tire and oil fuel with different blends of diesel (B10, B20, B30, and B40) had on the fuel characteristics, engine performance, and emissions characteristics. The characteristics of the fuel were tested and related with conventional diesel (B0). Additionally assessed are engine performance metrics including brake power (Pb), brake torque (Tb), and brake-specific fuel consumption (bsfc), as well as pollutants like CO, CO2, HC, and NOx. The generation of fuel from garage waste via thermal pyrolysis has been found to be a lucrative enterprise since it can replace diesel that is currently imported from outside and eliminate environmental problems brought on by incorrect handling of garage waste. The result show that fuel made from waste tire and engine oil can be used by blending in diesel engine.

Key word: Garage waste, Pyrolysis, Performance, Emission

CHAPTER ONE

INTRODUCTION

1.1. Background of study

Non-biodegradable synthetic organic compounds made by polymerization include engine oil and tires (Anene, 2017). To produce low molecular weight compounds like ethylene and propylene, crude oil is first slightly distilled to produce naphtha. Then, these low-molecular-weight compounds are polymerized in accordance with the desired properties to create materials like polyethylene, polybutadiene, natural rubber, olefins and paraffin's. Because handling these materials in either their powder or bulk form is challenging, they are then melted and molded into pellets. We can create different types of tire and engine waste by further processing these pellets.

On the other hand, Adama current methods of handling WTEO are unsustainable, informal, inefficient, uncoordinated and unrepresentative. Solid and liquid waste generation is increasing, and the trend in terms of volume, type and level of hazard is being fueled by population booms and business expansion. There are obvious problems with gathering, transporting and final disposing. Waste solid and liquid waste pollutes the environment and poses health risks to humans, livestock and wildlife. Poorly managed open landfills are now far from the fringes, causing air, and land and water pollution. This location poses a real health risk, especially for the surrounding residents. Open to all types of scavengers, whether human, domestic or wild (Tekahun B. 2007).

Ever since their inception in the 1900s, tires has taken over the role of various materials like wood, metals, and ceramics in the manufacturing process of goods. This is due to their lightweight, sturdy, and corrosion-resistant nature, along with their versatility in applications, easy handling, and cost-effectiveness (Nyarko & Adu, 2016). However, given that most plastic products serve a single purpose, managing WTEO can be a daunting task, given the enormous amount generated every day. There are several ways to manage WTEO, including recycling, incineration, and thermal or catalytic cracking.

Recycling is one way to reduce the amount of WTEO by recovering selected items for additional production use. Incineration is another method of disposing of WTEO that is becoming increasingly attractive to many communities, especially those facing declining landfill capacity and rapidly increasing landfill fees. Becoming a popular processing option However, incineration currently limits the potential use of WTEO for energy technology, releasing greenhouse gases and some highly toxic pollutants such as polychlorinated dibenzoparadioxins and polychlorinated dibenzofurans generate. Pyrolysis as a waste treatment option uses some heat source to break down WTEO. WTEO are originally composed of hydrocarbons, which are decomposed into crude oil and non-condensable during pyrolysis. If we fail to convert WTEO into productive resources, the only option left is to dispose of them in landfills or dump them into water bodies, which is currently being done as the most viable solution.

Thermal cracking, commonly known as pyrolysis, is the most beneficial to the environment technique for handling waste tire and engine oil defined previously. The process of converting waste tire and engine oil into useful resources is known as pyrolysis. As previously stated, such waste is produced by the composition of small molecular compounds such as ethylene and propylene. The long-chain polymer splits into monomers when heated in an oxygen-deficient reactor. Because cracking occurs at high temperatures, the monomer exists as a gas and has a high latent heat of vaporization. This energetic gaseous monomer is free to move. As a result, it is reasonable to place a pipe at the reactor's top to transport the gaseous monomer into a condenser, where it will be changed into a liquid by releasing its latent heat to the cooling water.

There are many various types of reactors, based on the structure and feeding of the bed. I decided to use a fixed bed batch reactor as a result. This kind of reactor starts the process with the introduction of the feed in tiny batches, and once all the material inside the reactor has been thoroughly digested, the feeding procedure is repeated. Batch reactors are frequently used in scientific research. Pyrolysis occurred in a fixed bed reactor immobile bed. Compared to batch reactors with significant temperature gradients, fixed bed reactors are simpler to construct and manage. A coiled tube heat exchanger is used to condense due to its great

efficiency in dealing with liquid and gas phase streams, small footprint, and convenience for moving energy-rich fluids non condensable to secondary condensation.

By producing fuel from WTEO, this research addresses both the issue of fuel scarcity and the impact on the environment. Oil produced by the pyrolysis technique is appropriate because tire and engine oil are both made of petroleum. The WTEO are plentiful and may be found in great amounts in the garage, on the sides of the road, in hospitals, in hotels, etc.

1.2 Problem statement

People regular activities generate both solid and liquid waste, which needs to be disposed of properly. Poor waste management, especially garage waste, is a concern in Ethiopia, as it is in other developing nations. For instance, the city of Adama is capable of producing a lot of this kind of garage waste like tire and engine oil. Numerous issues are caused by this ineffective waste management, including an increase in landfills and significant environmental pollutants. On the other hand, the world declining fuel reserves and increased environmental awareness searching for alternate and renewable fuels that may fulfill the rising energy demand. This work mainly deals with the production, characterization, and performance evaluation of fuel extracted from tire and engine oil by thermal pyrolysis.

1.3. Objective

1.3.1. General objective

The main objective of this study is production, characterization and performance evaluation fuel from garage waste tire and engine oil using thermal pyrolysis.

1.3.2 Specific Objectives

- Fabricating the small scale pyrolysis plant.
- Converting WTEO into fuel by using thermal pyrolysis.
- characterization of WTEO fuel
- Evaluating the performance of fuel on the engine.
- Cost-benefit analysis for mass manufacturing.

1.4 Significance of the study

WTEO is utilized in the production of fuel, which can be used to protect environmental pollution, prevent global warming, and enhance human health in substitute of fossil fuels. In order to boost people income, it will be crucial to urge them to gather WTEO in large amounts. The results of the study will be used by researchers as a springboard for further investigation. As a result, it can enhance fuel output for diesel engines efficiency and reduction of emissions.

1.5 Scope and Limitation of the Study

In this work, the WTEO produced in Adama Town is analyzed. The basic parts of the small scale pyrolysis plant, such as the reactor and heat exchanger, are designed and manufactured as part of the research as well. The next step in this research was a test fuel production once the system component parts were put together. Finally, the produced fuels undergo experimental testing for fuel characteristics, engine performance, exhaust gas analysis, and economic analysis.

The study limitation includes pyrolysis of the WTEO have unpleasant smell which released during the process. The result varied somewhat at different time because of measurement errors.

CHAPTER

LITERATURE REVIEW

2.1. Recycling of WTEO

The world is currently facing a major energy crisis, with the continuous decrement of non-renewable energy sources, and the WTEO need to sustainable development practices has become a pressing matter. Hence, waste conversion technologies have been gaining increasing attention as an alternative source of energy, especially for the transportation sector. The conversion of WTEO into a source of fuel has been the subject of much work recently. This literature review aims to examine the production and performance evaluation of fuel derived from garage waste.

Several studies have proposed different methods for producing fuel from WTEO. One such method involves pyrolysis, which involves the use of high heat and a lack of oxygen to break down complex molecules into smaller hydrocarbons, resulting in liquid oil. Another method involves hydro processing, wherein the WTEO is subjected to high pressure and high temperature to produce a liquid fuel. These methods have been shown to be effective in producing fuel from garage waste, with hydro processing having the added advantage of producing a fuel with properties similar to conventional diesel.

Furthermore, the performance evaluation of fuel derived from garage waste has also been studied, using various parameters such as heat value, viscosity, flashpoint, and carbon residue. One study found that the fuel derived from WT had a higher heat value than that of the conventional diesel fuel. Another study reported that the flashpoint of fuel produced from both WTEO was higher than the minimum requirement, indicating its safe use. However, the viscosity of the fuel produced from WTEO was found to be higher than that of conventional diesel.

Despite the promising results of using WTEO as a source of fuel, several challenges remain. The high sulfur content of WTEO poses a significant challenge in their conversion to high-grade fuel. Additionally, waste conversion technologies are confronted with issues like

scalability, cost-effectiveness, and environmental impact. However, with ongoing research in this area, these challenges can be addressed, making fuel derived from waste garage oil and tire a viable and sustainable energy source for the future.

In conclusion, the production and performance evaluation of fuel derived from WTEO has been the subject of much research in recent years. Pyrolysis and hydro processing methods have shown promising results in producing fuel with properties similar to conventional diesel. Performance evaluation studies have reported the fuel's high heat value, acceptable flashpoint, and safe use. However, challenges like high sulfur content and cost-effectiveness remain, which can be addressed with ongoing research. The results of these studies indicate that fuel derived from WTEO has the potential to be a sustainable alternative to traditional fossil fuels.

The primary type of solid waste found globally is WT, which consist of various types of tires including bicycles, rickshaws, motorcycles, auto-rickshaws, cars, taxis, microbuses, jeeps, tractors, buses, and trucks (Ayanoğlu & Yumrutaş, 2016). The disposal of WT is a frequent and troublesome form of waste. Every year, around 1.5 billion tires are manufactured and will ultimately become waste. The European Union has prohibited the disposal of WT, and instead, they must be recovered and recycled. Pyrolysis is an effective method that dissolves WT while producing helpful byproducts (Czajczyńska et al., 2017). Energy has always been and will likely continue to be crucial for sustaining daily activities. However, the current means of obtaining energy has largely relied on fossil fuels, which has created a dependency that has proven difficult to reduce (Karagöz et al., 2020). With industrialization and a continuously increasing global population, the need for energy is also rising. As a result, numerous nations are exploring alternative energy options to meet their requirements (Ayanoğlu & Yumrutaş, 2016)Tires possess significant energy value, but they are difficult to decompose and have hazardous effects on the environment and human health. The reusing of WT has therefore gained immense attention among research fields. Various methods are currently utilized to dispose of them, such as tire retreading, mechanical grinding, rubber reclamation, combustion, and pyrolysis. Pyrolysis, in particular, has regained prominence over the past decade since it is possible to optimize the process to produce quality fuels. WT offer oil, released gas, char, steel, and residual products that can all be reused. The released gas has sufficient calorific value for application as process energy

The utilization of renewable resources and waste conversion procedures is on the rise due to various factors such as global warming and the societal dependency on non-renewable sources for fuel and essential materials. Conversely, the mounting worldwide number of vehicles and insufficient technical and economic methods has magnified the issue of WT disposal with detrimental effects on the environment. With tires made of rubber containing a significantly higher calorific value than coal and noteworthy quantities of carbon black, it appears reasonable to explore ways to capitalize on their raw material and energetic potential. This could aid in the pursuit of alternative fuels, decreasing carbon dioxide emissions, and recycling of raw materials.

Rubber, carbon black, accelerators, and fillers are components of tires. Rubber is found as CXHY, which is a thermoset polymer and contains some fiber components. Tires for passenger and commercial vehicles are made by combining natural rubber (NR) and synthetic rubber (SR), including butyl rubber (BR) and styrene-butadiene copolymer (SBR). SR mainly comes from petroleum-based goods, but NR is sourced from the Heave tree.

The construction of tires is meant to endure tough physical and environmental conditions like ozone, light, and bacteria, which makes it challenging to recycle or process them for other purposes. Moreover, their large size and non-degradable nature make disposal in landfills problematic, with a lifespan of at least 80 to 100 years. Additionally, because tires are thermoset polymers, they cannot be melted or broken down into their chemical constituents.

Although the process of burning can be a convenient way to extract energy, the generation of pollutants such as dioxins, PAHs, VOCs, particulate matter, etc. during the combustion of complex waste like tire, makes it unfavorable to pursue due to its negative impact on both the environment and public health.

According to (Murillo et al., 2006), when WT are quickly heated in a process known as pyrolysis, they produce an oil fraction that typically makes up 30-60% of the total weight. This process can be performed using similar reactor types as those used for biomass pyrolysis, which include fixed, fluidized, and spouted beds, or screw and rotary kiln reactors. The resulting oil, called tires pyrolysis oil (TPO), has a high amount of carbon (approximately 85% by weight) and similar energy content to gasoil or light fuel oil at 42 mega joules per kilogram. However, TPO also has a high concentration of sulfur and aromatic components that

make direct use as fuel impractical. Therefore, the oil requires additional processing to remove these impurities, including hydrodesulfurization, hydro-dearomatization, and hydrocracking, with the latter techniques being the most promising for integrating TPO into refinery operation (Hita et al., 2016). Thus, the oil derived from co-pyrolysis of scrap tires and biomass materials could also be suitable for refining into high-quality fuels using hydro processing treatments.

WT have found extensive use in numerous energy-related applications such as power generation stations, factories that produce tires, cement kilns, and facilities that manufacture pulp and paper, among various others.

Since it allows for energy recovery, pyrolysis is seen as a promising thermochemical strategy for handling the problem of WTEO disposal. Due to the significant amount of natural rubber present in tires, this technique enables the removal of carbon black from tires, and the resulting volatile molecules (including both condensable and non-condensable compounds) have the potential for renewable energy recovery.

Analysis of fuel reveals the amount of moisture, volatile matter, fixed carbon, and ash that is present. According to studies, the polymeric compounds formed from NR and SR make up the majority of the volatile matter present in tires, while the fixed carbon should match the CB utilized in tire production. (De Marco Rodriguez et al. 2001) state that the amount of non-volatile matter should match the amount of solid residue left behind after pyrolysis, while the amount of volatile matter present should match the amount of gas and liquids created during the pyrolysis process.Vehicle tires have a high calorific value (35–40 MJ/kg), which is higher than the typical coal used in power plants (approximately 25–50%).

For thousands of years, people have been using pyrolysis to turn biomass into charcoal. Pyrolysis has also been used commercially to produce fuel gas and smokeless solid fuel from coal and mainly wood biomass. Pyrolysis is a type of thermochemical treatment that breaks down chemical bonds by heating the material in an oxygen-free environment like a vacuum or inert atmosphere. This process is the first step in combustion or gasification. While the term "pyrolysis" suggests the presence of oxygen, the more appropriate term is "thermolysis" because it accurately describes the lack of oxygen and reactive intermediates. Pyrolysis is sometimes called reverse polymerization, thermal depolymerization, or polymer cracking. The

main advantage of this process is that it can deal with waste materials that are difficult to recycle and create reusable products.

The process of thermochemical treatment has the ability to recycle feedstock and convert solid waste materials into high-energy fuels, valuable chemicals, monomers, and other materials. When solid materials are used, pyrolysis occurs and releases high-energy volatile gases and carbonaceous solids like char. Pyrolysis involves heating feedstock without oxygen in an inert atmosphere to over 400°C, causing different structures within the feedstock to decompose through various reactions. However, the products of pyrolysis are often low-value mixtures of hydrocarbons with a broad range of compositions, from light gases to coke. Depending on the desired outcome, the optimal conditions for the process must be determined, such as particle size, temperature, reaction time, heating rate, atmosphere, and flow.

2.2 A waste tire pyrolysis products

In general, polymers consist of carbon atoms that are bonded together with either single or double bonds. According to (Murillo et al., 2006), WT are defined by having double bonds between carbon atoms. When rubber undergoes thermal decomposition, it creates very reactive free radicals, which are molecules that are missing an electron. These free radicals can become a part of the original WT molecule. Additionally, (Aguado et al., 2008) explained that the process of thermal degradation follows a radical chain reaction pathway where the polymer backbone progressively breaks down through hydrogen transfer steps.

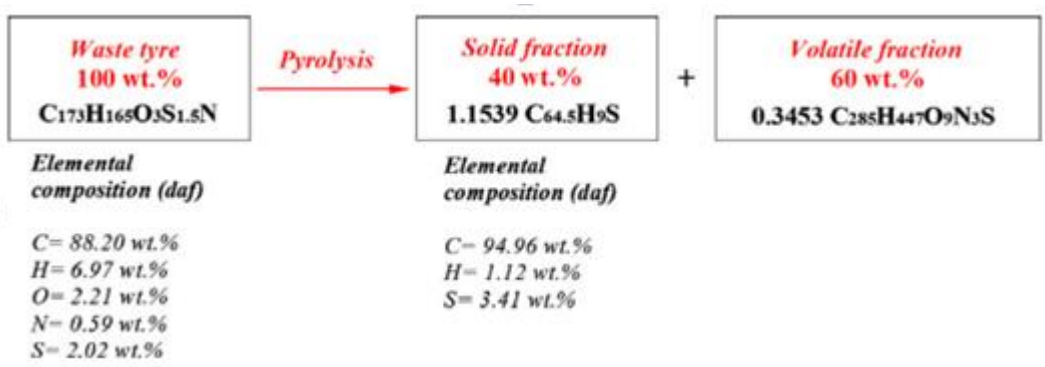

Figure 2. 1: Tire pyrolysis products (Aguado et al., 2008)

In general, it can be said that the WT pyrolysis procedure includes intermolecular free radical reactions, which change depending on the pyrolysis circumstances. The reactions that take place during tire pyrolysis were divided into three groups despite the difficulty in identifying the specific reactions at play: the primary pyrolysis reaction (250-520^{0}c), the secondary post-cracking reaction of pyrolytic volatiles (600-800^{0}c), which has a significant impact on BTX (benzene, toluene and xylene) yields, and the pyrolytic CB gasifying reaction with $CO_2/H_2O/O_2$ in the gases (750-1000^{0}c). According to the authors, temperature and reaction time, which are depicted by the reaction rates in the Arrhenius equation, determine the relevance of each reaction group.

2.3 Reactors for pyrolysis

(Scheirs, 2006) indicates that industrial facilities with a conical or tori spherical floor and a capacity ranging from 3 to 20 m^2 commonly carry out plastic pyrolysis and/or cracking by catalysis in continuous stirred tank reactors. The options for tire pyrolysis, however, are more varied. These include autoclaves, rotary kilns, screw conveyors (auger), fixed, spouted, entrained and fluidized beds, rotating cones, vortex reactors, melting vessels, plasma reactors, free-fall, tubing bomb reactors, as well as vacuum pyrolysis and the ablative process. Each reactor/configuration is utilized for different energy applications, such as distributed production (heat and/or electricity) and the manufacture of liquid fuels, and char each has benefits as well as drawbacks in terms of technical, economic, and ecological characteristics. Numerous technological equipment designs have been proposed, designed, and tested. (Meier & Faix, 1999) The BFBR and CFBR, the ablative process (the rotational cone and vortex reactor), and the vacuum pyrolysis were emphasized as the most pertinent reactor designs for fast pyrolysis. Additionally, (Malko w, 2004) gave a thorough analysis of cutting-edge pyrolysis and gasification methods for the disposal of municipal solid waste with energy recovery. Additionally, numerous arrangements for processing waste rubber and tire components through thermochemical and combustion processes in various types of reactors were shown

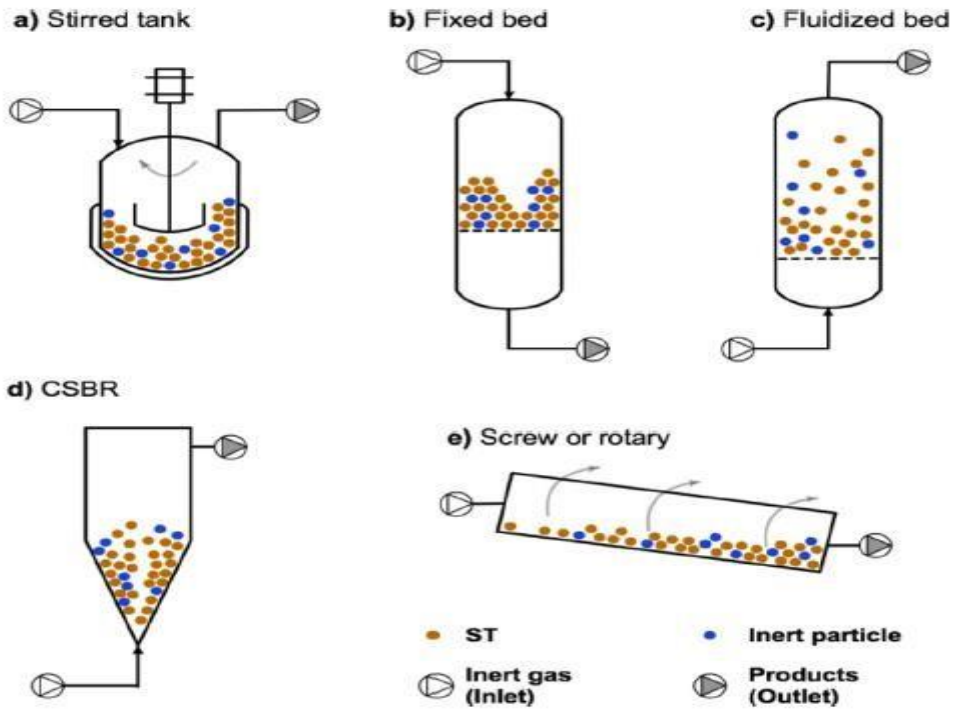

Figure 2. 2: type of reactor (Khiari et al., 2018)

2.4 Types of pyrolysis

Depending on operational characteristics like heating rate, volatile residence duration, and temperature, pyrolysis may be divided into several categories. The widest classification of pyrolysis is slow and rapid, with fast being referred to as flash pyrolysis. However, compared to rapid pyrolysis, flash pyrolysis can also refer to faster heating rates and shorter vapor residence durations. Additionally, pyrolysis can be categorized according to the environment in which it is performed; examples include oxidative, hydro, steam, catalytic, and vacuum pyrolysis. Based on the type of heating method employed, such as microwave or plasma, pyrolysis may also be categorized (Kumaravel et al., 2019)

Pyrolysis can be carried out successfully under various conditions, leading to different classifications. Depending on the operating parameters, there are numerous types of pyrolysis, including atmospheric, vacuum, catalytic, fast, ultra-fast (flash), and slow (Cheng et al., 2017).

Table 2. 1: type of pyrolysis(Cheng et al., 2017)

Process	Heating rate	Residency time	Temperature (ºC)	Target product
Slow carbonization	Very low	days	450-600	Charcoal
Slow pyrolysis	10-100 K/min	10-60 min	450-600	Gas, oil, char
Fast pyrolysis	Up to 1000 K/s	0.5-5 sec	550-650	Gas, oil, char
Flash pyrolysis	Up to 10000K/s	<1sec	450-900	Gas, oil, char

2.4.1 Slow pyrolysis

As implied by its name, slow pyrolysis entails a slow, low-temperature decomposition process. Low temperatures and relatively lengthy times for the solid and vapor components to remain inside the system (usually lasting a few minutes to several hours) are two characteristics of this form of pyrolysis. Furthermore, slow pyrolysis can occasionally be carried out at lower temperatures. This process involves extended residence durations, which increases the potential for secondary conversion of primary products and boosts the generation of coke, tar, and thermally stable compounds. Many people now refer to slow pyrolysis as "carbonization" as a result of this property. Slow pyrolysis' major goal is to create char, as opposed to fast pyrolysis, which primarily focuses on getting tar and gases. While some tar and gases may be collected, they are not always retrieved during slow pyrolysis

2.4.2 Fast pyrolysis

In contrast to slow pyrolysis, fast pyrolysis involves a rapid thermal breakdown process that needs a feedstock with small particle sizes and specific equipment to remove vapors quickly. By condensing the volatiles generated during pyrolysis before they have an opportunity to decompose into gaseous products, the high heating rates, and brief residence durations in the hot zone, and quick quenching of products favor the creation of liquid products. With a higher production of liquid fuels, chemicals, and derived products typically between 50 to 60 weight percent for rubber feedstock this process is noted for creating a liquid fuel with a greater calorific value.

In catalytic pyrolysis, a catalyst is used to increase the yield or quality of the products produced within a pyrolytic process. The generation of single-ring aromatic chemicals like

benzene and toluene in the liquid portion of the process has been achieved through research employing catalysts like zeolites and expanded perlite. A larger liquid output at lower pyrolysis temperatures and a rise in H^2 in the gas fraction have both been demonstrated by studies that show adding NaOH to the process can have these effects. During the catalytic pyrolysis of WT, it has been discovered that adding a catalyst improves the liquid fraction yield and its fuel characteristics.

2.5 Pyrolysis products

When processing entire tires, the procedure generates four output flows that include gas, fluid (oil), solid (char), and steel. Conversely, if rubber shreds are used as input material, the steel component will not be present in the output flow, as the mechanical separation of steel should have been completed beforehand.

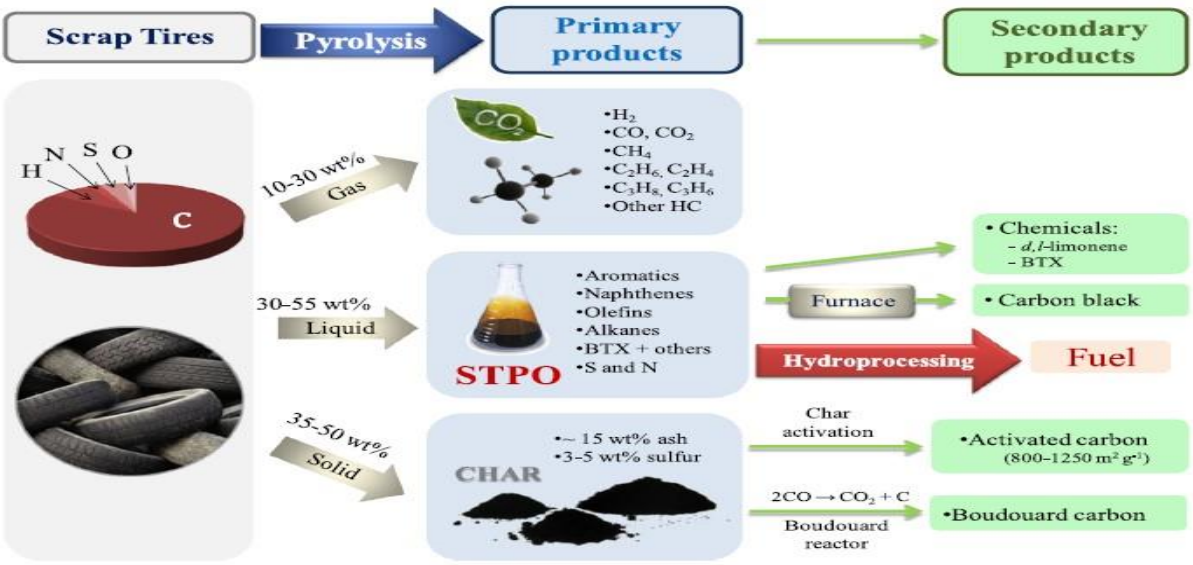

Figure 2. 3: Valuable product derived from Waste tire pyrolysis (Hita et al., 2016)

2.6 Energy requirement for pyrolysis

The energy required for pyrolysis, also known as enthalpy or heat for pyrolysis, is divided into two parts: the energy needed to raise the feedstock's temperature from room temperature to the reaction's required temperature (known as sensible energy), and the energy required to convert the feedstock into the reaction's byproducts (reaction enthalpy). The necessary heat for pyrolysis can be provided in a number of ways: (i) burning an auxiliary fuel; (ii) igniting the

gas and/or solid fraction generated during the process; (iii) using electric heating; and (iv) using hot sand, solvents, or molten salts as a heat transfer medium (heat carriers).

2.7 Parameter affecting pyrolysis process

Pyrolysis, a process where heat decomposes a substance, is an endothermic reaction that requires a consistent temperature in the reactor to continue. The temperature plays a significant role in determining the resulting products and conversion rates, thus, making it the primary controlling variable in pyrolysis. Other factors such as type of reactor, particle size, heating rate, chemical composition, and volatile residence time also contribute to the process outcome.

2.7.1. Temperature

Given that it regulates the chain of polymers cleavage reaction, temperature is one of the most crucial operating parameters in pyrolysis. The van der Waals force draws molecules together, preventing those molecules from collapsing. The molecules in the system tend to evaporate out of the surface of the object as the temperature in the system rises, increasing the motion of the molecules in the system. This occurs when the enthalpy of the CC bond in the chain is greater than the energy generated throughout the polymer chains by the van der Waals force, causing a broken carbon chain (Gao, 2010). With rising temperature, the pyrolysis liquid fuel product gains both quality and quantity.. Even when the temperature is raised, pyrolysis at very high temperatures results in a decrease in the liquid output. This is due to secondary breakdown, which occurs when the critical breakdown temperature is raised further and results in the production of more gaseous product by lowering the liquid yield.

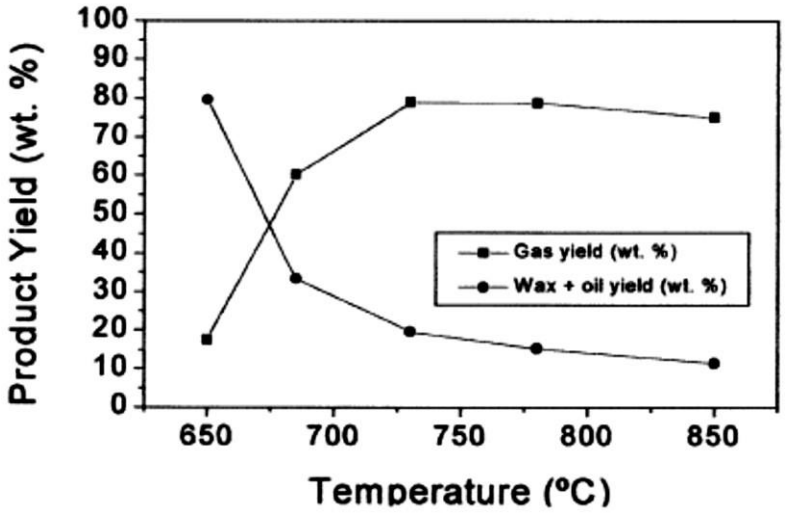

Figure 2. 4: Temperature vs product yield (Hita et al., 2016)

Figure 2.4: It can be concluded from this that the rate of reaction, which can impact the product composition of liquids, gases, and carbon for tire and lubricant oil, is most strongly influenced by temperature. The preferred product has a significant impact on the necessary operating temperature. A higher temperature of more than 50°C was advised when a gaseous or char result was preferred. This criterion applies to WTEO. If liquid was preferred instead, a lower temperature in the range of 300-500^{0}C was advised.

2.7.2 Type of reactor

The efficiency of heat transmission, mixing, residence durations in the gas and liquid phases, and principal product exit are mostly influenced by the reactor type used. The principal breakdown products' escape dynamics are determined by the reactor design, therefore various reactors produce varying amounts and qualities of product (Parku et al., 2020). There are two types of reactors used for tire and waste oil pyrolysis, according to the feed and product removal method or bed design.

2.7.3. Residence time

The residence time in slow pyrolysis and batch processes refers to the period of time from the beginning of heating of the starting waste oil and tire to the point at which the products are removed, whereas the period of residence in fast pyrolysis or continuous pyrolysis processes refers to the duration of contact of the waste oil and tire on the hot surface throughout the

reactor. More primary products can be converted further with a longer residence period, producing more thermally unstable byproducts such as hydrocarbons of low molecular weight and non-condensable petroleum gases (Aguado et al., 2008). A prolonged residence period during slow pyrolysis encourages the process of carbonation and increases the amount of tar and char in the final products. The residence duration, with the exception of the batch pyrolysis reactor in a closed system, is difficult to regulate directly but is modifiable by altering other operating parameters including the feeding rate, carrier gas stream rate, and product discharge rate. Following that, the residence time for these controlled operation parameters was determined (McMurry, 2000)

2.7.4. Use of catalyst

The distribution of the pyrolysis products is altered and tire and lubricant oil pyrolysis is optimized when catalyst is used. The catalyst can be applied to both academic and commercial pyrolysis procedures. (Miandad et al., 2016) thermal pyrolysis yields low-quality liquid oil and necessitates both high temperatures and long retention times. The temperature and residence time are reduced in tire and lube oil pyrolysis when a catalyst is used. The liquid yield, however, was only marginally increased by the use of some catalysts, such as silica-alumina (SA-2) and mesoporous silica catalysts (FSM), over thermal pyrolysis, with a minor increase of around 1.07wt%.

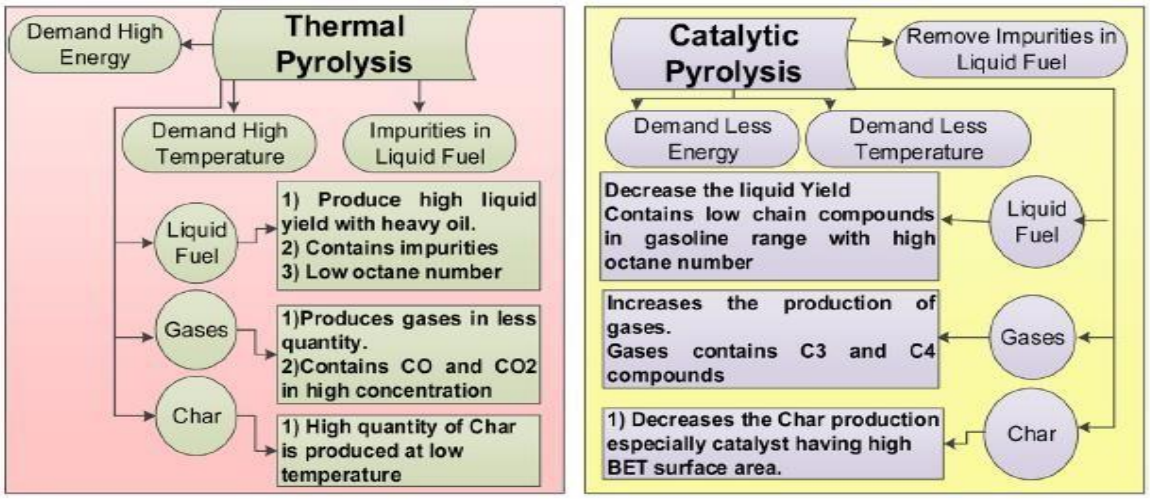

Figure 2. 5: Catalyst effect on pyrolysis (Miandad et al., 2016)

Several researchers have utilized a variety of catalysts, including ZSM-5, HZSM-5, FCC, natural zeolite, activated alumina, and red mud. Different catalyst effects can be seen on the procedure of pyrolysis and its byproducts

2.7.5 Pressure

It has been discovered that raising the pyrolysis pressure raises oil viscosity. On the other hand, it has been discovered that reduced pressure (typically connected with vacuum pyrolysis) reduces additional reactions in the gas phase by shortening volatiles' residence time; this has the potential to boost oil output. The solid carbon can become of greater value as an activated carbon adsorbent with a bigger surface area and higher reactivity by limiting secondary reactions, which can also reduce gas deposition on the surface of the carbon. According to the ideal gas law, lowering process temperature can also result in lowering process pressure (PV=nRT), which reduces the amount of energy needed (Haydary et al., 2012)

2.7.6. Particle size

Given that there is a high rate of heat transmission between the particles when the tire is smaller, the dimension of the tire materials added to the reactor affects how the pyrolysis product is distributed. High mass transfer rates for condensable gases to escape from fine particles are said to be available before secondary cracking, leading to larger liquid yields. Larger particles, on the other hand, restrict heat transfer and promote subsequent cracking. This is due, in part, to the fact that they provide a high level of resistance to the principal pyrolysis products that escape.

2.7.7 Structural composition of raw material

The chemical make-up and chemical composition of the waste oil and tire that will be pyrolyzed directly affect the pyrolysis products. Additionally, the pyrolysis processes are impacted by the chemical makeup of the starting material. Tire polymer molecules are categorized as linear, branched, and crosslinked based on their structural structure.

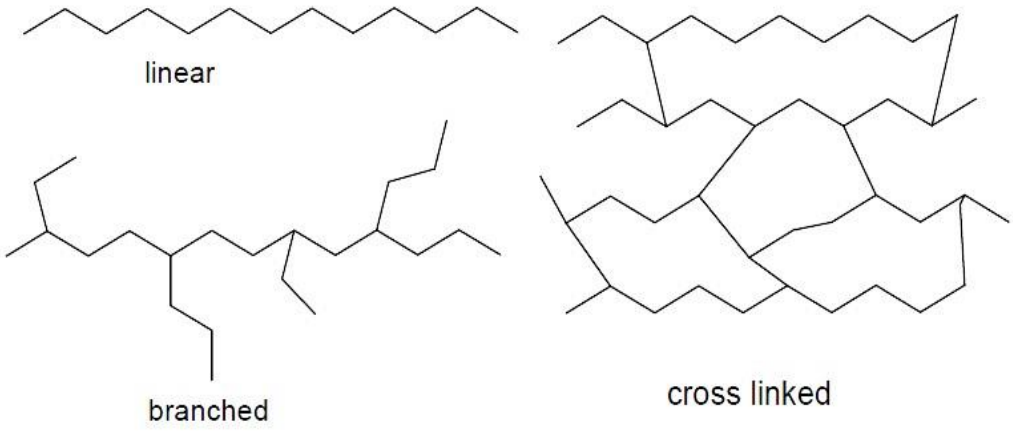

Figure 2. 6: Chemical composition (Hejna et al., 2020)

Only two extra units one at each end are coupled to the units in the linear polymer. When branches randomly extend outside of the primary polymer chain, the polymer is considered to be branched. Because of the branch points produced by the polymerization process, at least one of the monomers that exist in branched polymers is linked to greater than two functional groups. The branching structure and functional side group both significantly affect the pyrolysis result. An interconnected, branched polymer with the entire polymer chains united to form a single, big molecule is what is referred to as a crosslinked polymer. Instead of melting or evaporating during the pyrolysis process, the crosslinked polymer disintegrates.

2.8 Products of waste pyrolysis

They discovered that the two main byproducts of the rubber distillation were isoprene and dipentene (Midgley & Henne, 1929). Since the late 1960s, several WT pyrolysis experiments using a wide variety of process technologies have been conducted with large high liquid content waste through pyrolysis get high percent oil product yield (Li et al., 2004)

From an industrial perspective, various publications (Goddard, 1992) noted that the US Bureau of Reclamation made the first attempt at pyrolysis of WT. A laboratory device that can pyrolyze 10 kg of tires per day was created, and it produced 3.8 l of liquid, 3.2 kg of char, 1.4 kg of gas, and 1 kilogram of steel and char per tyre (Goddard, 1992). According to (Midgley & Henne, 1929), the device was a bench-scale retort that was externally heated, sealed, and typically used to examine coal coking. Condensers, electrostatic precipitators, acid and caustic

scrubbers, and other cleaning equipment were used to clean the volatile products. They obtained much cleaned 20 wt % of condensable fuel and the other is char and gas.

The following are brief comments on the characteristic process and representative outcomes of these studies.(Kaminsky et al., 1976) conducted research mainly focused on demonstrating the feasibility of pyrolysis of plastic feedstock and tires in a BFBR, with and without tire size reduction. They tested three-step scale-up facilities, including a laboratory plant (100 g/h), a pilot plant (30 kg/h), and a prototype plant (150 kg/h). In the prototype plant, the product yields were as follows: 18-25 w_t% of gas, 25-30 w_t% of liquid, 35-45 w_t% of char (including CB and filler materials), and 8-12 wt% of steel cord when over 150 whole tires (totaling 1500 kg) were processed in a single run. The gas fraction consisted mainly of CH_4 and C_2H_4, while the liquid had an aromatic nature.

(Fletcher & Wilson, 1981) of Foster Wheeler suggested a cross-flow approach to tyre pyrolysis, emphasizing the importance of achieving close gas-solid contact for efficient heat transfer. They reported successful operation of pilot plant based on this method, which yielded 21 w_t % gases and 27 w_t % liquid and the part char and other part of filer material.

2.9 Temperature of waste pyrolysis

(Lucchesi & Maschio, 1983)conducted tyre pyrolysis experiments in a countercurrent FBR and observed that the resulting pyrolysis gases contained enough energy to meet the process energy requirements. They also found that the liquid fraction contained a high proportion of aromatics, while the solid fraction could serve as a precursor for activated carbons. The temperature take to complete conversion is between 300 up to 600^0C.

(Bouvier & Gelus, 1986) conducted experiments using lube oil that comprises dense oil to dissolve oligomers created by devulcanization and depolymerization. The outcomes yielded a combustible gas, a liquid fraction, and an oil-CB suspension. The process was carried out at a temperature of approximately 380 ^{0}C.

(Boukadir et al., 1981)reported kinetic studies using TG analysis. The former discovered that the thermal degradation of tires occurred in two stages, based on their primary compounds: polybutadiene broke down at lower temperatures (below 300 ^{0}C) than polystyrene (between

300 and 450 ^{0}C). The latter study identified the parameters involved in the Arrhenius equation and revealed that rubber degradation is a one-step mechanism following a first-order reaction.

The University of Laval in Canada has been working on the development of the vacuum pyrolysis process for various feedstocks, including WT, since the early (Kaminsky, 1980) have been leading a research program that aims to establish a solid understanding of the reaction mechanism, pyrolysis product characteristics, and the design and operation of process development units. These units range from batch systems to an industrial-scale demonstration plant with a throughout capacity of 300 up to 600 ^{0}C (Chaala & Roy, 1996)

(Williams & Taylor, 2013)intensified the study of engine oil pyrolysis in FBRs, providing valuable insights into the process and complete product characterization. Since then, there has been a substantial increase in the size of particle the temperature become around 300 ^{0}C

2.10 Engine performance of blend fuel

(Wongkhorsub & Chindaprasert, 2013) The technical and economic viability of using plastic pyrolysis oil and tire pyrolysis oil as a substitute for diesel oil in diesel engines was assessed. Both oils were found to be capable of replacing diesel oil. However, plastic pyrolysis oil offers lower engine performance due to the enormous amount of plastic waste that needs to be processed to reduce environmental problems. Engine modification may be necessary to accommodate the combustion conditions of plastic pyrolysis oil. When using waste plastics in this process, it is important to use only PE or PP to prevent contamination with chlorine. Tire pyrolysis oil offers efficiency comparable to diesel oil at medium to high load but the desulfurization process has been questioned. But up to B10 it is somewhat related to the base line diesel.

(Sharma & Soni, 2013) This work provides a short overview of how to create diesel like fuel for use in engines from various types of waste oil that are commonly found today. The outcomes of the study indicate that diesel like fuel created from waste oil, specifically plastic pyrolysis oil, waste engine oil, and waste tire oil, are a technologically feasible, economical, and environmentally sustainable solution and also effective for engine performance without engine modification by blending with pure diesel. Finally conclude that up to B20 can used for engine performance without engine modification with different engine load.

2.11 Emission characteristics of WTEO fuel

(Cheng et al., 2017) According to the stability test, the combination of B5D85 with 100 ppm doping dosage has greater stability due to its higher dosage. In the same way, this combination also shows an increase of 2.94% in brake thermal efficiency and a decrease of 7.46% in smoke emission compared to diesel under full load. This reduction in emission will contribute to a cleaner environment and decreased environmental impact.

(Karagöz et al., 2020) In summary, waste tire pyrolysis oil-diesel blends can be used as a fuel additive in CI engines without any alterations. This method helps with waste-management and converting waste to energy while also preserving fossil fuel resources. The authors suggest using ternary or quadruple fuel types in future studies because binary TPL-diesel blends have 0% oxygen content. The addition of biodiesel, alcohol, liquid waste or metal-oxide nanoparticles can increase the oxygen content, reduce emissions, and improve combustion quality in comparison to the binary fuels.

2.12 Summary of literature review

Different result obtain in literature showed that use of waste tire and engine oil for the process of pyrolysis together is increasing conversion rate and quality of product and also possible to use such pyrolyzed fuel from WTEO for many purpose like cooking, industrial and also for engine performance with different blend ratio. From many experimental result fuel produced from waste tire and engine oil have related property with conventional diesel.

2.13 Research gap

From the above review, we can conclude that all types of WTEO convert into hydrocarbon fuel by pyrolysis**.** pyrolysis of solid waste with liquid waste enhances the conversion and fuel quality (Wang et al., 2022). This thesis, particularly considers a fuel produced from mixed WT and WEO as almost all researchers‟ works on one type of waste either WT or WEO, but not the mixed. This is as a gap or limitation why we can try to work on both types of mixing, further for engine performance, this research solves this gap.

CHAPTER THREE

MATERIAL AND METHODS

3.1. Material and Tools

Several materials are required in order to accomplish this goal. The various tools and techniques for component development and testing are covered in this chapter.

3.1.1 Material

Materials utilized in this study include the following

- Sheet metals
- Circular pipe
- Rectangular pipe
- Control valve
- Gasket

3.1.2 Tools

- Thermocouple
- Baker
- Cutter, driller, welder
- Electrode
- Hammer
- Meters

3.2. Methods

3.2.1 Overall Process

The flow diagram outlines of the thesis overall procedure.;

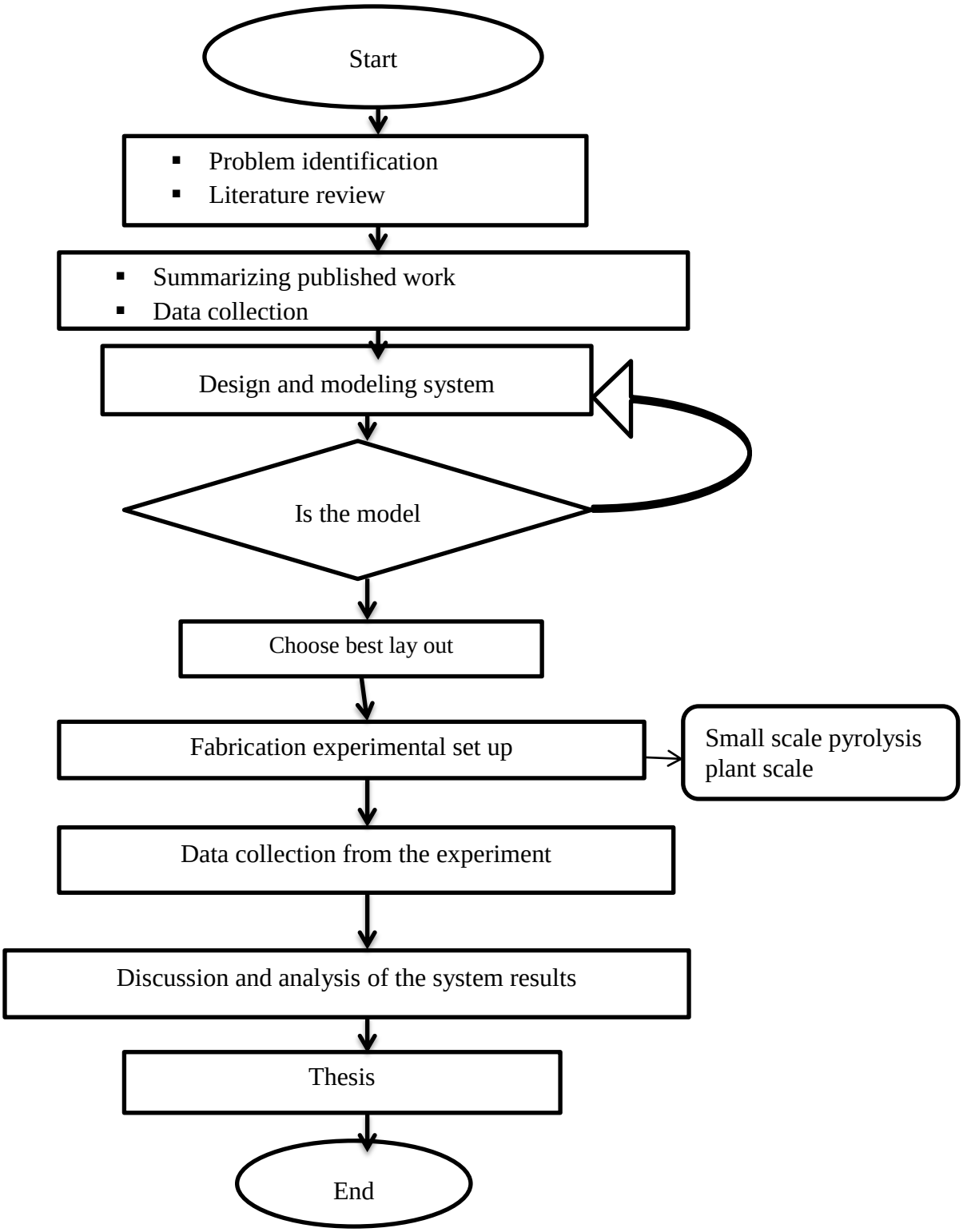

Figure 3. 1: General process layout of the thesis

3.3 Experimental Setup of small WTEO pyrolysis plant

WTEO gathered from the Adama town is separated, cleaned, and shredded into portions before being fed into a reactor that has been fired by a furnace. Condensation is carried out in two steps. The non condensable vapor from the heat exchanger is condensed in secondary condensation utilizing distillation cooling after the initial condensation is completed in water stored tanker and a copper heat exchanger. Through a tube that is installed at the top of the reactor, the decomposed pyrolysis gas is introduced to the condenser. The condenser is designed as a heat exchanger with circular flow. As a result, condensate is discharged from one end while the pyrolysis gas is delivered into the condenser coil at the other. In contrast, cooling water is kept in water tanks. Finally condensed fuel stored in the receiver.

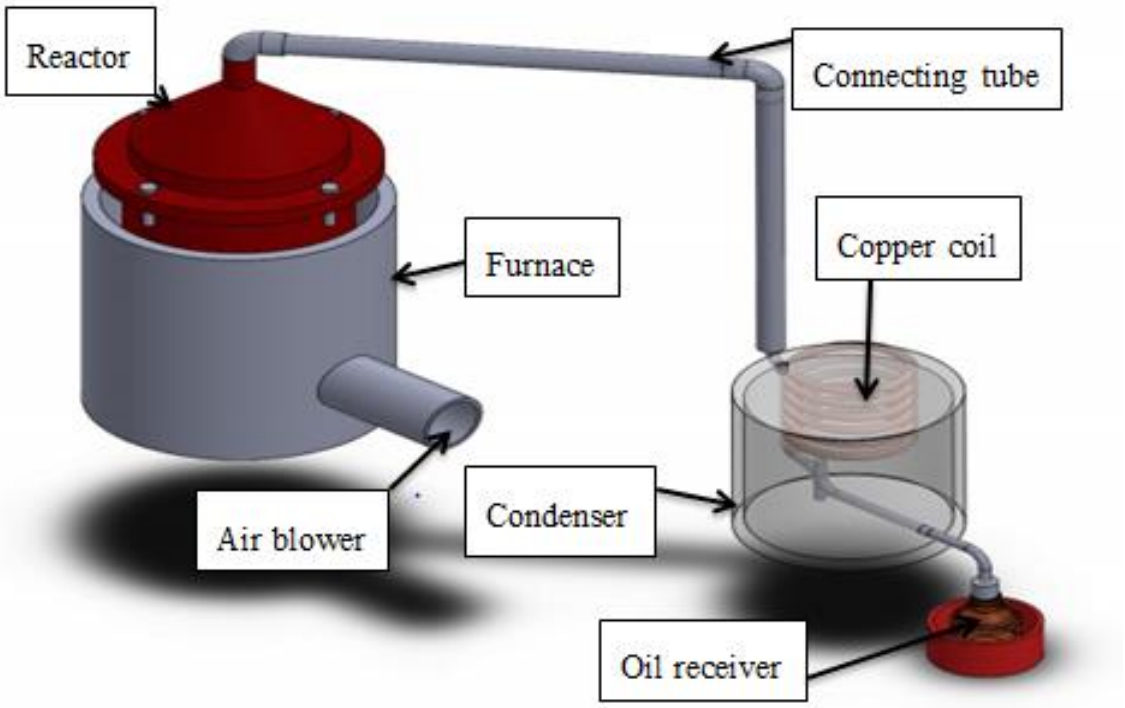

Figure 3. 2 Schematic of small scale plastic pyrolysis plant

CHAPTER FOUR

ANALYTICAL DESIGN

4.1 Design

4.1.1. Reactor design

The quality of heat transmission, mixing, the duration of the gas and liquid phases, and the escape of primary products are mostly influenced by the reactor type. The principal breakdown products' escape dynamics are determined by the reactor geometry; therefore various reactors produce products with varying quality and quantity. There are two groups of reactors that are employed in the pyrolysis of WTEO, depending on the technique for feeding and product removal or the design of the bed.

The type of reactor that will be built for this study is a fixed bed batch reactor. Due to the permanent nature of the bed and the batch feeding method employed, all of the raw material must be cracked after the reactor has been loaded with the tire and motor oil feedstock.

4.1.1.1. Size of rector shell

The pyrolysis reactor was designed to use the vertical cylindrical cross section with a shell-like shape. The base of the reactor, which is the bottom end, is circular and smooth to provide a better rate of heat transmission. The reactor was designed to operate at normal air pressure. The connection of pipes to direct vapor to the condenser, the installation of thermocouples, and the discharge of residue are all suggested at specific points.

The reactor volume looks to be greater if the reactor size is set to be able to handle all of the tire and engine oil waste produced in Adama town. Therefore, a reactor vessel with a volume of 10 liters is chosen.

$$V=\pi r^2 h \qquad 4.1$$

The geometry of the reactor vessel is designed to have an internal diameter of 180 mm and a height of 300 mm based on the chosen volume of the reactor vessel and equation 4.1 above. The reactor vessel's proper standard diameter is 172mm.

Note that the density of tire and lubricating oil feed stocks are (William D. Callister, 2001):

$\rho tire$ =840kg/m^3

$\rho oil = 800 kg/m^3$

$$V = \frac{m}{\rho} \quad 4.2$$

According to equations 4.1 and 4.2 above regarding reactor vessel volume, the reactor is capable of handling 6.4 kg of tire and motor oil at a time, independently.

Reactor shells are made thick enough to resist the pressure inside the reactor vessel. (Robert W.Serth, 2007).

$$t_{rs} = \frac{P \times R_i}{\sigma \times E - 0.6 \times P} \quad 4.3$$

Where

P = Inside pressure

R_i = inside radius of the reactor

δ = Allowable stress

E = Weld efficiency

t_{rs} = thickness of sheet metal used for reactor shell

Reactor pressure is equivalent to atmospheric pressure. The reactor component is made of carbon steel, and the form of welding to be used is a butt joint without the usage of backing strip. The working pressure is equivalent to 101325Pa, which is the allowed stress for the construction material at 4500C, but it is preferable for the design pressure to be 10% higher. (Eugene F., M, 2001). Therefore the design pressure equals to 111,457.5Pa, and joint efficiency equals to 60% (Eugene F., 2001). When all of these values are entered into equation 4.3, the thickness of the reactor shell is changed to 0.258 mm. The thickness of the reactor vessel increases to 3 mm when safety factor and corrosion allowance are taken into consideration. 6mm is the minimum vessel thickness that is standardized. The design is satisfactory because the thickness is less than half the inside radius.

4.1.1.2. Size of reactor cover

Reactor heads are shaped to be toruspherical to facilitate the discharge of pyrolysis gas. Equation to compute the head thickness (Tadesse, M., Fentahun, 2017).

$$t_{rh} = \frac{0.885PL}{\sigma E + 0.8P} \quad 4.4$$

Where:

L = External radius

δ= Allowable stress

E = Weld efficiency

t_{rh} = thickness of reactor head

When all the data is applied, the head thickness is 0.15mm. When safety is taken into account, it becomes 6mm.

4.1.2. Production rate

Vaporize energy required WEO and tire, $H_V = 36{,}820kJ/kg$

Specific heat capacity of tire, $C_p = 9{,}348J/kg$

Average value of latent heat of fusion of WEO and tire $H_f = 121.34kJ/kg$.

Heat energy required for the pyrolysis of 1kg of tire, $Q_H = 36{,}820kJ$

The amount of WTEO that must be pyrolyzed is 4 kg, and the process takes 3 hours to complete. As a result, 5 kilograms of waste tire and engine oil must be heated until it begins to melt at 115 °C.

$$Q_1 = m \times c_p \times \Delta T \quad 4.5$$

$$= 4kg \times 9.348\,{}^{kj}/_{kg.k} \times 90k$$

$$= 4206.7kj$$

Heat required to completely melting 4 kg waste tire and lubricating oil at 115°C,

$$Q_2 = 4kg \times 121.34\,{}^{kj}/_{kg} = 606.7kJ$$

Heat taken by 5kg liquid waste tire and lubricating oil till it reaches 500°C,

$$Q_3 = 4kg \times 9.348\,{}^{kj}/_{kg.k} \times 335k = 7705kj$$

Heat required for pyrolysis,

$$Q_4 = m \times Q_H \quad (4.6)$$

$$= 4kg \times 1047.62kJ/kg = 5238.1kJ$$

Q1 through Q4 together give the total amount of heat needed.

Q = 17,756kJ

Take 17,800 kJ

The rate of heat transmission is equivalent to,

$$q = \frac{Total\ heat\ required}{Time\ taken} \quad (4.7)$$

$$= \frac{17800kj}{3h} = 5{,}933.3\,{}^{kj}/_{h} = 1{,}648\ 15watt$$

Pyrolysis gas production rate:

$$m_E = \frac{Heat\ tranfer\ rate}{heat\ vapourization} \quad (4.8)$$

$$= 32.878\,{}^{kg}/_{h} = 0.009133\,{}^{kg}/_{s}$$

4.1.3. Design of Condenser

4.1.3.1. Sizing of a Coil Heat Exchanger

A schematic drawing of the condenser is shown in Figure: 4.1. It comprises of an immersed coil heat exchanger that is mounted on the tank's lateral wall and situated at the bottom of the tank. Helix coil heat exchanger crosses sectional cut way view.

4.1.3.2 Coil Heat Transfer Area

The input parameters used to size the helical coil heat exchanger are crucial for developing this type of heat exchanger. The first step in this scenario is to determine the coil heat transfer

area, A_o using Equation 4.9. Let's assume for the purposes of this equation that the water coming from the coil tube's maximum input and outflow temperatures are, respectively, 450°C and 500°C.

The above equation can be used to compute and quantify the thermal output of the reactor (hot fuel departs the reactor and is transported through a coil exchanger).

q = 1,648 W

Equation 4.9 was used to calculate the quantity of energy that was transferred through the coil HX to cool the fuel, Q and the results are shown below in terms of the mean temperature difference.

$$q = A_0 U_0 \frac{\Delta T_m}{C_r} \quad 4.9$$

$$\Delta T_m = T_{avg,\,\mathrm{f}} - T_{avg,\,\mathrm{w}} \quad 4.10$$

Where,

ΔT_m = the variation in the coil's average fuel temperature

$T_{avg,\mathrm{f}}$ average temperature of fuel and the average temperature of water in the tank, $T_{avg,\mathrm{w}}$.

ε = the efficiency of the heat transmission coefficient, which ranges from 0.6 to 0.8 but is typically 0.7, is affected by the coefficient of furring, which happens when thermal media are distributed unevenly.

C_r = the heat loss coefficient, 1.1 to 1.2

$$T_{avg,\,\mathrm{fuel}} = \frac{T_h - T_c}{2} \quad 4.11$$

$$= (450 + 50)/2 = 250^0 C$$

$$T_{avg,\,\mathrm{water}} = \frac{T_h + T_c}{2} \quad 4.12$$

$$= (50 + 25)/2$$

$$= 37.5\ ^0 C$$

Then, $\Delta T_m = 250 - 37.5 = 212.5^0 C$

For these types of heat exchanges, the overall heat transfer coefficient varied between 200 to 500 W/m^{20}C (Sinnott, R. K, n.d. 2015). The needed heat transfer area of the coil heat exchanger can be determined by Equation 4.13 if the total heat transfer coefficient of this heat exchanger is assumed to be 450 W/m2 ^{0}C, nominal value.

Using the value of C_r = 1.1,

$$A_0 = \frac{C_r Q}{\varepsilon U_0 \Delta T_m} \qquad 4.13$$

$$= \frac{1.1 \times 1648}{0.7 \times 450 \times 212.5} = 0.027 m^2$$

4.1.3.3. Dimension of condenser coil

High heat transfer area can be achieved by using multiple small-diameter pipes rather than a single large-diameter pipe. Copper tube with a nominal outer diameter of 8 mm and a thickness of 0.61 mm was used for this heat exchanger.

Thus, d_o = 8 mm and d_i = 6.78 mm

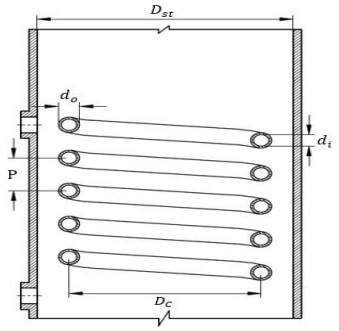

Figure 4. 1: sectional view of condenser

4.1.3.4. Coil Pitch

In these kinds of heat exchangers, the pitch of the helical coil, P, calculated by Equation (4.6), is a typical design value (Lazova et al., 2016).

$$p = 1.25 * d_o \qquad 4.14$$

Substituting the value of d_o,

$$p = 1.25\ x\ 8\ mm$$

= 10 mm

4.1.3.5. Copper tube length

The outer diameter can be used to determine the minimum necessary copper coil length, Lcoil, as follows:

$$L_{coil} = \frac{A_0}{\pi d_0} \quad 4.15$$

Substituting,

$L_{coil} = \frac{0.027m^2}{\pi \times 0.008m} = 1.377\text{m}$

The coil needed to make the required number of turns was approximately 1.5 m long.

4.1.3.6. Coil Diameter

Assuming that a coil with a diameter of 150 mm is used, the heat transfers efficiency direct proportional to number of turns:

4.1.3.7. Number of coils turns

The heat exchanger N coil number of coil turns, which takes into account the coil length and pitch, (Lazova et al., 2016) obtained using Equation 4.16.

$$N_{coil} = \frac{L_{coil}}{\sqrt{(\pi {D_c}^2) + P^2}} \quad 4.16$$

Substituting the values in Equation (4.8),

$$N_{coil} = \frac{1.5m}{\sqrt{(\pi \times 0.15^2) + 0.01^2}}$$

= 3.18

However, Ncoil just rounds the required number of coil turns to the next greatest integer, which is equivalent to 4 turns.

Covered volume by coil tube, V_c:

$$V_c = \frac{\pi}{4} d_0^2 L_{coil} \quad 4.17$$

$$V_C = \frac{\pi}{4}(0.008m)^2 \times 1.5m$$

V_C =0.00007536m^2

4.1.3.7 Amount water in condenser, Vst:

Taking into account the space taken up by the coil tube and the necessary 0.02 m^3 volume of water in the tank, the following can be calculated:

$$V_{st} = V_c + 0.01m^3 \quad 4.18$$

$$= 0.0200736\ m^3$$

4.1.4 Coil Heat-Transfer Analysis

The hot water temperature flow through the coil was previously thought to be consistent in order to size coil HX parameters, although it changes during the operation at any given time.

4.1.4.1 Heat gained by copper coil tube

Equation describes the rate of total heat exchanged throughout the full length of the coil, Q, expressed in terms of the logarithmic mean temperature difference (ΔTLMTD) (4.13) (Lazova et al., 2016).

$$\dot{Q} = U * A_o * \Delta T_{LMTD} \quad 4.19$$

4.1.4.2 Overall heat transfer

The three thermal resistances that are connected to the outer coil surface and used to describe the overall heat transfer coefficient, U, are as follows (Mohan et al., 2017).

$$UA_0 = \frac{1}{R_t} = \left(\frac{1}{\pi d_0 L_{coil} h_0} + \frac{1}{2\pi k_c L_{coil}} ln\frac{d_0}{d_i} + \frac{1}{\pi d_i l_{coil} h_i}\right)^{-1} \quad 4.20$$

The outer surface area of heat exchanger, A_o

$$A_o = \pi d_o L_{coil} \quad 4.21$$

The inner surface area of heat exchanger, A_i

$$A_i = \pi d_i L_{coil} \quad 4.22$$

The word Rt refers to the overall thermal resistance that is produced by adding the thermal resistances brought on by forced convection inside the coil, conduction across the tube's thickness, and natural convection outside the coil. Similarly, ho and hi stand for the heat transfer coefficients of forced and natural convection, respectively, kc for the copper tube's thermal conductivity, and di for the coil tube's outer and inner diameters.

4.1.4.3 Inner Convection Heat Transfer Coefficient

As per (Cuiping, L., Jianqing, D, 2007) The inner Nusselt number correlation of Equation 4.23 allows us to express the inside coil heat transfer coefficient, hi, as follows (Kakaç et al., 2002)

$$Nu_i = 0.0397(Re)^{0.784}(Pr)^{0.3} \quad 4.23$$

$$h_i = \frac{Nu_i \times K_c}{d_i}$$

Where, Pr is the Prandtl number.

$$P_r = \frac{C_P \times \mu}{K_c} \quad 4.24$$

In Refs (Kakaç et al., 2002) The curvature ratio corresponds to the critical Reynolds number for helical pipe flow, which determines whether the flow is laminar or turbulent, as follows:

$$Re_{cr} = 2300\left[1 + 8.6(\frac{d_i}{D_c})^{0.45}\right] \quad 4.25$$

Calculation of coil curvature ratio, $\delta = \frac{d_i}{D_C}$

$$= \frac{6.78mm}{150mm} = 0.0452$$

On substituting the value of, δ into Equation 4.25

Re_{cr} = 7,209.515 > 4000

Therefore, forced convection and turbulent flow exist inside the coil tube, according to Equation 4.25.

4.1.4.4 Outer Convection Heat Transfer Coefficient

The outer natural convection heat transfer coefficient was calculated using the correlation stated in Eq. 4.26 using the tube outer diameter as the characteristic length (Cuiping, L., Jianqing, D, 2007).

$$= 0.36 + \frac{0.518 * Ra^{0.25}}{\left[1 + \left(\frac{0.559}{}\right)^{\frac{9}{16}}\right]^{\frac{4}{9}}} \quad 4.26$$

Terms: Rayleigh number, $Ra = Gr * \mathrm{p}r$ 4.27

Grashof number, $G_r = \frac{g\beta d_{0\Delta T}^3}{V^2}$ 4.28

Where, g = gravity = 9.81, m/s^2

β = thermal expansion cofficient

ΔT = difference in temperature

υ = Kinematic viscosity

Equation 4.29, is then used to compute the pipe-outer heat transfer coefficient

$$ho = \frac{Nu_{do}K}{D_0} \quad 4.29$$

4.1.5 Equation of energy balance

Equation 4.30 provides the total energy balance of any vapor-fluid heat exchanger that satisfies the first law of thermodynamics (Kuppan,T, 2000) .

$$Q = UA_o\Delta T_{LMTD} = \dot{m}_{\mathrm{f}} C_p \Delta T \quad 4.30$$

This implies,

$$Q = \dot{m}_{\mathrm{f}}(T_{s,f} - T_{\mathrm{f},r}) = UA_o\Delta T_{LMTD} \quad 4.31$$

Where: $T_{s,\,f}$ = temperature of fuel inter condenser

$T_{\mathrm{f},\,r}$ = temperature fuel outer from condenser

$\dot{m}_{\mathrm{f}}$ = mass flow rate of fuel

However, from the initial storage tank temperature, the final water or vapor fuel temperature supplied to the following loop at each time step can be calculated as follows.

$$T_{s,f} = T_{s,i} + \frac{tstep}{\dot{m}_f c_P} \left(\dot{Q}_U - \dot{Q}_{Load} - \dot{Q}_{Loss}\right) \quad 4.32$$

4.1.5.1 Condenser heat transfer rate

The actual heat transfer rate of a heat exchanger can be determined using the following equation, Q act from an energy balance on the hot or cold fluids (Andrzejczyk, R., Muszynski, T, 2016).

$$\dot{Q}_{act} = C_h \left(T_{h,} - T_{h,}\right) = \left(T_{w,} - T_{w,}\right) \quad 4.33$$

This implies, $m_w C_{p,w} \left(T_{w,} - T_{w,}\right) = U A_o \Delta T_{LMTD}$

Where T_h and Th are the respective vapor fuel temperature at the coil intake and outlet respectively. mw is the mass of water, C_p,w is its specific heat capacity, and T_w,f and Tw,i are the temperatures of the water in its final and initial states, respectively. C_h and Cc are also the heat capacity rates of hot and cold fluids, respectively.

4.1.6 Pressure Drop

4.1.6.1 Pressure Drop in the Coil Tube

The total pressure drop inside a coil tube is determined by the sum of three resistances, such as resistance along the pipe, resistance to bending, and resistance to the import and export of connecting tube fittings (Sadic, 2002).

4.1.6.2. Pressure drop along the Pipe

The following equation can be used to compute the resistance along the pipe, Δpi:

$$\Delta Pi = \frac{f L_{coil} \rho V_i^2}{2 d_i} \quad 4.34$$

This formula can be used to calculate the friction factor, f, for turbulent flow inside a tube using the Reynolds number (Amitkumar,S.,Andhare,A.M, 2015)

$$f = \frac{7.2}{Re_i^{0.5}} \quad 4.35$$

Calculation of internal Reynolds Number, Re_i

$$Re_i = \frac{\rho_i V_i d_i}{\mu} \quad 4.36$$

The terms, ρ_h is hot water density ($820 Kgm^{-3}$), is the dynamic viscosity ($0.00006 {}^{m^2}/_{s}$),

d_i = $0.00678m$ and V_i is velocity of vapor fuel rate inside the tube assumed to 0.5 m/s (Verechshagin,O., Mukasheva,T., 2016)

On substituting the values: Re_i = 7,209.515 and = 0.0397 into Equation 4.34.

$$\Delta P_i = \frac{0.0397 * 1.5 * 820 * 0.5^2}{2 * 0.00678}$$

$$= 900.3\ Pa$$

4.1.6.3. Pressure Drop in Bends

The total pressure drop in a curve is calculated as the sum of the frictional head loss due to bend length, curvature, and excess pressure drop in the downstream pipe as a result of velocity profile distortion. The equation below provides the determination (Sadic, 2002).

$$\Delta P_b = K \frac{\rho V_I^2}{2} \quad 4.37$$

The total loss coefficient, K, is expressed as follows:

$$K = \frac{4 f L_{coil}}{D_h} + K \quad 4.38$$

Here, K* is the loss coefficient, and the suggested value for a turbulent flow is provided as follows:

$$K^* = \mathrm{B}\varphi \left[0.051 + 0.38 (\frac{R}{d_i})^{-1}\right] \quad 4.39$$

Where:

$$\mathrm{B}(\varphi) = \begin{cases} 1 & \text{for } \varphi = 90^0 \\ 0.9 \sin\varphi & \text{for } \varphi \leq 70 \\ 0.7 + 0.35 \sin\left(\frac{\varphi}{90}\right) & \text{for } \varphi \geq 70 \end{cases} \quad 4.40$$

$$D_h = 4 \frac{A_0}{P_w} = 4 \frac{Net\ free\ flow\ area}{wetted\ perimeter} \quad 4.41$$

Where: f = friction factor

K^* = loss coefficient

Dh = hydraulic diameter for pressure drops, with a value for a circular tube equal to the inner diameter of a coil tube, d_i

R = curvature radius, (D_c/2)

r = internal radius, m

φ = angle bending tube, in degree

Taking, Re = 7,209.515 φ = 360^0, R = 0.075m, D_h = 0.00678m and f = 0.0397

Substituting: (φ) = 0.7 + 0.35sin (φ/90) $for\ \varphi \geq 70^0$

= 0.7244

k^* =B (φ) [0.051 + 0.38$(\frac{R}{d_i})^{-1}$]

= 0.06183

Then, total loss coefficient

$$K = \frac{4fL_{coil}}{D_H} + k^* = \frac{4*0.0397*1.5}{0.00678} + 0.06183$$

= 35.2

Insert the above into equation (4.42)

$$\Delta P_b = K\rho\frac{V_f^2}{2} = 35.2\frac{820*0.5^2}{2} \quad 4.42$$

$= 3{,}608$Pa

4.1.6.4 Pressure Drop in the Fittings

Total loss coefficient is used to compute the pressure drop at the fitting on the connecting tubes for import and export (Cuiping, L., Jianqing, D, 2007) .

$$\Delta P_f = 1.5\frac{\rho v_i^2}{2} = 1.5\frac{820*0.5^2}{2} \quad 4.43$$

=153.75

The coil overall pressure drop, P, is then:

$$\Delta P = \Delta P_i + \Delta P_b + \Delta P_f \qquad 4.44$$

$$=900.3 + 3608 + 153.75$$

$$= 4662.03 \text{ Pa}$$

This result is acceptable because the overall pressure drop is less than the maximum value that a helical coil may experience, which is $0.3 * 10^5$ Pa (Cuiping, L., Jianqing, D, 2007).

CHAPTER FIVE

EXPERIMENTAL SETUP AND PROCEDURE

5.1. Components of pyrolysis plant

Using the materials and tools mentioned parts of WTEO pyrolysis setup are listed.

Reactor shell: The reactor shell has a welded conic at its upper edge and is shaped like a cylinder. The reactor shell bottom end is shaped like a flat surface. Similar to this, the reactor cap has a conical form with a hole in the center to allow pyrolysis vapor hydrocarbon to pass through and reach the condenser. As a result, a tiny vent for installing thermocouples is also provided on the reactor cover.

Condenser: The condenser is a circular coil copper tube filled with water through which the reactor gaseous output travels. The liquid hydrocarbon has now been sent to the receiver, and the gaseous hydrocarbon which has not yet been condenser is transferred to the second condenser and receiver, which also serves as a distillation cooling device. In contrast to the first condenser and receiver, the second condenser and receiver consist of a metal water container that is filled with water. With several experiments, the gaseous hydrocarbons at a temperature of around 450–600 °C were condensed to a temperature of 30–50 °C.

Receiver: Within the liquid form condensed pyrolysis gas is gathered within the receiver. The condensed liquid fuel is delivered to the second condenser and receiver.

Thermocouple: It is employed to gauge the temperature of water used as a condensation medium. The majority of the literature on waste tire and engine oil pyrolysis advocated keeping the water temperature below 25 °C in order to raise the temperature of the gaseous hydrocarbon to 40°C. In order to help with this task, this thermometer measures the water temperature.

Weight balance: As the raw material (waste) contains various forms of municipal solid and liquid wastes, it is used to quantify the precise mass of feedstock for proper weight percentage.

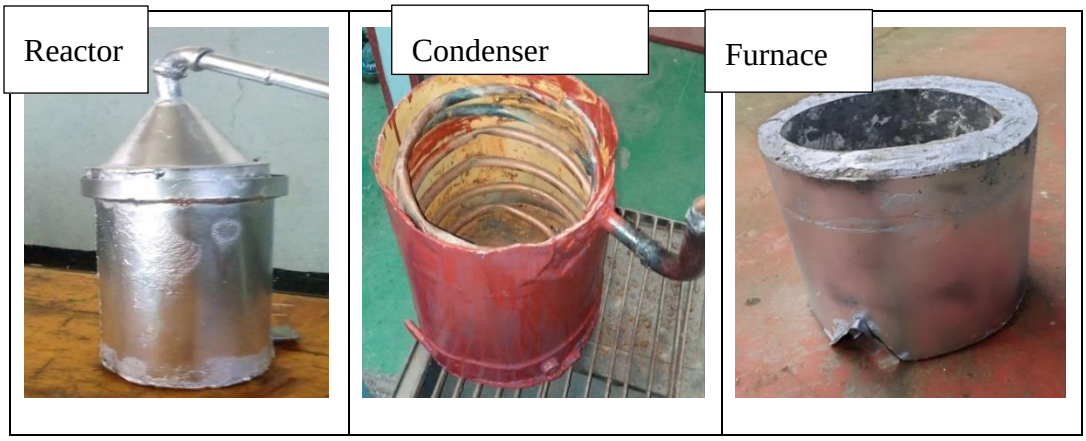

Figure 5. 1: Basic component of pyrolysis plant

5.2. Basic step for pyrolysis oil

- Collecting waste material
- Preparing experimental setup
- Production of oil by thermal pyrolysis
- Purification and filtration
- Fuel characterization
- Fuel blending procedure
- Testing the performance in diesel engine

5.2.1 Collecting waste material

Five basic tasks:

Collecting and preparation of feedstock:

The samples of WTEO were collected from garage which found in Adama town around 04 kebele. Collected samples were washed by soap and water and dried out in the 24 hour in case of WT and filtered in case of WEO. The material was manually filtered to establish its composition before being cut into roughly 5 to 10 mm sized pieces for the shredding process using a shredder machine found in a mechanical workshop. The major steps in sample preparation are listed below.

- Gather of WTEO.
- Removing steel wire.
- Shredding tire.

- Pyrolysis process.

5.2.2. Experimental set up.

The next step is to set up the pyrolysis apparatus following the collection and preparation of the required materials and wastes added to reactor. The batch reactor used in this experiment's pyrolysis setup is seen in Figure 5.2. It consists of a stainless steel reactor with a length of 250 mm, an internal diameter of 200 mm, and an exterior diameter of 250 mm that is sealed at one end, and an output tube at the other end for collecting the reaction's volatile/gas/oil products. Every piece of equipment on the reactor is carefully sealed so that nothing leaks into the environment outside or inside. To stop the back leak of gaseous hydrocarbons during pyrolysis, combine and then add the weighted feedstock to the reactor.

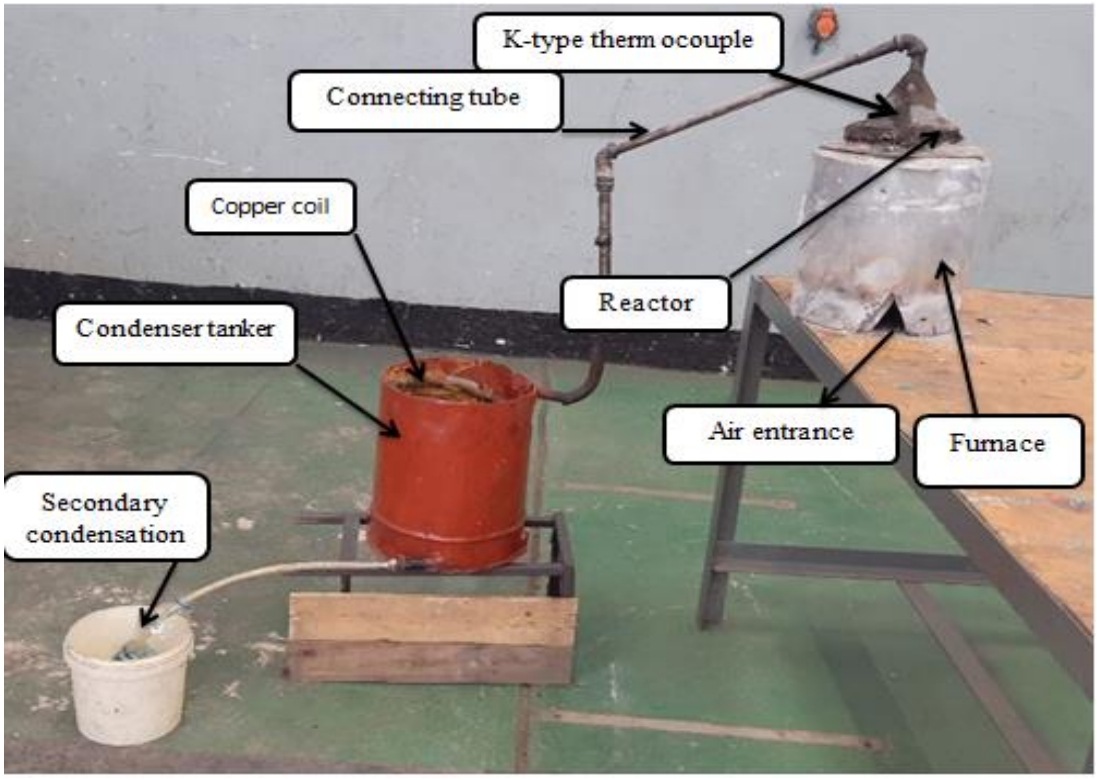

Figure 5. 2: Schematics of pyrolysis setup

5.2.3 Production of oil by thermal pyrolysis

The produced feedstock was subjected to a three hour slow pyrolysis process at temperatures between 300 and 600 °C without oxygen in a cylindrical batch reactor. However, the temperature gradually rises from about 25 ^{o}C to between 300 and 600 ^{o}C. The waste feedstock

can slowly fracture into gaseous form as the temperature rises, and the gases can then be condensed into liquid fuel, char, and minor escape gases. This is the main focus of the work. Batches of feedstock can be introduced to the reactor and heated until the required temperature, both in terms of quantity and quality is obtained. After pyrolysis, the quality and amounts are examined using weight percentage.

Figure 5. 3: Crude pyrolysis oil

5.2.4. Purification and filtration

Pyrolysis in the receiver resulted in contaminated fuel. There were wax, grease, and other contaminants. Consequently, the following procedures were used to remove the contaminants.

- Separation through gravity.
- Filtration.

Separation through gravity is the fundamental procedure. In this technique, impure fluid is poured into a container, where it separates into two layers with the bottom layer acting as a funnel after a while. Therefore, when liquid is poured, the denser liquid will settle in the bottom layer, most likely where water was discovered. Then, right above the water, a pale greenish-yellow waxy and greasy substance was discovered. Finally, the majority of the WTEO fuel is visible at the upper part layers. Thus, by opening the bottom valve, all the undesirable materials were eliminated, and the upper left fuel is then processed further.

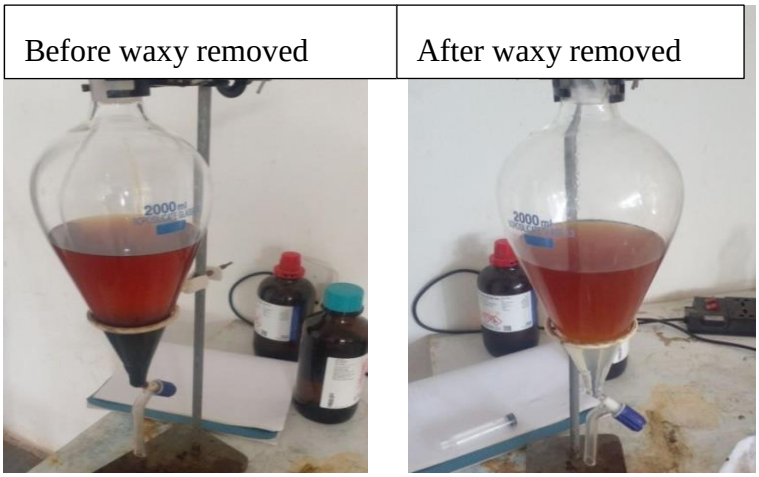

Figure 5. 4: Gravity separation processes

In case **filtration** the substances that are colloidal can be eliminated. The molecules smaller than the holes on the filter paper will pass through paper consequently, the varying sizes of tiny holes provide more clean fuel.

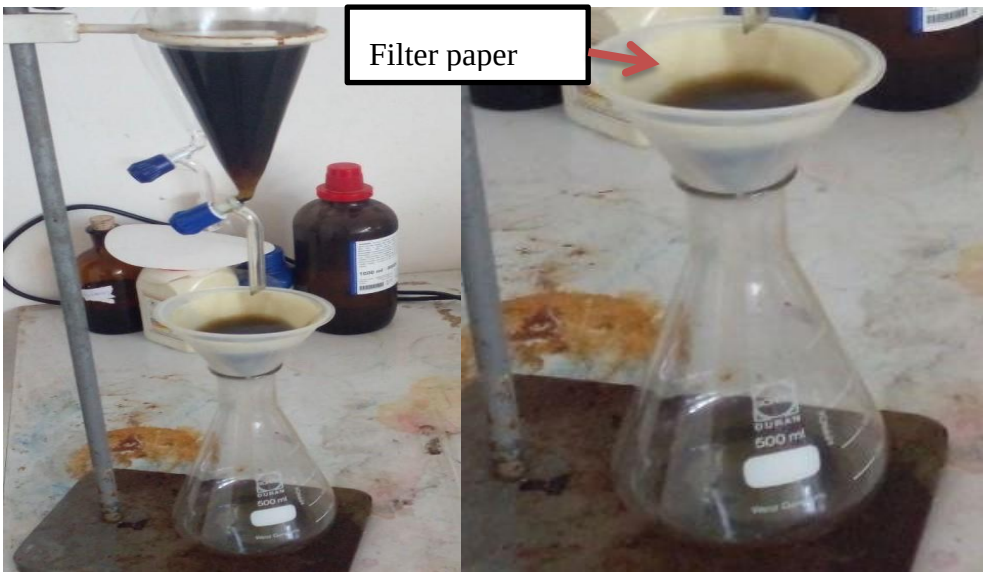

Figure 5. 5: Filtration processes

5.2.5 Characterization of liquid fuel

The WTEO fuel that would be put to the test in these trials was characterized. In accordance with the ASTM protocols for petroleum products in the ASTM, 2002 book, fuel attributes of the tested samples were assessed. However, different liquid fuel qualities were evaluated and

compared with expected results before different liquid fuel properties were characterized under operating settings that had a greater yield.

Percentage of char estimated as a percentage of the mass change between the contents of the sample boat before and after the experiment using Equation 3.2 below.

$$Char = \frac{W_C}{W_s} \times 100\% \quad 3.1$$

Where:

Char = Yield of char (wt. %)

The gas yield (NCG and wax) was determined by subtracting the sum of the condensable volatiles and char yields from 100 weight percent, as shown in equation 3.3 below.

$$NCG\ and\ wax = 100 - (liqiud\ \ oil + char) \quad 3.2$$

The total conversion, or the portion of the feed that transforms into products throughout the pyrolysis process, was calculated using equation 3.4 below.

$$Conversion\ efficiency = \frac{(W_s - W_c)}{w_s} \times 100\% \quad 3.3$$

Where:

W_C= char weight (kg).

W_S= feedstock weight (kg)

The percentage yield of liquid fuel can be determined using equation 3.5 below using the condensed liquid and feedstock.

$$Yield\ of\ liqiud\ fuel = \left({}^{W_1}/_{W_S} \right) \times 100\% \quad 3.4$$

Where:

W_1= Condensable fuel weight (kg).

W_S = Feedstock weight (kg).

After each run, the reactor was emptied to collect any remaining liquidified oil (wax) and char products on its interior walls. The amounts of non-condensable (NC) gas and wax product

from the experiment were then estimated using the corresponding masses measured after weighing the samples as shown in equation 3.6.

$$(NCG\ and\ wax)\% = wt.pyrolysis\ feed\ stock\% - (W.char + W.liquid\ fuel) \qquad 3.5$$

The purified fuel characteristics, including density and kinematic viscosity, flash point and pour point were evaluated using ASTM standards.

5.2.5.1 Density

The oscillating sample tube of the density meter was filled with a little amount of liquid sample. The increasing mass of the tube generated a change in the tube oscillating frequency, which was utilized along with calibration data to determine the density of the sample.

Using the relation below, density can be calculated.

$$\rho = \frac{mass\ of\ liquid\ sample}{volume\ of\ liquid\ sample}$$

The density of a 100ml volume can be determined using the above relationship and a precision analytical balance that can measure up to 83.8614 g. The ambient temperature should be considered in this situation.

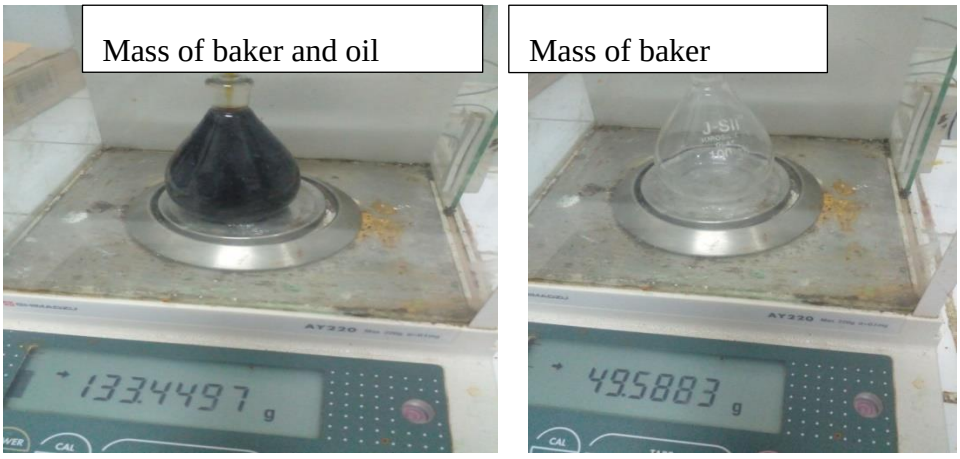

Figure 5. 6: weighing balance for density measurement

5.2.5.2. Viscosity

A fluid viscosity is a gauge of how resistant it is to flowing inside. Temperature affects viscosity, which decreases as temperature rises. The most crucial quality for fuel oil storage

and use is viscosity. It affects how much pre-heating is necessary for handling, storage, and effective atomization. If the oil is overly viscous, it could be challenging to handle, pump, and light the burner. Carbon deposits could build up on the walls or the burner tips as a result of poor atomization. As a result, pre-heating is essential for effective atomization. Each type of oil has a unique relationship between temperature and viscosity. An instrument known as a viscometer is used to test viscosity.

The viscosity was measured using the capillary viscometer manual's measurement standard and the amount of time required for a given volume of liquid to flow under gravity through a typical capillary tube.

Kinematic viscosity is the type of viscosity that is necessary. Kinematic viscosity is a measurement of a fluid natural resistance to flow in the absence of any external forces, with the exception of gravity. It is a force-independent quantity that is the dynamic viscosity to density ratio. By dividing a fluid's absolute viscosity by its mass density, one can determine the fluid's kinematic viscosity.

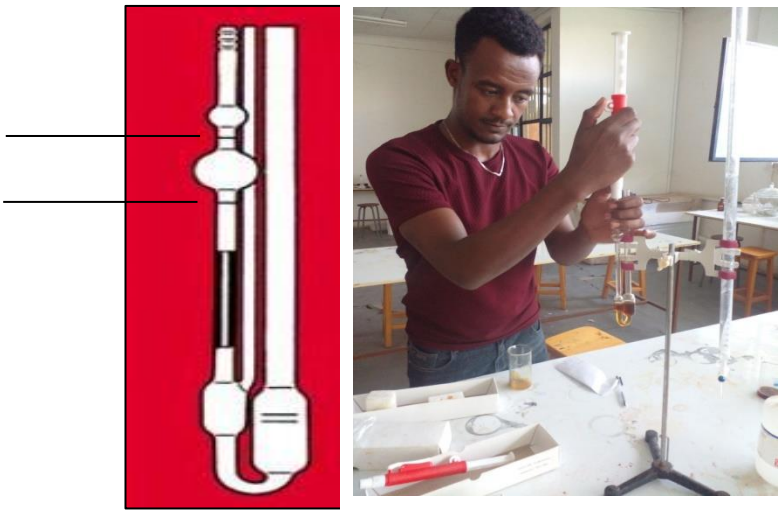

Figure 5. 7: viscosity measurements by viscometer

$$dynamic\ viscosity(V) = K * t$$

Where

K= viscometer instrument constant

t= time taken between two line (A to B)

5.2.5.3. Flash point

The lowest temperature at which a product emits just enough vapor to create a combustible combination with air is known as the flashpoint. Diesel engine performance is not directly correlated with the flashpoint of the fuel. However, it is crucial in relation to the legal requirements and safety precautions for handling and storing fuel. Standards for goods: handling, transit, and storage, as well as compliance with insurance and fire regulations. Using ASTM D93, standard test procedures, the flash points were measured with a pen sky martens closed cup tester.

The equipment and techniques involve heating a sample of fuel that is comparable to diesel under controlled conditions in a closed cup, adding an ignition source, and checking to see if the heated sample fuel is flashing. The flash point is the temperature at which the sample diesel like fuel flashes.

Figure 5. 8Apparatus for determination of flash point

5.2.5.2. Cloud point

The cloud point of a petroleum product, which is determined using an ice pack as shown in Figure 5.9, is an indicator of the lowest temperature at which it is still useful for some uses. The following mixtures are frequently used for temperature reduction:-

I. Mixture of water and ice up to, 100^0C.

II. Sodium chloride and ice, up to, - 120^0C.

III. Calcium chloride and crushed ice up to – 260^0C.

Applying a typical test procedure for petroleum products, cloud point was determined. When the normally clear gasoline was being cooled under precisely controlled conditions, the cloud point was found by visually checking for a cloud in the fuel. The temperature (^{0}C) associated with the first cloud formation in the fuel was recorded while the sample was being constantly monitored.

5.2.6. Ratio of fuel blending

Concentration ratios and liquid type were used to establish the blend process. Purified fuel and pure diesel in various proportions were the blending ingredients.B10 (10% fuel and 90% diesel), B20 (20% fuel and 80% diesel), B30 (30% fuel and 70% diesel), and B40 (40% fuel and 60% diesel) are the various blends available. The results of each fuel blending were performance and emission experiments were tested on single-cylinder diesel engines.

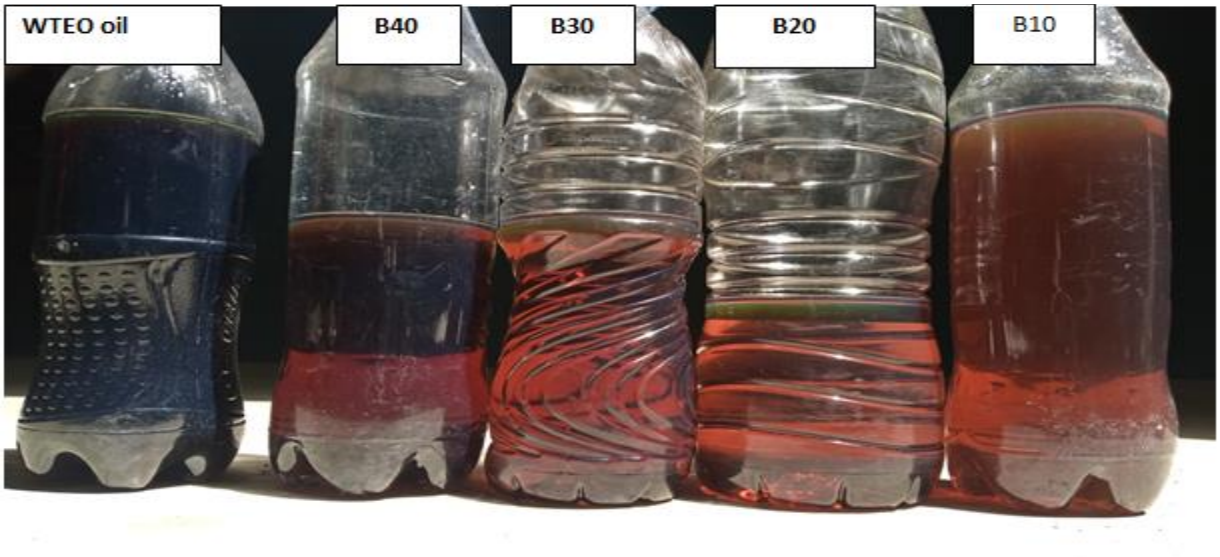

Figure 5. 9: Fuel blending

5.2.7. Engine performance test

Performance characteristics are carefully tested in this area. The School of Mechanical and Electrical Engineering at Addis Ababa Science and Technology University used the TBMC3-02 Computer Controlled Test bench for a single-cylinder diesel engine to conduct the engine performance test. The test apparatus is quite current; all test results, including those related to the exhaust or emission qualities, are directly read from the computer, which is built into the test bench. The essential components of the machine, which make up the entire test stand, are

represented in figure 3.10 below. They include an air-cooled diesel engine (1), an asynchronous motor (2), a fuel tank (3), a SCADA software control system (4), a computer (5), and an exhaust gas analyzer (TBMC_AGE) (6).

Figure 5. 10: Single cylinder diesel engine set up

In this study, pure diesel fuel and a mixture of WTEO oil and diesel fuel (10%, 20%, 30%, and 40% by volume) were put to the test. The same engine was used for both the performance and emission tests for each fuel, which means that as soon as the engine started running, the computer utilizing the integrated software began to record both the performance and engine emissions. The fuel tank is filled with fuel once the engine condition and lubricating oil level have been checked. Then the engine is started, and the test bench is used for the experiments.

5.2.7.2. Exhaust gas analyzer

Currently, one of the biggest poisoning agents is internal combustion engines. Despite not being individually representative, the pollution values are a harmful focal point when discussing all of the groupings. We are able to measure the concentration of various gaseous pollutants that are released into the atmosphere by a focus using a gas analyzer device consistently. The gas analyzer is shown in Figure 3.9 below.

Figure 5. 11: Analyzer of exhaust gas

CHAPTER SIX

RESULTS AND DISCUSIONS

This section presents the experimental study includes: the percentage yield of WTEO, characterization and performance evaluation on a single cylinder internal combustion engine of WTEO and their blend**.**

6.1 Temperature gradient and product for WTEO.

After collected feedstock dried , WTEO was ready to pyrolysis oil production, and from 2 kg of WT and 2 liter of WEO, 68.75% of the oil was extracted with maximum temperature 494 ^{0}C. See figure 6.1 and 6.2 below for the temperature gradient and product respectively results.

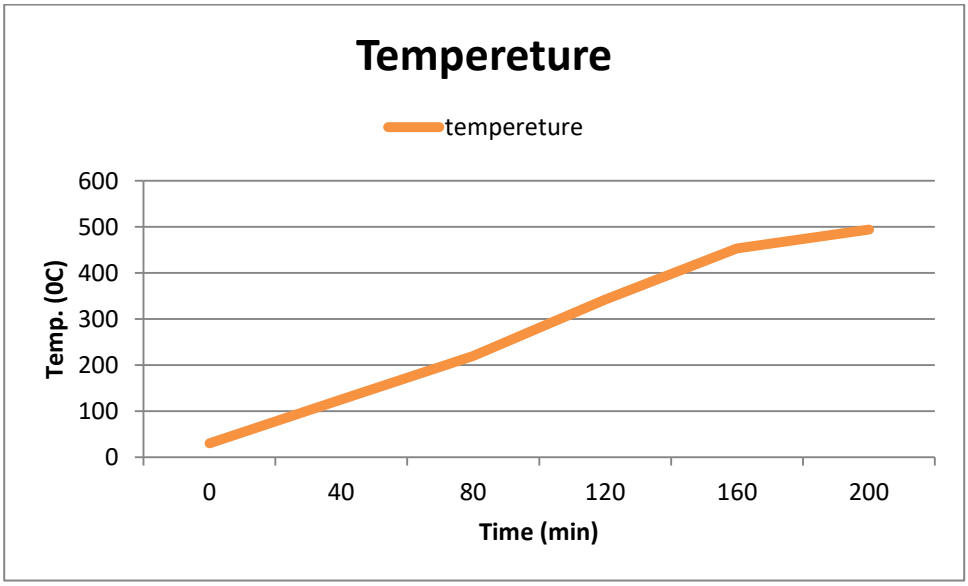

Figure 6. 1: Temperature gradient with time

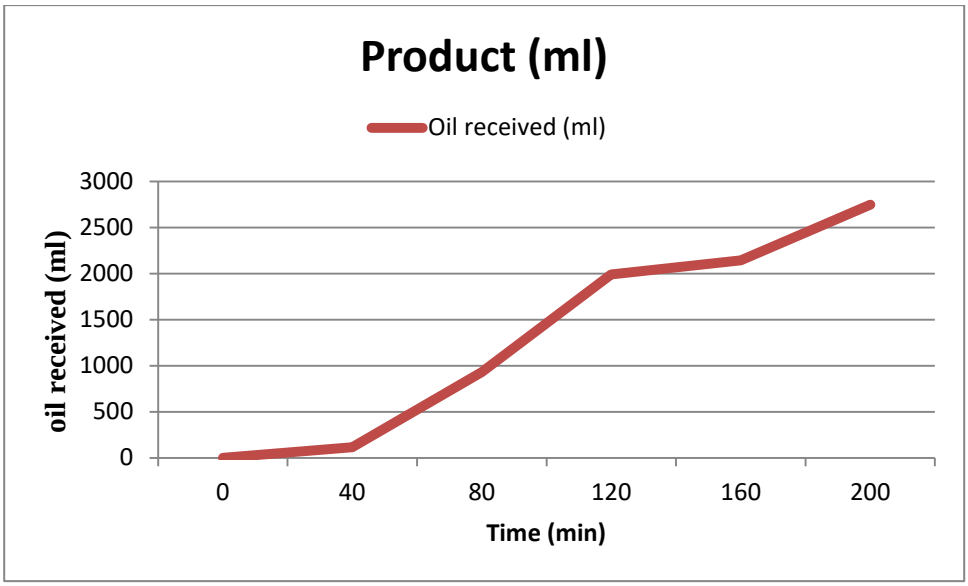

Figure 6. 2: Oil received with time

NB: Each mass of sample is in kg unless specified.

The total weight of receiver before the experiment (R_0) = 0.9Kg

The total weight of receiver after the experiment (R_1) = 3.65Kg

Weight of the feed sample (W_S) = 4kg,

Weight of char (W_C) = 0.9 Kg

The proportion of the feed that becomes products during the pyrolysis process is known as the overall conversion, and it was calculated.using Equation 6.1 below.

$$Conversion\ efficiency = \frac{(W_s - W_c)}{w_s} \times 100\% \quad 6.1$$

$$= \frac{(4-0.9)}{4} \times 100\%$$

$$= 77.5\%$$

$$Yield\ of\ oil\ = \frac{W_l}{w_s} \times 100\% \quad 6.2$$

$W_l = R_1 - R_0 = 3.65 - 0.9 = 2.75Kg$

$$Yield\ of\ liquid\ fuel\ = \frac{2.75}{4} \times 100\%$$

$Yield\ of oil$ =68.75%

Char yield product Efficiency (wt %)

$$Yield\ of\ char\ = \frac{W_c}{w_s} \times 100\% \quad 6.3$$

$$Yield\ of\ char\ = \frac{0.9}{4} \times 100\%$$

Yield of char=22.5%

The weight of NCG was estimated by subtracting the initial weight of WTEO from the total weight of the products (liquid, wax, and char). When there are no more wax and liquid byproducts (no more waste inside the reactor), the experiment time period comes to an end.

Wt. of NCG and wax = wt. of total feed -∑wt. (liquid oil +char)

Wt. of NCG and wax= 4kg -∑wt. (2.75kg + 0.9) kg

=0.35kg

NCG and wax =100%- (68.5% + 22.5%)

= 9%

Therefore, this is equal to 9 wt%

6.2 WTEO fuel and their blend characterization

Viscosity, density, calorific value, flash point, and fire point are the most important metrics used to define the physiochemical characteristics of fuel made from WTEO. Viscosity, density, and specific gravity are additional physiochemical characteristics that describe the quality of fuel. Numerous factors affect the quantity and quality of fuel. After that, WTEO-derived fuel must pass ASTM quality requirements in order to be utilized in place of petroleum in conventional diesel fuels.

Table 6. 1: Property tested fuel result

No	Property	ASTM standard quality	Results					
			B0	B10	B20	B30	B40	WTEO
1	Density (kg/m^3)	ASTMD 4052	830	830	830.5	831	832	838
2	Kinematic viscosity40^{0}C (mm2 /s)	ASTMD 445	2.7	2.7	2.6	2.6	2.5	2.1
3	Flash point	ASTMD 93	52	51	55	57	57	62
4	Fire point ^{0}C	ASTMD 92	56	55	57	59	58	64
5	Cloud point ^{0}C	ATSM6 75	-3	-6	-8	-11	-12	-21
6	pour point ^{0}C	ATSM6 751	-6	-9	-13	-15	-18	-24

The physicochemical properties of fuel that were discovered through experimentation are in accordance with the ASTM specification quality level, as shown in Table 6.2. The physicochemical properties of diesel may generally meet the standards of the petroleum ASTM standard. However, diesel can be utilized in place of petroleum.

1. **Density**

Density is a crucial factor in assessing the quality of WTEO fuel since it has a direct and indirect impact on the fuel injection system and engine performance. As shown in Table 6.2., the present biodiesel result has an ASTM-compliant density of 830 kg/m^3 at 40 °C. The densities of diesel oil and fuel derived from WTEO of B20 were 830 kg/m^3 and 830.5 kg/m^3, respectively. The outcomes of the experiment are then in line with those of diesel made from WTEO of a similar value. As a result, combustion engines (CI-engines) can use WTEO-based WTEO fuel as a pure fuel.

2. **Viscosity**

Kinematic viscosity with diesel fuel was found to be 2.8mm^2/sec. This proves that the extracted oil kinematic viscosity was much lower during the pyrolysis process and met within the parameters of the ASTM standard quality requirement. All WTEO dynamic fuel viscosity was found to be very similar to that of pure diesel (Keera et al., 2018)

3. Flash and fire point

Liquid fuel sample's flash and fire points can be used to determine its flammability. The flash point is the lowest temperature that the test specimen can reach after being adjusted to a barometric pressure of 101.3 kPa. When an ignition source is offered, the test specimen vapor will briefly catch fire under the specified test conditions at this temperature and spread throughout the liquid surface. The flash point value is not a physical constant, but rather the result of a flash point test that depends on the equipment and techniques used, and this is crucial to comprehend. The lowest temperature at which vapor combustion and burning begin is known as a liquid's fire point (Sundar et al., 2019). When an ignition source is employed, a fire point is produced. The heat produced by the fire point is self-sustaining because it creates enough vapors to mix with the air and keep burning long after the ignition source has been switched off.

4. Cloud and pour point

It is generally known that WTEO fuel has higher cloud point and pour point related to pure diesel (Sundar et al., 2019). However, WTEO has very low cloud and pour points, which make this, fuel an excellent substitute in cold weather. WTEO is therefore suitable for engine operation, especially in cold weather conditions, due to the lowest value of cloud point and pour point.

6.3 Engine performance analysis

Brake torque, brake power, and brake-specific fuel consumption were used to assess the engine performance when running on diesel and WTEO fuel blends combined with diesel. Various engine speeds were used during the studies. Because engine speed varies, variables like brake power, brake torque, and brake-specific fuel consumption were assessed for various engine speeds.

6.3.1 Brake power (Pb)

Brake power is a key measure of an engine performance potential since it shows the highest amount of engine power that can be used for braking. It is assessed using a dynamometer, a tool that loads the test engine while it is running at full speed. As the load grows, engine brake

power initially rises, followed by a slightly decline. In Figure 6.3, the overall trend of braking power versus load is shown. The blend ratio WTEO content increases when the brake power drops. This might be the result of WTEO's reduced calorific value compared to pure diesel fuel. The measured values from the tests indicate a reduction in brake power of 1.14%, 3.04%, 24.44%, and 31.55% for B10, B20, B30, and B40 respectively, when compared to B0 (pure diesel) at 3500 engine speed. B10 and B20 have almost similar brake power with pure diesel fuel.

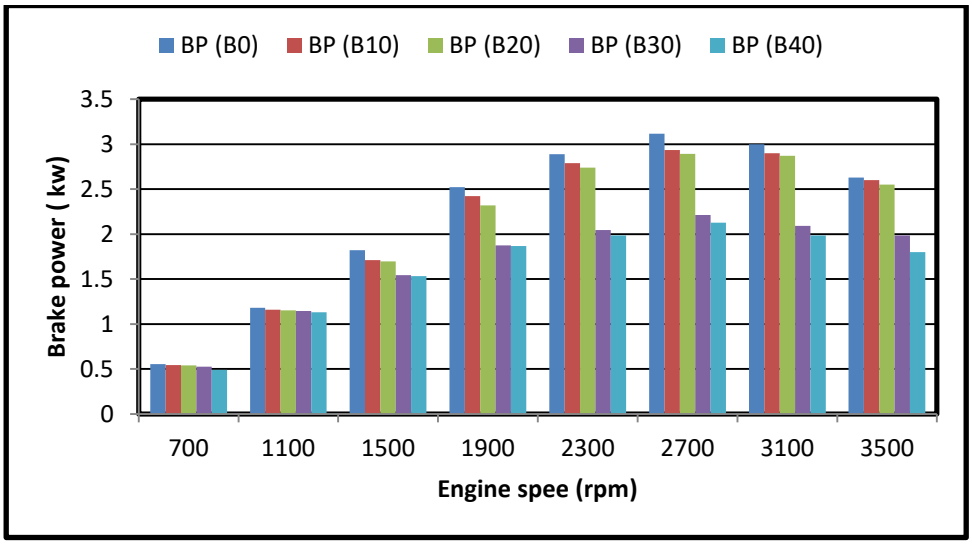

Figure 6. 3: brake power vs Engine speed

6.3.2 Brake torque (Tb)

The performance of fuel in the engine combustion chamber is also measured using a quantity called brake torque. As shown in Figure 6.4, the measured data from the test show that the braking torque is highest at medium part load and gradually decreases as engine load is increased. Additionally, the brake power diminishes as WTEO is added to the blend. The increased viscosity of WTEO fuel, which caused a decrease in brake torque, is one of the WTEO's fuel characteristics that might be blamed for this issue. At 3500 engine speed, the measured values indicate a decrease of 4.26%, 5.39%, 16.27%, and 16.95% for B10, B20, B30, and B40, fuel samples respectively, when compared to pure diesel fuel. B10 and B20 have almost similar brake power with pure diesel fuel.

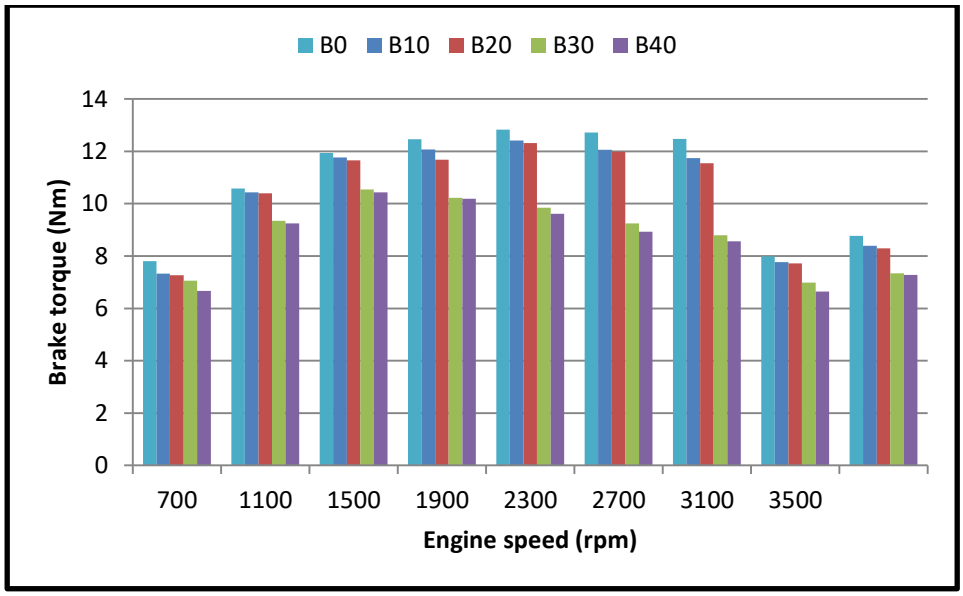

Figure 6. 4: brake torque vs Engine speed

6.3.3 Brake specific fuel consumption

Specific fuel consumption can also be read directly from the test bench, just like brake power and torque. The ratio of fuel burned per hour to brake power is known as the engine's brake specific fuel consumption. As the engine speed or braking power rises, the bsfc falls. This is due to the fact that as power grows, cylinder temperature rises, the delay time shortens, total combustion timing lengthens, and fuel is burned properly. However, this is only true up to a point after which it starts to rise. The bsfc for pure diesel and WTEO fuel blends with diesel decreased with increasing engine speed, as illustrated in (Figure 6.5). When the engine speeds above the limit at which the engine braking power was at its peak, the bsfc began to rise, which is a typical tendency of the bsfc curve for the CI engine. This demonstrates that the bsfc of pure diesel and WTEO mixes both decline and follow a steady path up to the maximum brake power before beginning a tiny increase. Comparing bsfc of the two fuels (pure diesel and WTEO blends): 1.4%, 4.65%, 19%, and 24% for B10, B20, B30, and B40, fuel samples respectively. The pure diesel bsfc is lower than blends of WTEO in all level of engine speeds but bsfc of 20% blending is closer to pure diesel bsfc

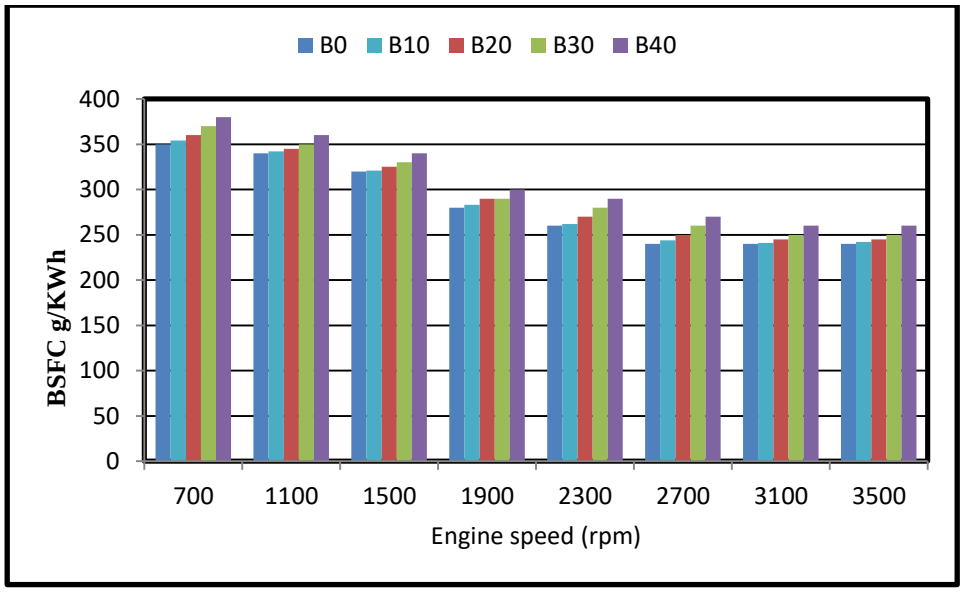

Figure 6. 5: Bsfc vs engine speed

6.4 Exhaust gas characterization

When applying diesel and WPO blends with diesel, the engine's emissions were assessed in terms of nitrogen oxides, carbon monoxide, carbon dioxide, and unburned hydrocarbons.

6.4.1. Nitrogen oxide emissions:

In diesel engines, NOx is primarily produced by three factors: thermal, prompt, and fuel-bound nitrogen. When diesel and alternative fuels are burned, one of the sources of nitrogen for the production of NOx is atmospheric (molecular) nitrogen. The phrase "thermal NOx" refers to NOx created in the combustion chamber when nitrogen (N_2) is heated to high temperatures and then oxidized. Diesel engine NO emission generation is influenced by the following crucial variables: cylinder temperature, air/fuel ratio, oxygen concentration, and reaction residence time (Tan et al., 2012). When WTEO fuel is added to a pure diesel sample, NOx emissions for the studied sample indicated a small rise. When compared to pure diesel fuel, all blend-containing fuel samples exhibited an increase in NOx emission at all engine loads for all WTEO blend concentrations, though it was still somewhat greater. Figure 6.7 illustrates the fluctuation in NOx emission with engine load. At 3500 engine speed, the NOx emissions increased by 0.1% ppm, 0. 92% ppm, 13.53%, and 19.69% for the B10, B20, B30,

and B40 fuel samples, respectively, when compared to pure diesel. Even if maximum increment at this engine speeds, B10 and B20 have closed result with pure diesel.

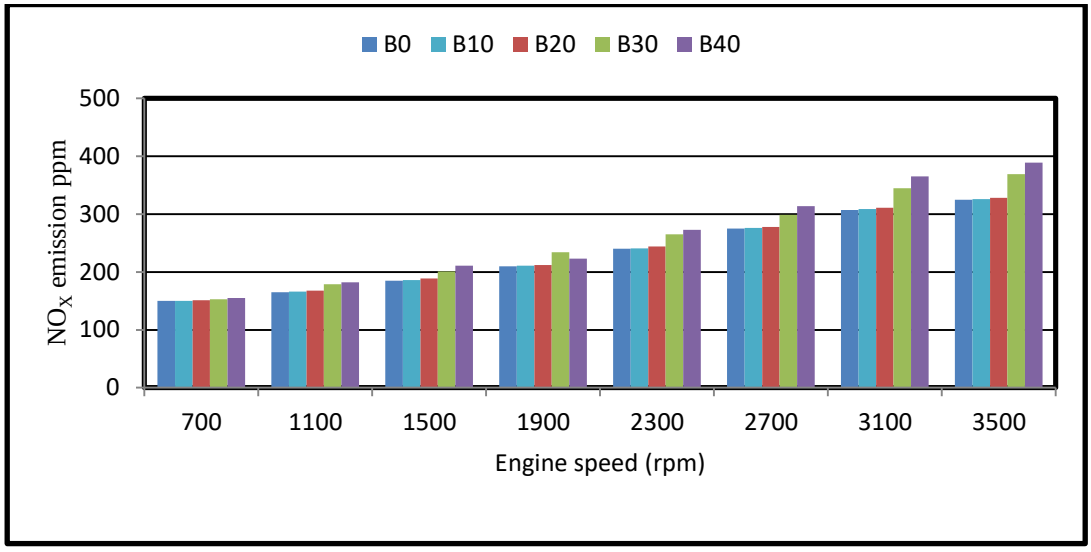

Figure 6. 6: NO_X emission characteristics

6.4.2. CO emissions:

Carbon content, oxygen content, and the fuel's combustion properties all affect the amount of carbon monoxide (CO) that is released into the atmosphere. When the fuel is burned, the carbon atom in it combines with the oxygen to produce CO up, which later transforms into CO2. However, a lack of oxygen would likely result in incomplete combustion, which would raise the level of CO emissions (Karthikeyan et al., 2020). Figure 6.8 displays the fluctuation in CO emission content as a function of load. According to the recorded data, CO emissions dropped as engine speed increased. On the other side, the CO emission has dropped as the proportion of WTEO fuel in the blend has increased at all loads. This is because the WETO fuel has a high oxygen content, which promotes full combustion. At 3500 engine speed condition the CO emission decreased by 1.98%, 4.65%, 16.28%, and 20.3% for B10, B20, B30, and B40 respectively when compared with pure diesel fuel. B10 and B20 have almost similar CO emission characteristics as pure diesel fuel.

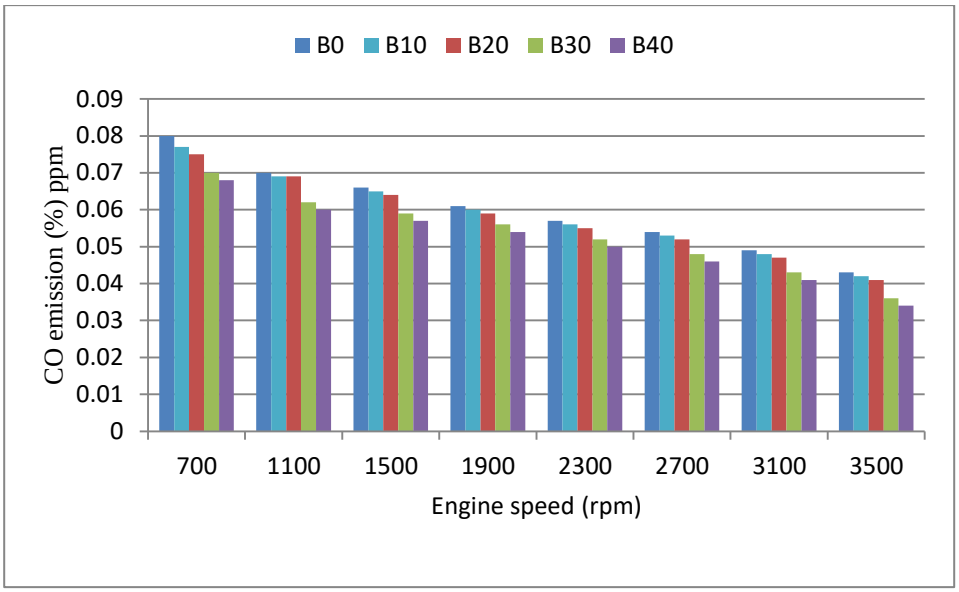

Figure 6. 7: CO emission characteristics

6.4.3. CO2 Emission:

A sign that the fuel has been burned completely is the release of CO2. For all of the test fuels with varied engine speeds, the emission was shown in Figure 6.9. As the engine speed increased, it was found that the CO2 emissions increased as well. Additionally, the addition of WTEO to fuel led to a complete combustion, which in turn produced increased carbon dioxide emissions. This is because a complete combustion requires a certain amount of oxygen, which is present in more fuel in WTEO blending. .At full load (3500 rpm) engine speed condition the CO_2 emission got increased by 0.5%, 2.56%, 7.69%, and 15.38% for B10, B20, B30, and B40 when compared to pure diesel. B20 blend showed better CO2 emissions with pure diesel, but as CO2 emissions are an indication of better and nearly full combustion, an increase in CO2 emissions is beneficial from the standpoint of performance and efficient combustion. Additionally, it is a compensation for the decreased CO emission.

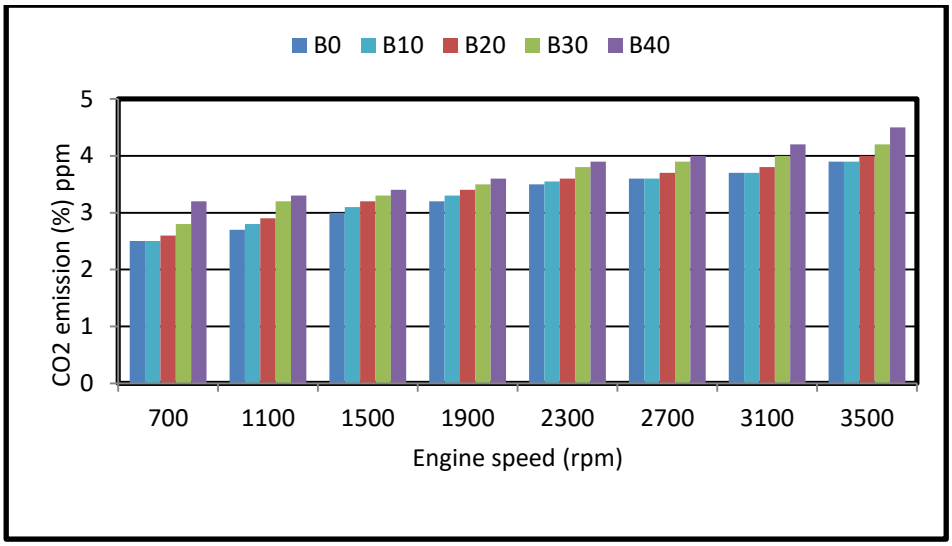

Figure 6. 8: CO2 emission characteristics

6.4.4. Hydrocarbon emissions:

HCs are a sign of incomplete combustion because they show up as unburned or just partially combusted fuel molecules in the released gases. Figure 6.10 displays the trend of the HC emission in relation to engine load. Due to a more complete combustion at increasing loads, when the engine operates at its designed or nearly optimal state, HC emission reduces as load increases. Due to additional oxygen in WTEO, which increases complete combustion, the HC emission decreased at all engine loads as the proportion of WTEO in the blend ratio increased. If complete combustion is occurring, a lower amount of unburned hydrocarbons will be present in the exhaust gases. The test results demonstrate an increase of 1.2%, 2.38%, 10.3% and 19.2% for B10, B20, B30 and B40 respectively when compared with pure diesel HC emission. Here B10 and B20 showed better HC emission which is closed to pure diesel emission.

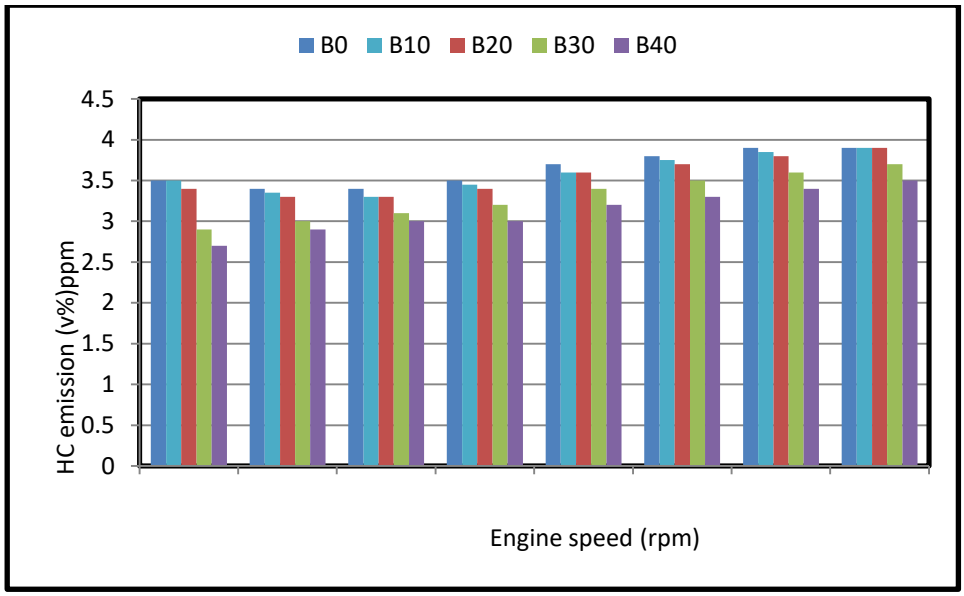

Figure 6. 9: HC emission characteristics

6.5 Cost Analysis of waste tire and engine oil pyrolysis

The initial investment for manufacturing the newly developed WTEO pyrolysis material cost is summarized in Appendix C table c.1.

6.6 Economic Analysis

The economic analysis is computed in this section, including the net cash flow rate, the initial investment needed, saving income from pyrolysis for fuel, the net present value, and the payback period. Since the value of all financial investments is ultimately determined by the value of cash flows paid and received, the expected cash outflows and cash inflows are the recommended inputs. Cash inflows such as increased cash from consumers, decreased cash outflows related to running costs, etc. Cash outflows such as initial investment, maintenance and repair, higher operating costs, overhauling of equipment, etc. Because the proposed project is acceptable when net present value is zero or positive, the determination of net present value is required. The presented project is unacceptable if the net present value is negative. It is necessary to determine the project's overall cash flow before calculating the NPV.

Cash out flow

- The initial investments needed for pyrolysis of WTEO application such as construction of experimental setup and installation of the system for all system should be determined. From experiment for pyrolysis 4Kg of the WTEO 2Kg of wood charcoal is consumed for 3 hours. So annually it becomes 32birr/day ×365days = 19,710ETB.
- The cost of newly developed set up is 5985ETB.
- Cost for purchase WTEO 100birr/day × 365days= 36500ETB
- During the fuel preparation process, 50 liters of water are used for condensation and cleaning. The cost for 50 litter of water is then consumed, and it costs 6 Birr annually will be 6 birr/day ×365 day= 2190ETB

Cash in flow

- Savings from selling the char WTEO for asphalt bitumen annually 10,000ETB.
- Fuel extracted from 4kg of WTEO is 1.91liter , so 7.64 liter can be extracted per day and annually it becomes 458.4birr/day× 365days=167316ETB

See the appendix C table C.2 the net annual cash flow in pyrolysis of WTEO is 115316ETB.

i.e. $Net\ annual\ cash\ flow = Annual\ cash\ - Annual\ cash\ out\ flow$

$Net\ annual\ cash\ flow$ = 177316 − 64385ETB

=112931ETB

Payback period

The cash payback period establishes how long it will take for the investment's net yearly cash inflow to equal the cost of the capital investment (the initial investment) for pyrolysis WTEO.

$$Cash\ payback\ period = Cost\ of capital\ investment \div Net\ annual\ cash\ flow$$

$$Cash\ payback\ period = 64385ETB \div 112931ETB$$

$$Cash\ payback\ period = 0.57\ Year$$

The payback period is less than a year, and the more attractive the project is, the shorter the payback period.

Determine the net present value (NPV)

$$NPV = -Initial\ investment + \frac{net\ annual\ cash\ flow}{(1+R)^Y}$$

$$NPV = -\ 64385 + \frac{112931}{(1+0.15)^1}$$

$$NPV = 33815.86 ETB.$$

Due to the fact that the investment is more attractive the larger the positive NPV (project).

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

This study looked at the viability of using WTEO as an alternative fuel and substitute for diesel fuel and the effects of mixing WTEO with different amounts of diesel (B0, B10, B20, B30, and B40) on the fuel characteristics, engine performance, and emissions characteristics. The test was carried out on a single-cylinder direct injection diesel engine using WTEO fuel that was created by pyrolyzing waste tire and engine oil gathered from Adama town. All blend fuel characteristics, including density, kinematic viscosity, flash point, fire point , cloud point and pour point were assessed and compared with those of diesel. Additionally assessed are engine performance parameters like brake power (Pb), brake torque (Tb), brake specific fuel consumption (bsfc), and emissions metrics like CO, CO2, HC, and NOx.

7.2 Conclusion

The idea of waste to energy specifically converting it into a useable energy source, force us to locate a specific contribution to waste management and environmental protection. By converting WTEO to alternate energy, we simultaneously address the issues of environmental pollution and fuel scarcity. It would greatly benefit our economy to take into account such low-cost production method. To accomplish this, the general operating principles are the thermal breakdown of WTEO inside the reactor and the condensation of the pyrolysis gas acquired in two stages: primary condensation in a copper circular coil and secondary condensation in distillation cooling. According to the study and analysis of this work, WTEO of solid and liquid wastes can be used as alternative fuels for diesel engines in the future. Here is a conclusion that can be taken from the results of the experiment. WTEO's decomposition uses less energy and produces more high quality pyrolysis oil than a single tire would. The pyrolysis of WTEO experiment produced a maximum of 68.75% condensable liquid fuel, 22.5% char, and 8.75% non-condensable gas by weight. The mass sample could be converted into fuel with a maximum conversion efficiency of 77.5% during pyrolysis. Some WTEO fuel

and blend properties have undergone testing up to B40.The smallest difference in terms of brake torque, brake power, and fuel consumption between pure diesel and its blend up to B20. When it comes to emissions, the WTEO blends pure diesel emission up to B20 with nearly identical NOx, CO, HC, and CO2 emissions at all levels of engine speeds. The fuel made from WTEO oil of wastes has possible solutions for the environment and the economy, and more research on this subject should be taken into consideration based on the results discussed above.

7.3 Recommendation

The following suggestions are provided based on the findings of this study to help other researchers in the future get better results on this and related topics.

- Heat exchangers should be utilized with fluids that have a lower tendency to foul for greater heat transfer rates. Distillation cooling is preferred while pyrolyzing WTEO due to the increased amount of tar produced from waste pyrolysis.
- It is necessary to develop a method that allows a cooling system to circulate water naturally by gravity in order for this research to be applicable in rural locations.
- Since the chemical structure of liquid fuels created by WTEO pyrolysis is unknown, a final analysis should be conducted before consumption..
- Even though the results have indicated that a diesel engine can run on WTEO fuel as an alternative fuel without significant modification, it is strongly advised that more research be done (future works) taking into account all engine operating factors.
- WTEO may be converted into solid fuel, which can be used in place of asphalt bitumen.

Reference

Aguado, J., Serrano, D. P., and Escola, J. M. (2008). Fuels from Waste Plastics by Thermal and Catalytic Processes: A Review. *Industrial & Engineering Chemistry Research*, *47*(21), 7982–7992. https://doi.org/10.1021/ie800393w

Amitkumar,S.,Andhare,A.M. (2015). *Design and Thermal Evaluation of Shell and Helical Coil Heat Exchanger* (Vol. 1–37). International Journal of Research in Engineering and Technology.

Andrzejczyk, R., Muszynski, T. (2016). *Performance analyses of helical coil heat exchangers. The effect of external coil surface modification on heat exchanger effectiveness* (Vol. 37). Thermodynamics.

Anene, A. F. (2017). Experimental study of catalysis in plastic pyrolysis. , *Natural Sciences and Maritime Sciences*.

Anuar Sharuddin, S. D., Abnisa, F., Wan Daud, W. M. A., and Aroua, M. K. (2016). A review on pyrolysis of plastic wastes. *Energy Conversion and Management*, *115*, 308–326. https://doi.org/10.1016/j.enconman.2016.02.037

Ayanoğlu, A., and Yumrutaş, R. (2016). Production of gasoline and diesel like fuels from waste tire oil by using catalytic pyrolysis. *Energy*, *103*, 456–468. https://doi.org/10.1016/j.energy.2016.02.155

Boukadir, D., David, J.-C., Granger, R., and Vergnaud, J.-M. (1981). Preparation of a convenient filler for thermoplastics by pyrolysis of rubber powder recovered from tyres. *Journal of Analytical and Applied Pyrolysis*, *3*(1), 83–89. https://doi.org/10.1016/0165-2370(81)80028-9

Bouvier, J. M., and Gelus, M. (1986). Pyrolysis of rubber wastes in heavy oils and use of the products. *Resources and Conservation*, *12*(2), 77–93. https://doi.org/10.1016/0166-3097(86)90019-2

Chaala, A., and Roy, C. (1996). Production of coke from scrap tire vacuum pyrolysis oil. *Fuel Processing Technology*, *46*(3), 227–239. https://doi.org/10.1016/0378-3820(95)00065-8

Cheng, H., Chen, C., Wu, S., Mirza, Z. A., and Liu, Z. (2017). Emergy evaluation of cropping, poultry rearing, and fish raising systems in the drawdown zone of Three Gorges Reservoir of China. *Journal of Cleaner Production*, *144*, 559–571. https://doi.org/10.1016/j.jclepro.2016.12.053

Cuiping, L., Jianqing, D. (2007). *Design of Coil Heat Exchanger for Remote-Storage Solar Water Heating System,*. Solar Energy and Human Settlement.

Czajczyńska, D., Krzyżyńska, R., Jouhara, H., and Spencer, N. (2017). Use of pyrolytic gas from waste tire as a fuel: A review. *Energy*, *134*, 1121–1131. https://doi.org/10.1016/j.energy.2017.05.042

Daugaard, D. E., and Brown, R. C. (2003). Enthalpy for Pyrolysis for Several Types of Biomass. *Energy & Fuels*, *17*(4), 934–939. https://doi.org/10.1021/ef020260x

de Marco Rodriguez, I., Laresgoiti, M. F., Cabrero, M. A., Torres, A., Chomón, M. J., and Caballero, B. (2001). Pyrolysis of scrap tyres. *Fuel Processing Technology*, *72*(1), 9–22. https://doi.org/10.1016/S0378-3820(01)00174-6

Eugene F., M. (2001). *Pressure Vessel Handbook*. Pressure Vessel Handbook Publishing Inc..

Fletcher, R. A., and Wilson, H. T. (1981). The role of pyrolysis in the disposal of waste tyres. *Resource Recovery and Conservation*, *5*(4), 333–342. https://doi.org/10.1016/0304-3967(81)90015-9

Gao, F. (2010). *Pyrolysis of Waste Plastics into Fuels*. https://doi.org/10.26021/3251

Goddard, HaynesC. (1992). Incentives for solving the scrap tire problem through existing markets. *Journal of Hazardous Materials*, *29*(2), 165–177. https://doi.org/10.1016/0304-3894(92)85067-B

Haydary, J., Jelemenský, Ľ., Gašparovič, L., and Markoš, J. (2012). Influence of particle size and kinetic parameters on tire pyrolysis. *Journal of Analytical and Applied Pyrolysis*, *97*, 73–79. https://doi.org/10.1016/j.jaap.2012.07.003

Hejna, A., Korol, J., Przybysz-Romatowska, M., Zedler, Ł., Chmielnicki, B., and Formela, K. (2020). Waste tire rubber as low-cost and environmentally-friendly modifier in thermoset polymers. A review. *Waste Management*, *108*, 106–118. https://doi.org/10.1016/j.wasman.2020.04.032

Hita, I., Arabiourrutia, M., Olazar, M., Bilbao, J., Arandes, J. M., and Castaño, P. (2016). Opportunities and barriers for producing high quality fuels from the pyrolysis of scrap tires. *Renewable and Sustainable Energy Reviews*, *56*, 745–759. https://doi.org/10.1016/j.rser.2015.11.081

Kakaç, S., Liu, H., and Pramuanjaroenkij, A. (2002). *Heat Exchangers* (0 ed.). CRC Press. https://doi.org/10.1201/9781420053746

Kaminsky, W. (1980). Pyrolysis of plastic waste and scrap tyres in a fluid bed reactor. *Resource Recovery and Conservation*, *5*(3), 205–216. https://doi.org/10.1016/0304-3967(80)90001-3

Kaminsky, W., Menzel, J., and Sinn, H. (1976). Recycling of plastics. *Conservation & Recycling*, *1*(1), 91–110. https://doi.org/10.1016/0361-3658(76)90009-6

Karagöz, M., Ağbulut, Ü., and Sarıdemir, S. (2020). Waste to energy: Production of waste tire pyrolysis oil and comprehensive analysis of its usability in diesel engines. *Fuel*, *275*, 117844. https://doi.org/10.1016/j.fuel.2020.117844

Karthikeyan, S., Prathima, A., Periyasamy, M., and Mahendran, G. (2020). Assessment of the use of Codium Decorticafum [Green seaweed] biodiesel and pyrolytic waste tires oil blends in CI engine. *Materials Today: Proceedings*, *33*, 4224–4227. https://doi.org/10.1016/j.matpr.2020.07.235

Keera, S. T., El Sabagh, S. M., and Taman, A. R. (2018). Castor oil biodiesel production and optimization. *Egyptian Journal of Petroleum*, *27*(4), 979–984. https://doi.org/10.1016/j.ejpe.2018.02.007

Khiari, B., Kordoghli, S., Mihoubi, D., Zagrouba, F., and Tazerout, M. (2018). Modeling kinetics and transport phenomena during multi-stage tire wastes pyrolysis using Comsol®. *Waste Management*, *78*, 337–345. https://doi.org/10.1016/j.wasman.2018.06.002

Kumaravel, V., Mathew, S., Bartlett, J., and Pillai, S. C. (2019). Photocatalytic hydrogen production using metal doped TiO2: A review of recent advances. *Applied*

Catalysis B: Environmental, *244*, 1021–1064. https://doi.org/10.1016/j.apcatb.2018.11.080

Lazova, M., Huisseune, H., Kaya, A., Lecompte, S., Kosmadakis, G., and De Paepe, M. (2016). Performance Evaluation of a Helical Coil Heat Exchanger Working under Supercritical Conditions in a Solar Organic Rankine Cycle Installation. *Energies*, *9*(6), 432. https://doi.org/10.3390/en9060432

Li, S.-Q., Yao, Q., Chi, Y., Yan, J.-H., and Cen, K.-F. (2004). Pilot-Scale Pyrolysis of Scrap Tires in a Continuous Rotary Kiln Reactor. *Industrial & Engineering Chemistry Research*, *43*(17), 5133–5145. https://doi.org/10.1021/ie030115m

Lucchesi, A., and Maschio, G. (1983). Semi-active carbon and aromatics produced by pyrolysis of scrap tires. *Conservation & Recycling*, *6*(3), 85–90. https://doi.org/10.1016/0361-3658(83)90033-4

Malkow, T. (2004). Novel and innovative pyrolysis and gasification technologies for energy efficient and environmentally sound MSW disposal. *Waste Management*, *24*(1), 53–79. https://doi.org/10.1016/S0956-053X(03)00038-2

McMurry, P. (2000). A review of atmospheric aerosol measurements. *Atmospheric Environment*, *34*(12–14), 1959–1999. https://doi.org/10.1016/S1352-2310(99)00455-0

Meier, D., and Faix, O. (1999). State of the art of applied fast pyrolysis of lignocellulosic materials—A review. *Bioresource Technology*, *68*(1), 71–77. https://doi.org/10.1016/S0960-8524(98)00086-8

Miandad, R., Barakat, M. A., Aburiazaiza, A. S., Rehan, M., and Nizami, A. S. (2016). Catalytic pyrolysis of plastic waste: A review. *Process Safety and Environmental Protection*, *102*, 822–838. https://doi.org/10.1016/j.psep.2016.06.022

Midgley, T., and Henne, A. L. (1929). Natural and synthetic rubber. i. products of the destructive distillation of natural rubber. *Journal of the American Chemical Society*, *51*(4), 1215–1226. https://doi.org/10.1021/ja01379a034

Mohan, K., Usha, K. M., Anandapadmanabhan, E. N., and Chakravarthy, P. (2017). Effect of Fibre Orientation on the Properties and Functional Performance of Ablative Materials for Solid Rocket Motors. *Transactions of the Indian Institute of Metals*, *70*(9), 2407–2413. https://doi.org/10.1007/s12666-017-1102-1

Murillo, R., Aylón, E., Navarro, M. V., Callén, M. S., Aranda, A., and Mastral, A. M. (2006). The application of thermal processes to valorise waste tyre. *Fuel Processing Technology*, *87*(2), 143–147. https://doi.org/10.1016/j.fuproc.2005.07.005

Nyarko, A., and Adu, K. (2016). Impact of Sachet Water and Plastic Bottle Waste on Agricultural Land in the Ada East District of Ghana. *Asian Research Journal of Agriculture*, *1*(3), 1–10. https://doi.org/10.9734/ARJA/2016/28461

Parku, G. K., Collard, F.-X., and Görgens, J. F. (2020). Pyrolysis of waste polypropylene plastics for energy recovery: Influence of heating rate and vacuum conditions on composition of fuel product. *Fuel Processing Technology*, *209*, 106522. https://doi.org/10.1016/j.fuproc.2020.106522

Robert W.Serth. (2007). *Process Heat Transfer Principles and Application* (7 th). Elsevier Science.

Sadic, H. L. (2002). *Heat exchangers, Selection, Rating, and Thermal Design* (2nd ed).

Scheirs, J. (2006). Overview of Commercial Pyrolysis Processes for Waste Plastics. In J. Scheirs & W. Kaminsky (Eds.), *Feedstock Recycling and Pyrolysis of Waste Plastics* (pp. 381–433). John Wiley and Sons, Ltd. https://doi.org/10.1002/0470021543.ch15

Sharma, M. C., and Soni, N. (2013). *Production of Alternative Diesel Fuel from Waste Oils and Comparison with Fresh Diesel: -A Review*. 54–58.

Sinnott, R. K. (n.d.). *Chemical Engineering Design,* (4 th, Vol. 1–6).

Sundar, K., Udayakumar, R., Periasamy, C., and Khurana, S. (2019). Cotton Seed Oil and Rice Bran Oil as a Source of Biodiesel in India. *Journal of Physics: Conference Series*, *1276*(1), 012086. https://doi.org/10.1088/1742-6596/1276/1/012086

Tadesse, M., Fentahun. (2017). *Dairy Farming and its Economic Importance in Ethiopia*. *12*, 42–51.

Tan, P., Hu, Z., Lou, D., and Li, Z. (2012). Exhaust emissions from a light-duty diesel engine with Jatropha biodiesel fuel. *Energy*, *39*(1), 356–362. https://doi.org/10.1016/j.energy.2012.01.002

Verechshagin,O., Mukasheva,T.,. (2016). *Methodology to calculate Design Parameters of Screw Heat Exchanger for Vat Pasteurizer*. *11*, 2955–2961.

Wang, J., Qi, X., Dong, X., Luo, S., Feng, Y., Feng, M., and Guo, X. (2022). The co-pyrolysis of waste tires and waste engine oil. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *44*(4), 9764–9778. https://doi.org/10.1080/15567036.2022.2136797

Williams, P. T., and Taylor, D. T. (1993). Aromatization of tyre pyrolysis oil to yield polycycli

aromatic hydrocarbons. *Fuel*, *72*(11), 1469–1474. https://doi.org/10.1016/0016-2361(93)90002-J

Wongkhorsub, C., and Chindaprasert, N. (2013). A Comparison of the Use of Pyrolysis Oils in Diesel Engine. *Energy and Power Engineering*, *05*(04), 350–355. https://doi.org/10.4236/epe.2013.54B068

APPENDIXES

Appendix-A: Thermocouple Calibration

Thermocouples are instruments used to measure temperature and are made up of two wires connected at one end by different metals. The type K thermocouple, which has a measurement temperature range of -200 to +1260°C, is the most often used thermocouple. By comparing the measurement values of a reference thermometer and other thermometers, one can calibrate thermometers using a reference thermometer in a temperature calibration test. In the thermal laboratory of Adama Science and Technology University, a calibration test for a four channel digital K-type thermocouple was carried out using a thermometer and a water pan of boiling water for 21 minutes.

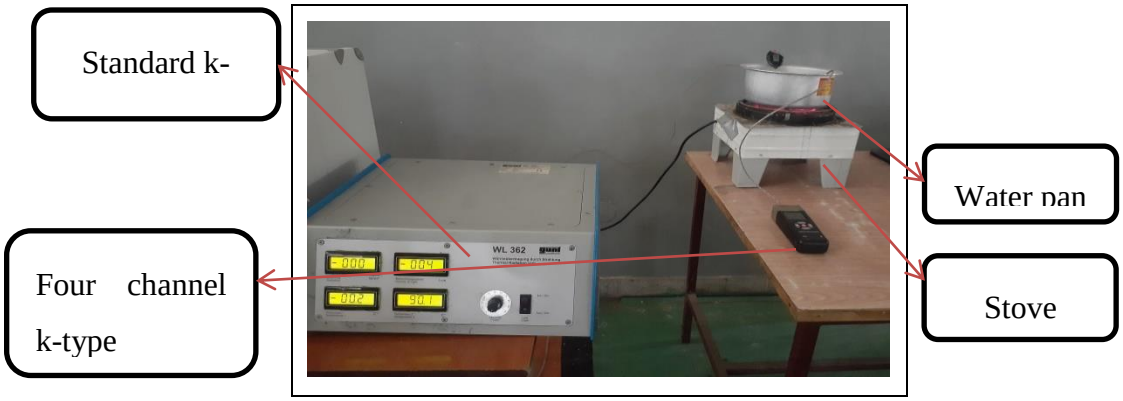

Figure A. 1Thermocouple calibration

Table A. 1: Water temperature measuring test by using K-type thermocouples

Time (min)	T_1(standard k-type thermocouple)	T_2 (four channel k- type thermocouple)	Uncertainty %$((T_1-T_2)/T_1)$ * 100%
1	30.7	30.4	0.977
3	33.1	33	0.302
5	38.9	38.6	0.771
7	43.8	43.6	0.456
9	49.9	49.7	0.400
11	55.6	55.2	0.719
13	61.7	61.5	0.324

15	69.6	69.1	0.718
17	75.3	75.2	0.132
19	80.8	80.5	0.371
21	87.7	87.3	0.456
22	96.8	95.6	0.206

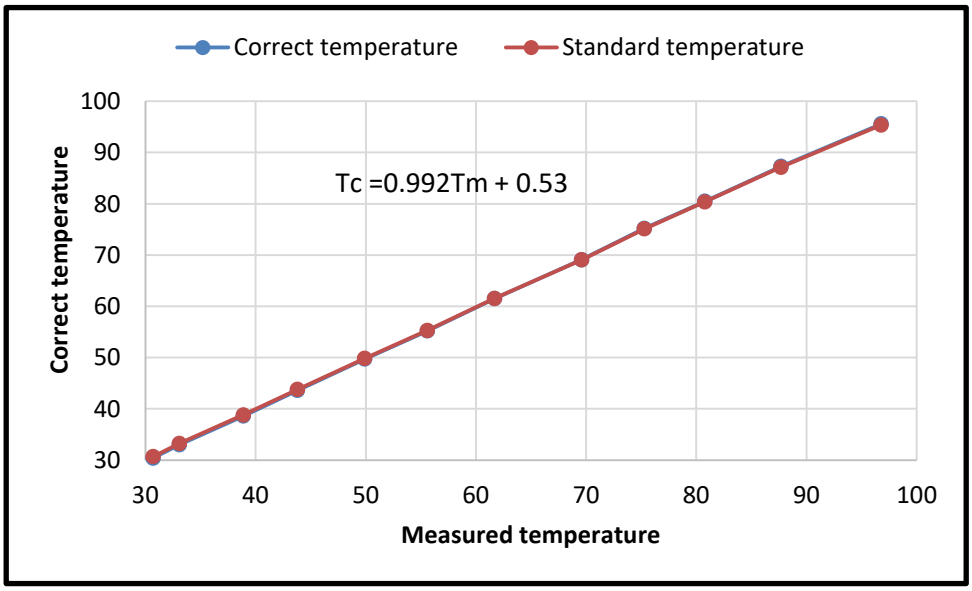

Figure A.2 temperature measured value with correct value

Appendix-B: Experimental observation of the temperature distribution and oil received

Table B. 1: Temperature distribution and oil received

Time (minute)	Temperature (^{0}C)	Total amount of oil received(ml)
0	30	0
10-40	125	116
40 -80	220	932
80- 120	280	1990
120 – 160	323	2145
160- 200	454	2750

Appendix C: Economical analysis

Table C. 1: Initial investment cost

Material cost					
No	Item	Unit	Unit price	Quantity	Remark
1	Sheet metal	pcs	1200	1	2mm thickness
2	Circular Hollow Steel	pcs	1100	1	$\emptyset 10mm$
3	Grinder disc	pcs	90	1	
4	Cutter disc	pcs	125	1	
5	Gate valve	pcs	230	1	
6	Gypsum	25kg	160	1	
7	Electrode	packet	850	1	$\emptyset 2.5 \times 300$
8	Copper coil	m	120	4	
9	Painting	spray	250	3	
10	Labor cost	1000			
Total selling cost = 5985					

Table C. 2: Cash out flow and cash in flow

No	Activities	Type of cash flow	Expense	Saving
1	Wood charcoal	Cash out flow	19,710	
2	Total cost for setup	Cash out flow	5985	
3	Purchase of tire and engine oil waste	Cash out flow	36500	
4	Water for condensation and cleaning	Cash out flow	2190	
5	Fuel extracted for form waste	Cash in flow		10,000
6	Char of waste tire and engine oil	Cash in flow		167316
Total expense and savings excluding initial investments			64385	177316
Net saving (Net annual cash flow) from using			112931ETB	

biogas per annum	

Appendix D: Result of single cylinder performance

ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

College of mechanical and electrical engineering

Name : Simegn mulugeta

Sample type: liquid oil

Table: physiochemical property

No	Property	Test Results					
		B0	B10	B20	B30	B40	WTEO
1	Density (kg/m^3)	830	830	830.5	831	832	838
2	Kinematic viscosity40^{0}C (mm2 /s)	2.0	2.0	2.0	2.0	2.0	1.95
3	Flash point	55	55	54	54	54	50
4	Fire point ^{0}C	56	55	57	55	56	52
5	Cloud point ^{0}C	-27	-25	-23	-21	-16	-4
6	pour point ^{0}C	- 30	-27	-25	-20	-14	-6

Table: B0

Time(s)	ST-1	ST-2	ST-3	ST-4	ST-5	SC-1	SC-2	SP-1	Torque	SV-1	ST-6	Power(kW
50.000	19.262	106.737	18.761	47.495	27.049	91.069	0.000	0.989	7.853	3198.543	40.541	0.554
66.700	19.399	105.806	18.922	48.609	27.186	91.732	0.000	0.988	10.435	2889.730	40.954	1.181
105.100	19.528	158.574	19.211	50.668	26.846	81.379	0.000	0.987	11.94	2649.340	42.087	1.82
149.900	19.709	197.009	19.426	53.662	28.249	75.454	0.000	0.986	12.459	2338.162	43.458	2.523
186.600	19.875	210.577	19.640	55.853	29.174	67.016	0.000	0.985	12.825	2028.925	44.787	2.889
221.100	20.043	209.387	19.912	57.136	30.553	59.739	0.000	0.984	12.12.724	1714.407	46.530	3.115
283.400	20.365	190.476	20.428	62.844	32.751	37.191	0.000	0.983	12.479	1067.618	50.615	3
297.900	20.510	183.433	20.558	62.891	32.616	40.565	0.000	0.982	7.987	1065.694	51.628	2.63
310.000	20.586	177.254	20.617	62.784	32.020	27.101	0.000	0.982	8.768	711.272	52.450	2.63

Head, Department of
Mechanical Engineering

Table: B10

Time(s)	ST-1	ST-2	ST-3	ST-4	ST-5	SC-1	SC-2	SP-1	Torque	SV-1	ST-6	Power(kW)
199.500	19.225	43.451	18.153	39.827	21.944	91.144	0.000	0.980	7.321	319	3.052	28.452	0.492
275.300	19.300	44.239	18.555	43.985	22.752	92.635	0.000	0.981	10.431	288	2.26	30.824	1.132
374.800	19.544	139.919	18.916	48.501	24.316	83.588	0.000	0.981	11.765	262	9.961	34.467	1.532
453.400	20.008	201.983	19.328	54.918	28.785	76.757	0.000	0.979	12.07	232	4.191	38.708	1.867
499.900	20.162	209.443	19.730	57.118	30.552	68.291	0.000	0.978	12413	201	7.894	42.160	1.987
533.900	20.349	205.565	20.037	58.853	31.849	61.209	0.000	0.976	12.070	170	3.593	45.047	2.046
579.200	20.580	196.054	20.354	62.346	33.678	53.281	0.000	0.975	11.765	138	8.819	49.252	2.212
604.500	20.717	186.169	20.532	64.500	33.833	41.491	0.000	0.974	7.764	106	2.480	51.700	2.092
627.900	20.827	169.502	20.659	64.515	33.017	25.966	0.000	0.973	8.394	708.085		53.991	1.987

Table: B20

Time(s)	ST-1	ST-2	ST-3	ST-4	ST-5	SC-1	SC-2	SP-1	Torque	SV-1	ST-6	Power(kW)
98.500	22.094	118.366	21.694	68.367	31.866	90.664	0.000	0.963	7.265	3179.589	5 6.248	0.525
245.400	22.208	87.502	22.845	71.766	29.911	92.325	0.000	0.960	10.393	2868.147	52.511	1.1465
288.300	22.213	149.438	23.387	72.253	29.633	82.416	0.000	0.961	11.65	2636.204	52.388	1.545
346.700	22.239	201.293	23.800	74.144	31.246	75.347	0.000	0.961	11.678	2327.505	53.324	1.876
374.800	22.341	210.067	24.052	74.766	33.117	67.732	0.000	0.960	12.312	2020.859	54.159	2.046
413.700	22.508	209.322	24.443	75.682	34.504	60.410	0.000	0.960	11.987	1711.650	56.039	2.212
448.900	22.777	202.286	24.641	77.261	35.528	52.552	0.000	0.959	11.543	1392.193	58.029	2.092
475.300	22.945	191.037	24.786	77.679	35.343	39.405	0.000	0.959	7.721	1069.214	59.854	1.987
494.400	23.087	177.968	24.903	78.091	34.870	26.006	0.000	0.958	8.295	712.365	61.288	1.987

ክፍል ምህንድስና
ት/ት ክፍል ኃላፊ
Head, Department of
Mechanical Engineering

Table 3: B30

Time(s)	ST-1	ST-2	ST-3	ST-4	ST-5	SC-1	SC-2	SP-1	Torque	SV	ST-6	Power(kW
125.100	24.013	124.843	25.474	80.807	34.924	89.635	0.000	0.952	7.058	3168.278	63.053	0.542
156.400	24.089	115.460	25.614	81.206	34.186	91.553	0.000	0.952	9.34	2862.462	62.361	1.154
193.900	23.984	155.945	25.953	81.357	33.740	82.672	0.000	0.953	10.546	2587.380	61.793	1.698
225.200	24.000	169.697	26.081	81.717	34.570	77.099	0.000	0.952	10.23	2283.549	61.554	2.318
253.900	24.030	174.189	26.205	82.259	34.932	69.211	0.000	0.953	9.85	1983.096	61.388	2.738
281.200	24.075	176.565	26.389	82.279	36.018	60.817	0.000	0.952	9.248	1703.239	61.654	2.891
310.100	24.137	175.760	26.474	82.485	36.840	52.585	0.000	0.952	8.791	1392.482	62.490	2.87
335.300	24.172	168.928	26.593	82.778	36.375	38.531	0.000	0.952	6.98	1068.365	63.230	2.55
361.900	24.310	155.128	26.716	83.285	34.963	24.018	0.000	0.951	7.341	710.555	64.385	2.55

Table 4: B40

Time(s)	ST-1	ST-2	ST-3	ST-4	ST-5	SC-1	SC-2	SP-1	Torque	SV-1	ST-6	Power(kW)
90.300	24.907	114.021	26.623	82.445	35.487	89.743	0.000	0.947	6.664	3161.353	62.652	0.543
116.000	24.949	107.859	26.737	82.837	34.903	90.912	0.000	0.947	9.25	2855.204	62.673	1.161
160.400	24.872	151.235	27.183	83.136	34.606	84.235	0.000	0.948	10.435	2563.330	62.404	1.711
199.700	24.841	163.266	27.334	83.725	35.474	77.549	0.000	0.948	110.19	2276.532	62.059	2.423
233.500	24.832	167.734	27.569	84.273	35.650	69.312	0.000	0.948	9.609	1974.982	62.139	2.79
259.300	24.825	169.216	27.767	84.333	36.454	60.906	0.000	0.948	8.925	1694.350	62.628	2.936
301.300	24.889	169.264	28.017	84.782	37.842	54.061	0.000	0.948	8.567	1388.197	64.296	2.899
337.200	25.024	162.023	28.339	85.248	37.071	41.354	0.000	0.946	6.64	1063.036	66.137	2.6
361.000	25.127	151.818	28.466	85.648	35.896	27.200	0.000	0.945	7.281	705.717	65.319	2.6

Approved by:

የሜካኒካል ምህንድስና ትምህርት ክፍል ኃላፊ
Head, Department of Mechanical Engineering

Signature: