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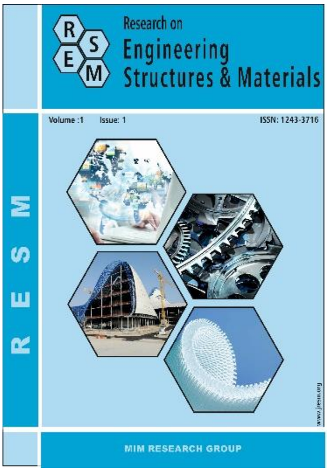

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Research Article

Recovery of waste tyres by pyrolysis in a fixed bed reactor for liquid fuel production: effects of pyrolysis conditions on oil yield

Derya Yesim Hopa*[,1], Alime Yilmaz[2], Tuba Aksoy Bahtli[3]

[1*]*Department of Chemical Engineering, Afyon Kocatepe University, Afyonkarahisar, Turkey*
[2] *Department of Chemical Engineering, Pamukkale University, Denizli, Turkey*
[3] *Department of Metallurgical and Materials Engineering, Necmettin Erbakan University, Konya, Turkey*

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Abstract

One of the major environmental problems around the world is disposal of waste tyres without any purpose. Disposal of waste tyres is an increasing environmental problem. Also because of high content of valuable chemicals and other compounds hidden in the waste tyres, disposal of them is an economical problem as well.

Pyrolysis is a thermochemical process that can be used for recovery of the valuable chemicals in the waste tyre. Pyrolysis is a recycling process in which, liquid product can be used as a fuel directly or can be mixed with petroleum refined oils. Derived gaseous product can also be used as a fuel and solid product can be considered as a fuel and low grade carbon black.

In this work, granulated waste tyres have been pyrolyzed in a fixed bed reactor under different conditions of temperature, heating rate and inert purging gas (N2) flow rate. The purpose of the study was to optimize the pyrolysis parameters in order to produce the highest amount of oil. 400°C, 450°C and 500°C were selected and the maximum yield of liquid product was observed at 450°C. Among the heating rates of 10°C/min, 15°C/ min and 20°C/min; 10°C/min was the parameter that gave maximum oil yield. And while working at 450°C and 10°C/min; N_2(g) flow rate was examined by using 0.5 L/min, 1 L/min and 1.5 L/min. The maximum oil yield was observed at 1 L N_2(g) /min. According to the results of the study; at 450°C, with a heating rate of 10°C/min and 1 L N_2(g)/min gave the maximum yield of oil, which is 53.33 wt.%. The pyrolytic oil from waste tyre had the Gross Calorific Value of 42.6 MJ/kg which is very close to that of commercial diesel no 2 (around 42-46 MJ/kg). The pyrolytic oil produced is a promising fuel and can be used as a source of energy after some future work for make it suitable for use in vehicles or in other areas like factories or houses etc.

1. Introduction

The use of renewable sources and waste valorisation is increasing because of factors such as global warming, the increase of energy demand and availability of waste materials. Therefore, it is necessary to study how to obtain an energy benefit with a minimum of environmental impact. In our decade, one of the major environmental problems is disposing of waste tyres. Dumped waste tyres in lanfills causes serious environmental problems. So uncontrolled dumping waste tyres inhibited by laws. In Turkey, 175 bin 186 tons of waste tyre were generated in 2014 [1,2,3]. Pyrolysis is a thermo-chemical conversion method occurring in the absence of oxygen to convert biomass into valuable solid, liquid and gas products. During pyrolysis, a great number of reactions occur. Higher molecular weight compounds break to form lower molecular weight short chain molecules. The condensable liquid hydrocarbon mixture is known as pyrolytic oil [4].

*Correspondingauthor: dyhopa@aku.edu.tr
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Pyrolysis is a recycling process that can deal with waste tyres. This process has a lot of advantages; derived liquid product can be used as a fuel directly or mixing with petroleum refined oils. Liquid product is also an important source of refined chemicals. Derived gas product can be used as a fuel, derived solid product can be considered as a fuel and low grade carbon black [5].

In the literature there are many reports about effect of varied parameters on the pyrolytic oil yield. Temperature effect, heating rate effect,gas flow rate effect. Williams et al was studied for pyrolysis of waste tyres at varied temperatures; 300 °C to 720 °C and varied heating rates; 5 to 80 °C/min under nitrogen gas flow rate and in fixed bed reactor. As temperature was increased, liquid and gas product yield increased, solid product yield decreased. Beyond 600 °C there was minimum difference on the product yield. When heating rate of 5 °C/min was used; at 300 °C, 720 °C ; %3 ,% 54.8 liquid product yields were obtained respectively [6]. Laresgoiti et al studied at different temperatures. They reported that liquid product yield increased as temperature increased. Yields were 24.8 wt % at 400 °C, 38 wt % at 500 °C, 38.5 wt % at 700 °C [7]. Aydın and Ikılıc pyrolyzed waste tyres in a nitrogen swept fixed bed reactor at a range of 400-700 °C temperatures. They found that oil yields were 31 wt % at 400 °C, 40 wt % at 500 °C and there was negligible effect at higher temperatures. They also studied on effect of nitrogen gas flow rate on product yield, found negligible effect on product yield [8].

The objective of this work was to investigate the effects of pyrolysis parameters on the yield of pyrolytic liquid. In this work, granulated waste tyres have been pyrolyzed in a fixed bed reactor under different conditions of temperature, heating rate and inert purging gas (N_2) flow rate. The purpose of the study was to optimize the pyrolysis parameters in order to produce the highest amount of oil.

2. Material and Method

2.1 Materials

Waste tyres were supplied by Selçuk Rubber and Plastic Plant in Konya /Turkey (Member of LASDER and waste tyre grinding company). Waste tyres were shredded. Size of waste tyres was between 0.85-1.6 mm. Waste tyres contained no steel thread and no textile netting.

2.2 Pyrolysis process

Pyrolysis experiments were conducted in a fixed-bed, stainless steel reactor with an inner diameter of 5 cm. The reactor was heated with a furnace system outside of the reactor which is showed in Figure 1. The temperature of the furnace was controlled with a PID controller. The gases produced from pyrolysis reactions come through the condenser which is attached to the reactor outlet. The vapors passing through the condenser, in which water is circulating as a cooling medium, are taken into the liquid product collector tube. Pyrolysis runs were made at different conditions with a holding time of 20 min. at maximum temperature. The yield of liquid product, solid product (char) and the gas product was calculated for all pyrolysis temperatures. Pyrolysis experiments were carried out under nitrogen atmosphere at the temperatures of 400 ˚C, 450 ˚C,500 ˚C, 20 ˚C/min heating rate. Experiments were carried out 10 °C/min, 15 °C/min heating rate at 450 ˚C. For at 450 ˚C temperature and 10 ˚C/min heating rate, 0.5, 1, 1.5 L/min nitrogen gas flow rates were investigated. The calorific value of oil was measured by using a bomb calorimeter (IKA-WERKE, model: C 2000 Basic).

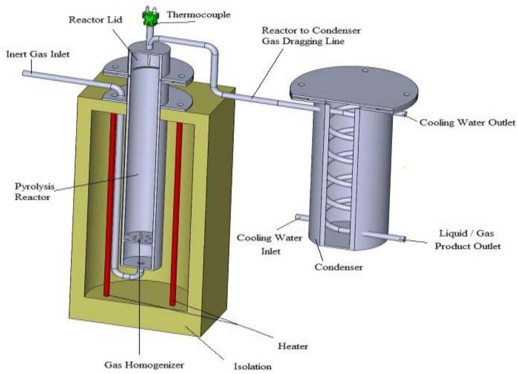

Fig. 1. Schematic diagram of pyrolysis reactor

3. Results and Discussions

3.1 Analysis of feedstock

Proximate analyses of waste tyres were determined according to ASTM standarts. Only the moisture analysis was done by using moisture analyzer (AND, MX-50). Proximate analyses of waste tyres and ASTM standarts are shown in Table 1.

Table 1. Proximate Analyses of Waste Tyres

Unit	Moisture	Ash	Volatile Matter	Fixed Carbon
%	0.24	8.66	62.63	28.47
Method	And, MX-50 Moisture Analyzer	ASTM D 3174	ASTM D 3175	Calculated by mass difference

3.2 Pyrolysis Yield of Waste Tyres

Pyrolysis of waste tyres were carried out at 400,450,500 ˚C temperatures, at a selected heating rate of 20 ˚C/min and a selected N_2 flow rate of 1 L/min. Maximum liquid product yield was observed at 450 ˚C temperature. Results for all product yields are shown in Table 2.

After it was observed that the optimum temperature for oil yield was 450°C, a new series of experiments were done in order to determine the optimum heating rate. Pyrolysis of waste tyres were carried out at 450˚C; and at different heating rates of 10, 15 ,20 ˚C/min.

According to the results of these experiments, the optimum heating rate that gave the maximum liquid product yield was 10 ˚C/min. The results of this serie of experiments can be seen in Table 3.

Table 2. Product yields at different pyrolysis temperatures (wt. %)

Constant parameters	Temperature	Solid Yield	Liquid Yield	Gas Yield (*)
Heating rate: 20 ˚C/min	400 ˚C	35.19±0.02	41±0.001	23.81±0.01
N_2 flow rate: 1L/min	450 ˚C	36.11 ± 0.53	43.25±1.21	19.35±2.21
	500 ˚C	37.32±0.368	41±0.02	21.68±0.368

(*) Calculated by mass difference

Table 3. Product yields at different heating rates (wt. %)

Constant parameters	Heating Rate	Solid Yield	Liquid Yield	Gas Yield (*)
Temperature: 450 ˚C	10 ˚C/min	37.69±0.45	53.33±0.79	8.98±1.24
N_2 flow rate: 1L/min	15 ˚C/min	36.70±0.43	44±0.55	19.3±0.87
	20 ˚C/min	36.11 ± 0.53	43.25±1.21	19.35±2.21

(*) Calculated by mass difference

According to the results of experiments given in Table 4, the maximum oil yield was held at the heating rate of 10 ˚C/min. According to that result, the last pyrolysis parameter, which is inert gas flow rate was observed. In order to observe the effect of different N_2 gas flow rates on oil yield, experiments were carried out at constant parameters of 450 ˚C; 10 ˚C/min; and the varying flow rates of N_2 gas: 0.5 L/min , 1 L/min,1.5 L/min. Maximum liquid product yield was observed at 1 L/min N_2 flow rate . Results are shown in Table-4.

Table 4. Pyrolysis Yields of Waste Tyres at Different N_2 Gas Flow Rates (% wt)

Constant parameters	N_2 Flow Rate	Solid Yield	Liquid Yield	Gas Yield (*)
Temperature: 450 ˚C	0.5 L/min	36.97± 0.27	45.67±0.41	17.36±0.14
Heating rate: 10 °C/min	1 L/min	37.69±0.45	53.33±0.79	8.98±1.24
	1.5 L/min	35.88±0.23	41.03±0.14	22.82±0.08

(*) Calculated by Difference

Waste scrap tyres were pyrolyzed at different temperatures, different heating rates and different N_2 flow rates. Results show that maximum liquid yield can be obtained at 450^{o}C temperature, 10 ^{0}C/min heating rate, 1 L/min N_2 flow rate. The effect of temperature, heating rate and N_2 flow rate on oil yield are given in Figures 2, 3 and 4 respectively.

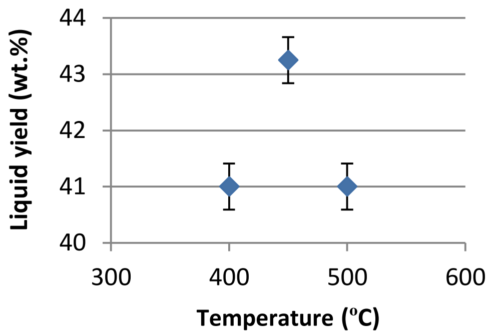

Fig.2. Changes in Liquid yield with varied temperatures

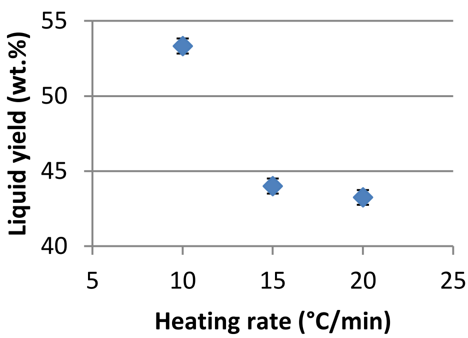

Fig.3. Changes in Liquid yield with varied heating rates

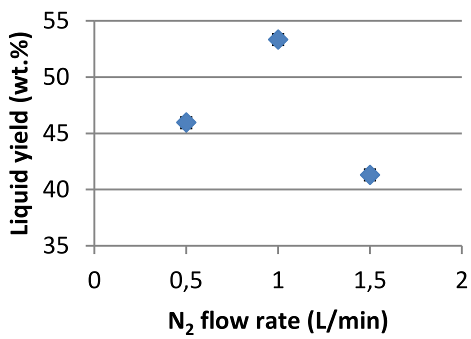

Fig.4. Changes in Liquid yield with varied N_2 flow rates

4. Conclusions

Scrap waste tyres with no steel and no textile netting was pyrolyzed at different temperatures, different heating rates and under different nitrogen gas flow rated atmosphere in a fixed bed reactor to investigate the optimum temperature. Waste tyres were pyrolyzed at 400,450,500 ^{o}C temperatures at 20^{o}C/min under 1 L/min N2 gas flow rated atmosphere. Maximum liquid product yield was observed at 450 ^{o}C, 43.25 wt %. Optimum pyrolysis temperature was observed as 450^{o}C.

To investigate optimum heating rate, waste tyres were pyrolyzed at 10,15,20 ^{o}C/min heating rates under 1 L/min N_2 gas flow rated atmosphere at 450 ^{o}C (as optimum pyrolysis temperature). Maximum liquid product yield was observed at 10 ^{o}C/min; as 53.33 wt %. Optimum pyrolysis heating rate was determined as 10 ^{o}C/min.

To investigate optimum N_2 gas flow rate, waste tyres were pyrolyzed at 0.5, 0.75, 1 L/min N_2 gas flow rates at 10 ^{o}C/min and at 450 ^{o}C (as optimum pyrolysis heating rate and temperature). Maximum liquid product yield was observed at 1 L/min; as 53.33 wt %. Optimum pyrolysis N_2 gas flow rate was determined as 1 L/min.

According to this study, optimum pyrolysis parameters are; 450 ^{o}C temperature, 10 oC/min heating rate and 1 L/min N_2 gas flow rate.

Evaluation of waste tyres by pyrolysis is very important in terms of environmental protection. Optimization of pyrolysis parameters will contribute to economic aspects and will improve quality of liquid product which is used as fuel.

5. Acknowledgment

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