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Procedia Manufacturing 35 (2019) 847–853

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

2nd International Conference on Sustainable Materials Processing and Manufacturing

(SMPM 2019)

Process Scheme for the Production of Liquid Fuel from used tires via Fast Pyrolysis

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Abstract

One of the common products of thermal pyrolysis discussed in some studies is the Pyrolytic oil. A novel process scheme for the synthesis of bio-lube from used tires has been highlighted in this work. The methods involved in the different stages of production have also been itemized with used-tire-oil seen as a potential intermediate product. The intermediate material is then expected to undergo fast pyrolysis and esterification/transesterification to obtain the final lube oil which requires appropriate blending with sufficient additives to achieve the desired specification for a particular application. The general feature of fast pyrolysis is the thermal degradation of the solid fuel in short reaction time which is an advantage for the quality of oil produced in absence of oxygen. The study has shown that fast pyrolysis is a very efficient way of processing used tires and there is need to further develop lube oil from tire-pyrolysis.

Peer-review under responsibility of the organizing committee of SMPM 2019.

Keywords: Fast Pyrolysis; Used/Waste Tires; Lube Oil; Process Scheme Synthesis

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2351-9789
Peer-review under responsibility of the organizing committee of SMPM 2019.
10.1016/j.promfg.2019.06.031

1. Introduction

Over 11 million worn used tires are generated and disposed indiscriminately on a yearly basis in Nigeria. These tires are not suitable for trucks and vehicles due to wears or punctures, and they are classified among the problematic sources of waste due to their increasing numbers and non-biodegradability. They are difficult to break down and separate, which makes reprocessing hugely challenging. Synthetic rubbers from petroleum are used in manufacturing tires and most people believe that burning of these tires is the best form of disposal due to their flammability. The same characteristics such as cheap availability, bulkiness and resilience, that make waste tires problematic also makes them attractive targets for recycling. Apart from cost of purchase, scarce land space for landfilling, environmental and health related issues are of chief concern for scrap tires. Letho et al., [1] discussed bio oils synthesis via fast pyrolysis and added that they often have better physical and chemical characteristics than petroleum fuels and these properties make them potential sources for fuels in burners without the need for pilot flames or support fuel during combustion, hence the need to give them special attention for future applications [2]. An experimental investigation of the property-effect on combustion performance of bio-ethanol blends produced via fast pyrolysis was successfully carried out by [3]. Amongst the most promising technologies for biomass conversion to liquid fuels is fast pyrolysis through which promising bio-oils/fuels [4] that can serve as potential replacement fuels for petroleum fuels can be obtained for use in thermal devices [5, 6, 7] and can as well help cushion the effect of liquid fuel shortages [8, 9]. Based on the findings from the research projects executed by Girard and Blin [10] and Blin and Girard [11], bio-oils were reported to have zero eco-toxicological effects but little mutagenic consequences thus reaffirming their less harmful effects relative to conventional diesel fuels. Currently, there is extensive ongoing research to address the few undesirable properties of bio-oils and the methods of upgrade include physico-chemical and catalytic upgrade methods which may require complex or sophisticated systems. Despite these efforts and advances in research, there is no evidence of the use of fast pyrolysis for the production of lubricants from used tires hence, the reason this research is being taken into consideration. Furthermore, it has been proven by [12] that lubricants can be obtained from biodiesel which serves as a viable intermediate product for bio-lube synthesis. In this paper, a proposed process scheme for the developmental stages of the intermediate and final product has been discussed for possible implementation as a means of converting used vehicular tires to bio-lubes.

1.1. Methods of utilizing Scrap Tires

Some authors have identified thermal pyrolysis as one of the effective approaches for managing and utilizing solid wastes such as scrap tires [13, 14]. Thermal pyrolysis was used to convert these tires into economically viable products (Table 1). One of the common products of thermal pyrolysis discussed in some studies is the pyrolytic oil. The study of Nisar et al., [15] identified and characterized char, gaseous and tar fractions as part of the products from the pyrolysis of scrap tires. The factors responsible for this process can be controlled to optimize the product of interest and minimize by-products. Kumaravel et al., [14], in their study, mentioned type of gaseous atmosphere, retention time of the volatiles at reaction zone, temperature and pressure as the parameters governing the pyrolysis process.

Table 1: Previous works on Scrap Tires Optimization Pyrolysis Technique

Author(s), Year	Optimization Technique used	Feedstock	Decision Variables	Major Findings
Haydary et al., [16]	Pyrolysis	Tire	Particle size and Kinetic parameters	The direct effect of particle size and thermal decomposition kinetics on pyrolysis time was established
Miandad et al., [17]	Pyrolysis	Tire waste	Catalytic pyrolysis	Higher heating values liquid oils that required refining and blending were produced
Hita et al., [18]	Pyrolysis	Scrap Tires	Valorisation pathways	Limitations to high quality oil

				was established and a two stage hydrocracking strategy was proposed
Choi et al., [19]	Pyrolysis	Scrap Tires	A continuous two-stage pyrolysis	A reduction in sulphur content in the produced oil was observed
Mkhize et al., [20]	Pyrolysis	Waste Tire	Quenching	The technique increased the yield of tire derived oil and functioned as gas cleaner
Hurdogan et al., [21]	Pyrolysis	Waste Tire	Performance and emission characteristic	The produced diesel blends indicated similar performance with fossil diesel in term of torque and power output
Alvarez et al., [22]	Pyrolysis	Waste truck Tire	A conical spouted bed reactor	The produced oil yield decreased with increase in temperature as the gas increases
Nisar et al., [15]	Pyrolysis	Waste Tire rubber	Influence of temperature	$C_1 – C_5$ gaseous hydrocarbon fraction and $C_{16} – C_{19}$ liquid hydrocarbon fractions were detected
Wang et al., [23]	Pyrolysis	Co-Pyrolysis	Biomass and waste Tire	An increase in the hydrocarbon percentage was observed with this blend at the initial and final stages of the process

A recent study by Zeaiter et al., [24] proposed the use of solar energy as the source for heating the pyrolytic reactor through heat transfer fluids. This approach may not be new in engineering but the authors stated that the study is the first to apply the technique of solar radiations in heating the pyrolysis reactor; thus, saving cost and energy. The study also identified decrease in efficiency of the technique due to variation in season. They observed an increase in summer and a decrease in winter.

2. Evolution of Pyrolysis Processes

Slow pyrolysis is a conventional method that has been employed for many years to produce charcoal with small amount of bio-oil obtained as by-product. The production of charcoal in sub-Saharan Africa still depends heavily on this process. The device used incorporates the use of clay or sand mounds to create an oxygen free environment. The heating rate for slow pyrolysis ranges between 1 ºC/min and 30 ºC/min [25].

Fast pyrolysis is a thermochemical conversion technique that has been applied mostly in biomass processes but, its general features include the thermal degradation of the solid fuel in short reaction time mostly in the absence of oxygen. Its yield in biomass and rubber conversion has shown a high percentage mass [26]. The technique operates within the atmospheric pressure and moderate temperature range. Its advantage is in the short residence time, avoiding the cracking of vapour to bring about unwanted gasification that will affect the productivity (Table 2). The residence time of vapour is the time it takes the pyrolysis gases to evacuate from the zone of pyrolysis to the quenching unit; this informs the degree of secondary cracking reactions.

Table 2: Different kinds of Pyrolysis and their possible yields from studies

Process	Condition required	Liquid yield	Charcoal yield	Gas yield
Fast Pyrolysis	Temperature range of 450 to 550°C and a short vapour residence time	70%	17%	13%
Carbonization	Temperature range of 400 to 450°C and long residence time	30%	35%	35%
Gasification	Temperature of 900°C	4%	15%	81%

There are various types of reactor beds considered in fast pyrolysis technique. They have been applied in different research and industries, and they are;

1. Fluid Bed
2. Spouted fluid Bed
3. Transported/Circulating Bed
4. Rotating cone vortex
5. Ablative
6. Auger
7. Fixed Bed, and
8. Vacuum

There are also types of fast pyrolysis discussed in some studies, which are;

1. Flash Pyrolysis – it has very short gas residence time under high temperature and a high heating rate has been recorded.
2. Microwave Pyrolysis – it utilizes the energy efficiently and provides rapid heat because, the particles are mainly heated by radiation

An appropriately selected operating parameter and reactor design, based on the properties and types of the scrap tires of interest, can be combined with carefully selected operating conditions to increase the quantity and quality of the products. Fast pyrolysis of natural rubber seed has been reported in a fixed bed with 15°C per minute increase in temperature [13]. From the yield obtained in their study and literature, it is clear that fast pyrolysis has more benefits than slow pyrolysis.

3. Comparison of the techniques used in utilizing scrap tires

Literature has shown that pyrolysis and gasification have been applied as suitable paths for producing alternative solid, liquid and gaseous fuels. The comparison is made using four criteria namely: The basic features of each method, their applications, advantages and disadvantages. From table 3, it is seen that fast pyrolysis gave a high yield of liquid fuel which is the focus of this study.

Table 3: Comparison of existing techniques in conversion of scrap Tires to Economically viable products

Criteria	Pyrolysis	Fast Pyrolysis
Basic features	Oxygen free environment and heating rate between the range of 1 °C/min and 30 °C/min	Absence of oxygen and temperature range of 450 to 550°C
Applications	Economic utilization of used/ scrap tires	Economic utilization of used/ scrap tires
Advantages	Production of charcoal with fuel liquid fuel as by-product	High yield of liquid fuel and short residence time for gaseous fractions
Disadvantages	High yield of gaseous products at increased temperature	Low yield of gaseous products at increased temperature

There are few commercial fast pyrolysis plants presently, and the aspects of fast pyrolysis in scrap tires utilization needs further research to make the process more reliable so as to improve the quality of the liquid fuel produced. Many organizations are actively involved in research on fast pyrolysis of biomass materials; such attention should be considered in growing and expanding the applications of this technique in scrap tire utilization with several variations in the types of reactor being investigated.

3.1 Scrap Tires Pyrolysis products

Waste utilization and refinery is defined as a group of thermo-chemical processes aimed at producing fuels from valorization of waste; for this study, our emphasis is on tires. Table 4 illustrates the different products produced in different studies and the process used in actualizing these objectives.

Table 4: Products from Pyrolysis of Scrap/ waste Tires

Author(s), Year	Process used	Product(s)
Tan et al., [27]	Modified chemical percolation devolatilization	Light gases with increase in methane yield
Miandad et al., [17]	Effect of advanced catalysts	Liquid oil with aromatic and aliphatic hydrocarbons
Alvarez et al., [22]	Conical spouted bed reactor	Tire oil from pyrolysis
Nisar et al., [15]	Pyrolysis	C_1-C_5 gaseous fractions and C_{16}-C_{19} liquid fractions
Hurdogan et al., [21]	Pyrolysis	Waste tire oil from pyrolysis
Wang et al., [23]	Co-pyrolysis	Polycyclic aromatic hydrocarbons and char residuals
Mkhize et al., [20]	Condensation of the hot volatiles	Tire derived oil
Choi et al., [19]	Continuous two-stage pyrolysis	Pyrolysis oil

3.2 Existing Gaps

From this study, two major existing gaps have been identified, and further studies should be geared towards development of these gaps. They are;

1. Massive utilization of fast pyrolysis in utilization of scrap/ waste tires
2. Production of lubricant and lubrication oil from the existing process

3.3 The Novel Process Scheme for effective synthesis of lube oil from used tires

The process scheme (Fig. 1) is divided into different functional units: collection, characterization and feeding of scrap/ used tires (identification of the tire compositions), Pyrolysis of the used tires in the pyrolytic reactor, esterification/ transesterification, product separation and quenching of pyrolysis products to produce bio-oil, Polyol-synthesis and Blending to produce lube oil. The yield and quantity of products will be dependent on the composition of the waste tires used for the production process.

Heating requirement for the process scheme can be estimated using

$$\left\{\begin{matrix}\textbf{Heat Lost by}\\ \textbf{Furnace}\end{matrix}\right\} \Rightarrow \left\{\begin{matrix}\textbf{Heat gained}\\ \textbf{by Waste tires}\end{matrix}\right\} + \left\{\begin{matrix}\textbf{Heat gained by}\\ \textbf{reactor walls}\end{matrix}\right\}$$

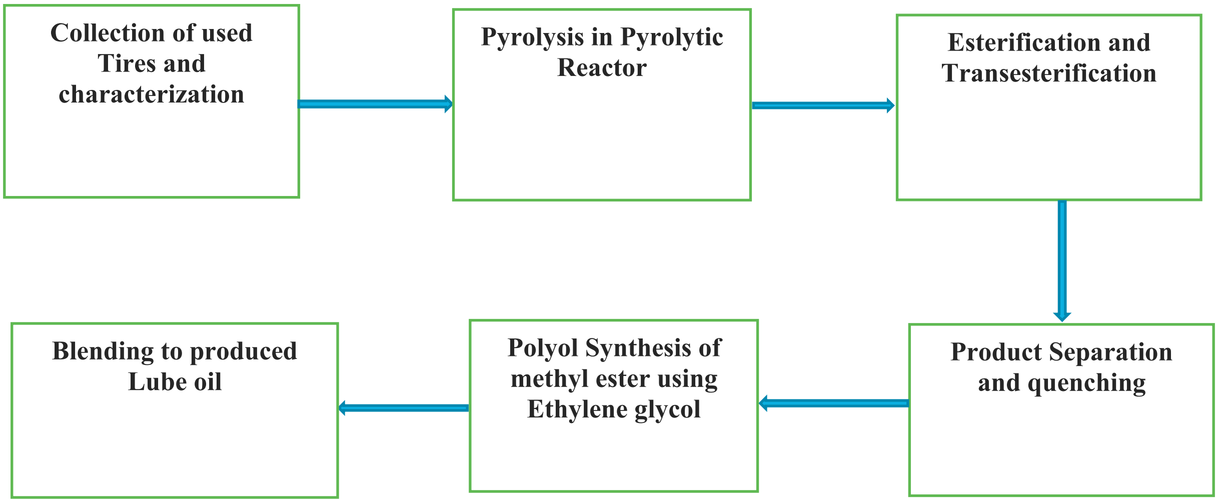

Figure 1: Proposed process scheme for Lube oil synthesis from used Tires

4. Conclusions

In this study, we looked at the novel process scheme for the synthesis of lube oil from used tire pyrolysis. A few utilization techniques used in processing waste tires oil and their various products was discussed. Based on the above findings, we deduced the following conclusions:

1. Thermal pyrolysis is one of the effective approaches of managing and utilizing solid wastes such as scrap tires.
2. The parameters governing the pyrolysis process and products were also identified.
3. High yield of oil and short residence time of vapour were established as major advantages of fast pyrolysis.
4. Comparison of the available techniques in some literature showed fast pyrolysis as a favourable thermal decomposition process.
5. The novel process scheme for the synthesis of lube oil from used tires has great potential for contributing to national development.

Acknowledgements

The authors would like to thank Covenant University Centre for Research Innovation and Discovery (CUCRID) Ota, Nigeria for its support in making the publication of this research possible.

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