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Effect of Process Parameters on the Production of Pyro-oil from Waste Tyres

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Abstract: Waste tyres are one of the major causes of environmental pollution, their non-biodegradability nature contributes to hazardous adverse effect they have on the environment. An estimated of 1.5 billion tyres are discarded annually all over the world. In this research, waste tyres were pyrolysed in a fixed bed pyrolyser reactor at 350- 450 ˚C to produce pyro oil as the main desired product. The effect of time of extraction, quantity of gas consumed and quantity of catalyst on percentage oil yield were investigated. The oil yield obtained from the process was found to be 31.1%. The pyro oil properties include: a viscosity of 2.08 cSt, density of 924 kg/m^3, flash point of 65 ˚C, pour point of -13˚C, cetane number of 63.19 and calorific value of 37.68 MJ/kg.

Keywords: Pyrolysis, Pyrolyser, Pyro-oil, Recycling, Waste Tyres,

I. INTRODUCTION

Globally, it is estimated that approximately 1.5 billion tyres are decommissioned as End of Life Tyres (ELT) annually (Williams 2013). This figure includes passenger car-tyres which account for 85% of the total while the remaining 15% is composed of truck-tyres and other categories. That also gave an estimate of about 4 billion scrap tyres currently stockpiled in landfills all over the world (WBCSD, 2018) with 1.5 billion added every year (Xiangxue et al., 2012). In Nigeria, it is estimated that 259 million tyres are discarded yearly. The same characteristics that make waste tyres problematic, their cheap availability, bulk, and resilience, also make them attractive targets for recycling (FORAMFERA, 2022). This would imply that in the next few decades, problems associated with waste tyres will amplify if current disposal ways are not drastically increased. It needs not be over-emphasised then that the current scrap (or waste) tyres disposal and management method in Nigeria (Chukwuebuka, et. al., 2020) and elsewhere on the globe is grossly inadequate with overwhelming growing grave of environmental, public health and economic consequences (Zheng, et al. 2011). Hence safer and sustainable ways for disposal of ELTs are attracting increasing interest worldwide.

Energy plays a vital role in the economic growth, progress, and development, as well as poverty eradication of any nation. This challenge calls for the exploration of other sources of energy. Energy demand in Nigeria is at present far more than the supply, thereby negatively retarding the country's socio-economic and technological developments (Sambo et al., 2010). Nigeria is edging closer to a serious energy crisis as a result of an ever-increasing energy demand that exceeds its supply. The steady increase in energy consumption coupled with environmental pollution has promoted research activities in alternative and renewable energy fuels (Oyedepo, 2012). Many countries in the world are continuously developing materials and methods for effectively utilizing alternative fuel resources available in their region (Kyle, 2013). Alternative fuels, also known as non-conventional or advanced fuels, are any materials or substances that can be used as fuels, other than conventional fuels. Conventional fuels include: fossil fuels (petroleum (oil), coal, propane, and natural gas), and nuclear materials such as uranium. Some well-known alternative fuels include biodiesel, bioalcohol (methanol, ethanol), chemically stored electricity (batteries and fuel cells), hydrogen, on-fossil methane, non-fossil natural gas, vegetable oil and other biomass sources. (Czajczynska, 2017).

Recycling is one of the three ways for utilizing and minimizing of the huge amount of waste. Others are land filling, incineration (with or without energy recovery) and open burning. Neither land filling, incineration or open burning can solve the growing problem of huge amount of waste tyres. Pyrolysis is the thermal decomposition of materials at elevated temperatures in an inert atmosphere. It involves a change of chemical composition and is irreversible. The word is coined from the Greek - derived elements pyro "fire" and lysis "separating". Pyrolysis is most commonly used in the treatment of organic materials. In general, pyrolysis of organic substances produces volatile products and leaves a solid residue enriched in carbon, char (Kyle, 2013). Extreme pyrolysis, which leaves mostly carbon as the residue, is called carbonization. The process is used heavily in the chemical industry, for example, to produce ethylene, many forms of carbon, and other chemicals from petroleum, coal, and even wood, to produce coke from coal.

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Aspirational applications of pyrolysis would convert biomass into syngas and biochar, waste tyres back into usable oil, or waste into safely disposable substances. (Zhou, 2017). The increase in petroleum and petrochemical prices opened the ways for industries to invest in the decomposition of waste tyres to useable oil.

II. METHODOLOGY

2.1 Collection and Preparation of Waste Tyres

The collection of waste tyres is quite an easy task as waste tyres are in abundance and can be obtained in large quantities from dumpsites or at vulcanizer's shop. Thus, the waste tyres used for this study was obtained from a vulcanizer along Poly Road. The collected waste tyres were thoroughly washed to remove dirt and were later dried.

2.2 Procedure

The feed (1kg of waste tyre) is charged into the reactor (batch reactor) through the top. To increase the temperature of the reactor, the reactor is heated using a gas burner. The material (waste tyre) gets evapourated, the vapour is then condensed at the condenser. Out coming product from the condenser is collected using a liquid collector or vessel. Three products are obtained in the pyrolysis process, namely, Tyres pyro oil, pyro gas, and char.

The pyrolysis process involves the heating and cooling operations which are very important factor for a pyrolysis plant. The reactor and heat source were designed in such a way that the produced heat is quickly transferred into reactor chamber. Initially, the recorded temperature was only 30℃, but after only 30 minutes the temperature rose to 120℃ and the temperature reading was recorded. Finally, during the next 120 minutes of the reactor's operation, the reactor heated up to a temperature of about 420℃ (± 50 ºC). The total time for the reactor's heating for the first run was 4 hours. The same procedure was repeated at 6 hours and 8 hours. The flow diagram for the pyrolysis of waste tyres is shown in Figure 1.

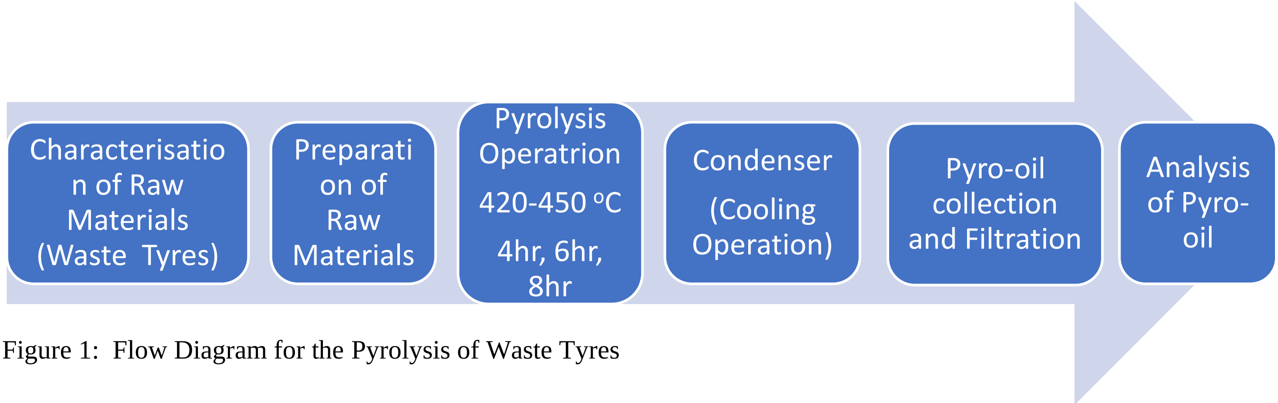

Figure 1: Flow Diagram for the Pyrolysis of Waste Tyres

III. RESULTS AND DISCUSSION OF RESULTS

3.1 Produced Pyrolysis Oil from Tyres

Plate 1: Pyro-oil from Waste Tyres

Plate 1 shows the refined pyro oil that was produced through the pyrolysis of waste tyres. 250ml of the refined oil was extracted from 1kg of the tyre.

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3.2. Effect of Process Parameters on Percentage Yield

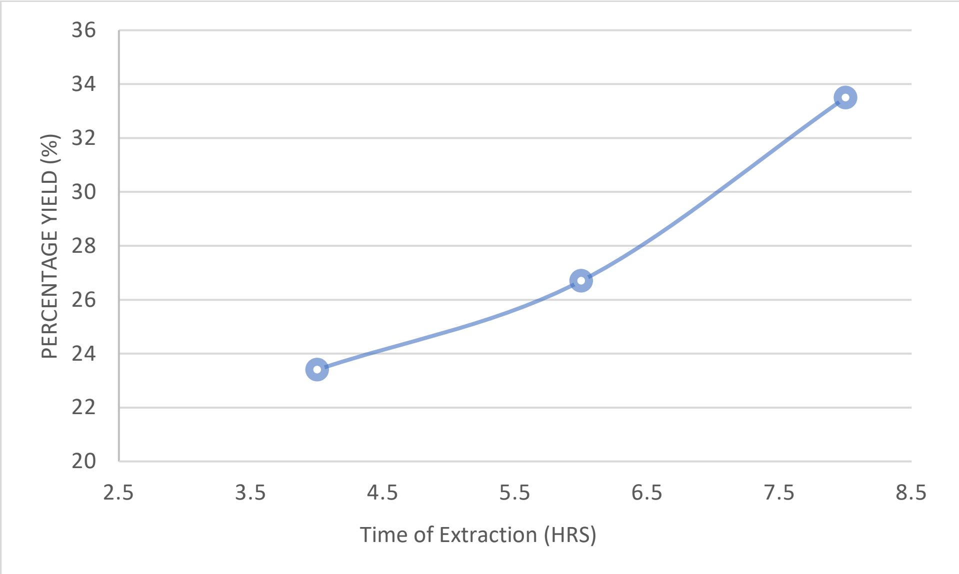

Figure 2: Effect of Extraction Time on Percentage Yield of Oil

From Figure 2 it can be seen that as the time of extraction increases from 4 to 8 hours so is the percentage of oil yield from 23.4 to 33.5%. Thus, increase in time of extraction results in the increase in percentage oil yield.

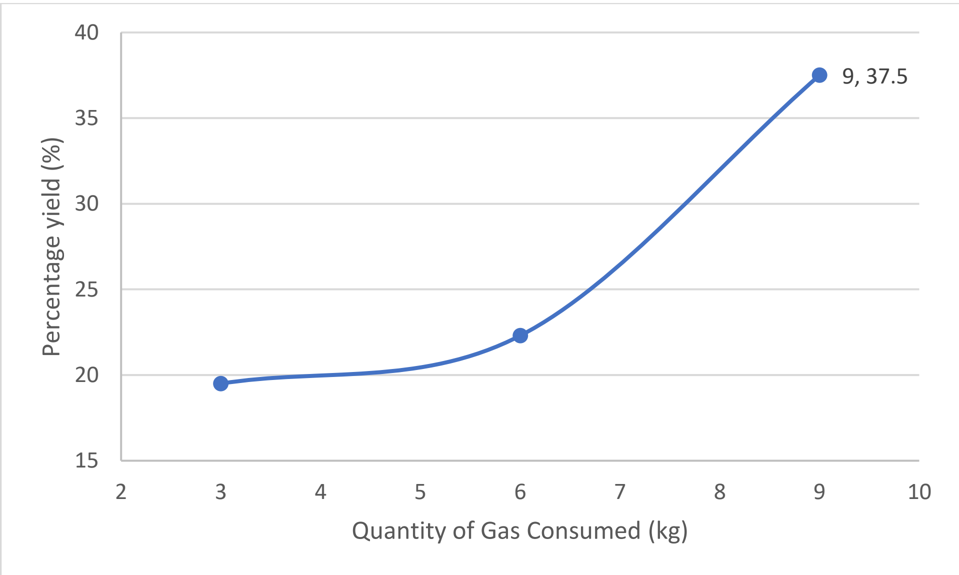

Figure 3: Effect of Gas Consumed on Percentage Yield of Oil

The effect of quantity of gas consumed is depicted in Figure 3. It can be seen that as the quantity of gas increases from 3 to 9 kg so is the percentage of oil yield from 19.5 to 37.5 %. Thus, increase in quantity of gas consumed results in the increase in percentage oil yield.

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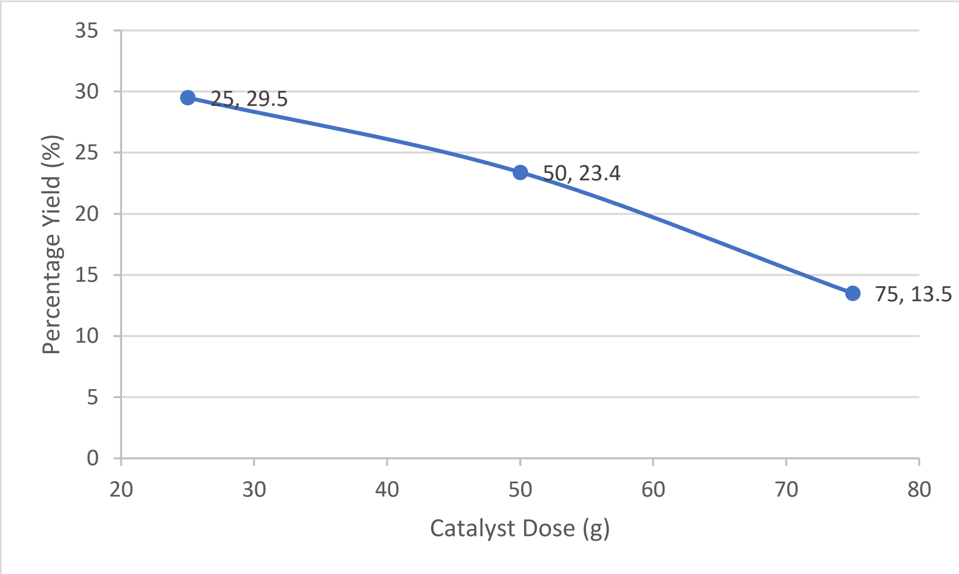

Figure 4: Effect of Catalyst on Percentage Yield of Oil

From Figure 4 it can be seen that as the quantity of catalyst (Zeolite) increases from 25 to 75 g, the percentage of oil yield experienced a sharp decrease from 13.5 to 29.5 %. Thus, increase in quantity of catalyst results in the decrease in percentage oil yield.

3.3 Proximate Analysis of Waste Tyres Pyrolysis Oil

Table 1: Properties of Waste Tyres Pyrolysis Oil

S/No	Properties	Tyres Pyrolysis Oil	Diesel Oil (Ahmad et. al., 2014 & Baiden, 2018)
1	Viscosity (mm^2/s)	2.08	1.9 - 4.5
2	Density kg/m^3	0.924	0.870
3	Flash point (^oC)	65	52 – 96
4	Pour point (^oC)	-13	-15
5	Saponification value (mmKOH/g)	244.35	244.74
6	Iodine value	24.32	40
7	Cetane number	63.19	45 – 55
8	Calorific value (MJ/kg)	37.68	41-46
9	Colour	Dark	Yellowish

Viscosity: The viscosity was measured using the IP-50 methodology at the temperature of 45 ˚C. From Table 1 the viscosity of the waste tyre pyrolysis oil was found to be 2.69 mm^2/s as compared to that of diesel oil which ranges between 1.9 – 4.5 mm^2/s.

Density: From the result in Table 1, the density of the waste tyres pyrolysis oil is 0.924 kg/m^3, which is higher than that of standard diesel 0.870 kg/m^3.

Flash Point: Flash point is the lowest temperature at which a chemical can vaporize to form an ignitable mixture in air. It is used to characterize the fire hazards of fuels. The flash point of the pyro oil was to be 65˚C. The flash point is quite low which indicate higher flammability.

Pour Point: The pour point is the temperature at which the oil loses its flow characteristics. It was measured using a fridge and an infrared thermometer. The pour point was found to be -13 ˚C. The low pour point value of the waste tyres pyro oil indicates that it is not suitable in cold temperature applications or cold weather countries.

Saponification Value: The saponification value of waste tyres pyro oil was estimated by the ASTM titration method. The value for waste tyres pyro oil was found to be 244.35 mmKOH/g which is so close to that of diesel oil.

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Iodine Value: The iodine value for waste tyres pyro oil was recorded to be 24.32. The iodine value is far lower than that of diesel (40), the lower the iodine value, the less unsaturated fatty acid bonds present in an oil.

Cetane Number: cetane number is the combustion value of diesel fuel. It measures the delay between when diesel is ignited and when the combustion begins. The cetane number of the waste tyres pyrolysis oil was measured. The value of the cetane number gotten was 63.19, which is high compared to standard diesel (45 – 55). A higher cetane number means the fuel will burn faster, more completely and will have more power. This is an important attribute which brings about better performance, running more smoothly and producing less harmful emissions Calorific value: Calorific value can be defined as the amount of heat produced on combusting a unit volume of fuel. It depends on methane content, the value for waste tyres pyro oil was recorded to be 37.69 MJ/kg.

Colour: Visually, tyres pyrolysis oil is a dark, dense liquid with an intense smell.

IV. CONCLUSIONS

The following conclusions can be made from the research work

1. Pyrolysis oil was produced through the use of a locally fabricated pyrolyser from waste tyres.
2. The pyrolysis process shows that the effect of extraction time and quantity of gas consumed have significant effect on the pyro oil yield. As both parameters increase as the percentage pyro oil yield also increases. The highest pyro oil yield of 37.5% was recorded at 10 hr of operation and utilizing 9kg of LPG. Though, the use of Zeolite catalyst did not favour pyro oil yield in this study.
3. This study showed that the thermal pyrolysis of waste tyres leads to the production of fuel oil, which is valuable resource recovery. Some properties of the fuel oil (such as density, viscosity, flash point, pour point, and saponification value) matches within the specifications of petro diesel fuel standards while others (such as calorific value, cetane number and iodine value) are not within the range. The pyro oil has a cetane number of 63.19 and a calorific value of 37.68 MJ/kg.
4. The physiochemical properties of the pyro oil can be exploited to make highly efficient fuel when blended with other petroleum products.

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