Fixed Bed Pyrolysis of Scrap Tyre for Liquid Fuel Production

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ABSTRACT

The thermochemical conversion of scrap tyre into liquid fuel by continuous fixed bed pyrolysis process has been taken into consideration in this study. The scrap tyre was characterized through proximate, ultimate and thermo-gravimetric analysis to investigate its suitability as feedstock for this consideration. Scrap tyre in particle form was pyrolysed in an externally heated 0.28 m^3 fixed bed reactor with nitrogen as a carrier gas. A biomass source heater in cylindrical shape and a gravity feed type reactor feeder were used to heat and to feed the reactor respectively. The pyrolysis products were liquid, char and gas. The product yields were significantly influenced by the process conditions. At an optimum reaction condition of fixed bed temperature of 450^0C, feedstock size of 3 – 5 cm and operating time of 75min, an oil yield of 64 wt % of dry feed stock was obtained. The oil obtained at this optimum process condition was analyzed for their properties as an alternative fuel and was compared with petroleum products. The fuel properties compared were physical properties, calorific value, elemental (CHNOS) analysis and chemical composition using Fourier Transform Infra-Red (FTIR) spectroscopy.

1. INTRODUCTION

The conventional fossil fuels have been depleting at an alarming rate and hence, the focus on alternative renewable sources of energy is increasing. As a result organic solid waste as a renewable source of energy has continued to attract increased attention [1]. In South Asian developing countries, especially in Bangladesh the production of rubber product is very high. Due to the rapid economic progress, the number of motor vehicles in Bangladesh is increasing rapidly and has exceeded one millions by the end of 1999 [2]. Accordingly a large amount of rubber products and scrap tyre accumulated is creating problems regarding its disposal. Also direct burning of these wastes creates a serious environmental problems. As carbonaceous solid wastes are the source of energy, therefore, the potential of recovering these wastes into useful form of energy by pyrolysis into liquid fuel, should be considered. In this way the waste would be more readily usable and environmentally acceptable [3]. This liquid of high heating value is easily transported, and can be burnt directly in the thermal power plant, can easily be injected into the flow of a conventional petroleum refinery, can be burnt in a gas turbine or upgraded to obtain light hydrocarbon for transport fuel [4]. The solid char can be used for making activated carbon. Besides the char has its potential to be used as fuel. The gas has high calorific value, sufficient to be used for the total energy requirements of the pyrolysis plant [5]. Recently some work has been carried out with scrap tyre as feedstock at the Fluid Mechanics Laboratory of Mechanical Engineering Department of Rajshahi University of Engineering and Technology (erstwhile Bangladesh Institute of Technology Rajshahi) to obtain liquid fuel using fixed bed pyrolysis technology.

2. MATERIALS AND METHODS

2.1 Materials

The scrap tyre was collected locally at Rajshahi Small gab (Bangladesh). It was then shredded and sieved to three different particle sizes of 0-1 cm, 1-2 cm and 3-5 cm. The feed particles were oven dried for 24 hours at 110 °C prior gab to pyrolysis.

2.2 Characteristics of Scrap Tyre for Pyrolysis Process

For the purpose of investigating the suitability of scrap tyre locally available in significant amount as feedstock for pyrolysis so as to obtain value added liquid product, the following analysis has been considered:

- Proximate and elemental analysis
- Thermo gravimetric analysis (TGA)

Important parameters like volatile matter, fixed carbon, ask content and moisture content of the scrap tyre feedstock are essential in order to examine the suitability for pyrolysis process, can be obtained from proximate analysis of the feedstock. High volatile matter content with low ash and sulfur content are the main criteria for pyrolysis conversion [6]. The ASTM (American Society of Testing Materials) Standard D3172-73 (1984) test procedures for solid fuel, entitled " Standard Method for Proximate Analysis of Coal and Coke" was used for the proximate analysis. The ultimate analysis in terms of carbon, hydrogen, nitrogen and sulfur (CHNOS) content is also important in order to make necessary material balances of each oxygen, component. The ultimate analysis was conducted in a C-H-N-S analyzer, according to the ASTM standard procedures. Oxygen content was determined by difference (ash free basis). The proximate and ultimate analyses of solid scrap tyre feedstock are p r e s e n t e d

Table 1 Proximate and Elemental Analysis of Scrap Tyre

Proximate analysis	(wt%)	Elemental analysis	(wt%)
Moisture content	0.82	Carbon (C)	80.30
Volatile matter	62.70	Hydrogen (H)	5.18
Fixed carbon	32.31	Oxygen (O)	10.33
Ash content	4.17	Others	3.19
		C/H	15.50

The thermal characteristics of scrap tyre particles have been investigated by thermo ravimetric analyzer (TGA) study. The instrument used for this purpose was of model SHIMADZU TGA-50 and the test was conducted at the laboratory of Institute of Fuel Research and Development, BCSIR, Dhaka, Bangladesh. TGA gave information about the temperature at which pyrolysis was initiated, when the rate of devolatilization was maximum and finally the temperature at which the process was completed. The TG curve also indicated the fractional weight loss of volatile matter in the sample with temperature and time. The plot obtained at heating rate of 10°C/min over a temperature range of 0 to 1000°C for scrap tyre is presented in Figure 1.

2.3 Fixed bed Pyrolysis Reactor System

Scrap tyre was pyrolyzed continuously in an externally heated stainless steel fixed bed reactor system. The main components of the system are fixed bed reactor, gas preheating chamber, reactor feeder, liquid condenser and ice-cooled liquid collector. The effective length of the reactor is 340 mm and it is 76 mm in diameter. The gap schematic diagram of the fixed bed pyrolysis reactor is shown in in table 1.

finger 2. A cylindrical biomass source heater was used to heat the reactor and the gas-preheating chamber. The temperature of the reactor was controlled by varying the supply of air by means of an air blower. Nitrogen gas was supplied in order to maintain the inert atmosphere in the reactor and also to dispose of the pyrolyzed vapor product to the condenser. A maximum amount of liquid product was obtained at 450°C and at atmospheric pressure for a sample size of 3 to 5 cm. Pyrolysis vapor was condensed into liquid in the condenser and it was then collected in the liquid collector. The uncondensed gas was flared to the atmosphere.

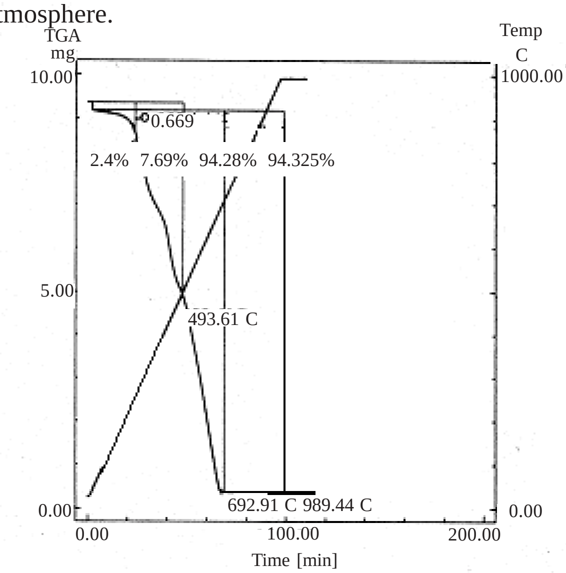

Fig. 1. TG plot for scrap tyre in helium at heating rate of 10 ^{0}C/min

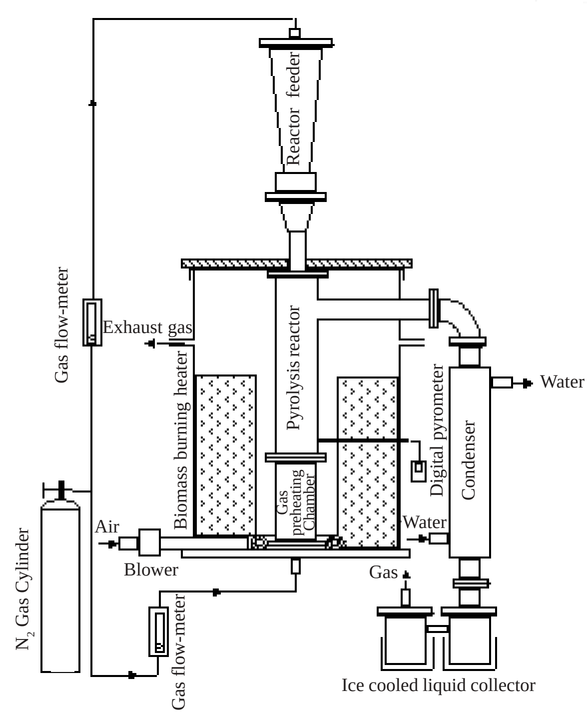

Fig. 2. Schematic diagram of fixed bed pyrolysis system

2.4 Oil Product Analysis

2.4.1 Compositional Analysis

The functional group compositions of the pyrolysis liquid were analyzed by Fourier Transform Infrared spectroscopy (FTIR) to identify the basic compositional group. The FTIR instrument of model SIMADZU FTIR 4500 and an on-line pen plotter were used to produce the ir-spectra of the derived oil. A thin uniform layer of the liquid was placed between two salt cells and exposed to infrared beam. The absorption frequency spectra were recorded and plotted. It provided the absorption spectrum in percentage incident intensity, along the wave numbers 4000 to 500 cm^{-1}. The standard ir-spectra of hydrocarbons were used to identify the functional group of the components of the derived liquid. The test was conducted in the laboratory of the department of Chemistry of Rajshahi University.

2.4.2 Physical and Chemical Analyses

The pyrolysis oil at the maximum liquid yield condition was characterized for its physical properties. These properties were determined according to the standard of American Society of Testing Materials (ASTM) test methods. The properties determined were: kinematic viscosity, density, pH value, flash point, pour point and gross calorific value. The elemental analysis of the oil was conducted at the Analytical Research Division of BCSIR, Dhaka. The elemental composition of the derived oil was determined using a Carbon, Hydrogen, Nitrogen and Sulfur (CHNS) elemental analyzer of model EA 1108. Oxygen was calculated by difference.

3. RESULTS AND DISCUSSION

3.1 Characteristics of Scrap Tyre

Table 1 shows that volatile content in the scrap tyre was 62.70 wt% of the sample. This higher percentage is usually favorable to obtain liquid by pyrolysis technology. Hazardous product creating agents, such as sulfur and nitrogen were not found in the elemental analysis. The TG plot presented in Figure 1 shows that heat propagated into the solid drove off the inherent moisture at about 110^{o}C, which was less than 1% of the total sample weight. From the plot it was found that at a heating rate of 10^{o}C/min, devolatilization of solid scrap tyre was initiated at about 250^{o}C and the rate was maximum between temperatures 300^{o}C and 450^{o}C. At a temperature of less than 700^{o}C, devolatilization of volatile in the sample was completed. From these results the idea to operate the pyrolysis system at a moderate temperature of around 600^{o}C was realised to obtain maximum percentage of liquid product.

3.2 Product Yields

Three products were obtained from the pyrolysis of scrap tyre. These were liquid, solid char and gas. The liquid obtained from scrap tyre was a single-phase dark brownish color product of acrid smell. The liquid product was collected in two ice-cooled collectors connected in series. The char was collected from the reactor that retained the original geometrical shape of the scrap tyre feedstock. The gas was flared to atmosphere. It was measured by difference. The water was not removed from the liquid since evaporation or distillation at normal temperature of around 100^{o}C or higher can cause significant and potentially deterious physical and chemical changes in the liquid [7].

3.3 Effect of Operating Conditions on Product Yields

3.3.1 Effect of Operating Temperature

Pyrolysis of scrap tyre produced a maximum yield of 64 wt% of oil, 32 wt% of solid char and 4 wt% of gas at an operating temperature of 450°C for feed particle size of 3-5 cm. The effect of variation of operating temperature on the pyrolysis product derived from scrap tyre is presented in Figure 3. From the plotted result it is apparent that a fairly sharp optimum exists in temperature at which maximum yield of liquid is achieved. The liquid yield rises sharply from about 45% of the fed at a low temperature of 400°C to a maximum value of 64% at 450°C; then it drops to about 40 % at a operating temperature of 550°C. It can be postulated that the decrease of liquid yield at higher temperatures is due to the rapid increase of gas yield, since the char product at this temperature also decreases. The reason behind this trend according to pyrolysis theory is that at higher temperatures secondary decomposition reaction takes place which produces more gaseous products.

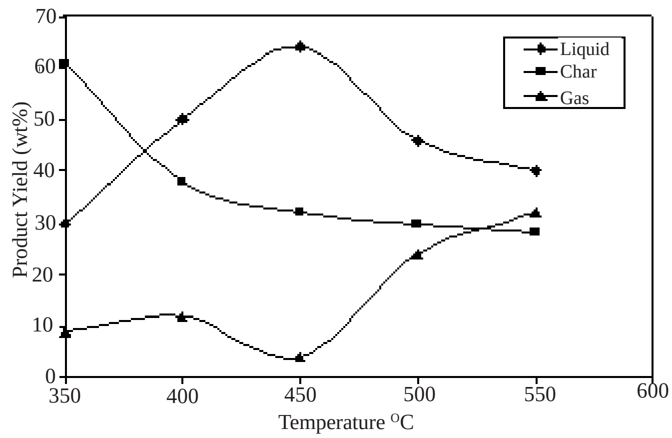

Fig. 3. Effect of temperature on product yields for particle size of 3-5 cm of scrap tyre pyrolysis

3.3.2 Effect of Feed Size

Figure 4 shows the liquid yield for three different feed size respectively. From the plotted result it is found that the oil yield is the highest for larger feed size (3 to 5 cm). The maximum liquid yield

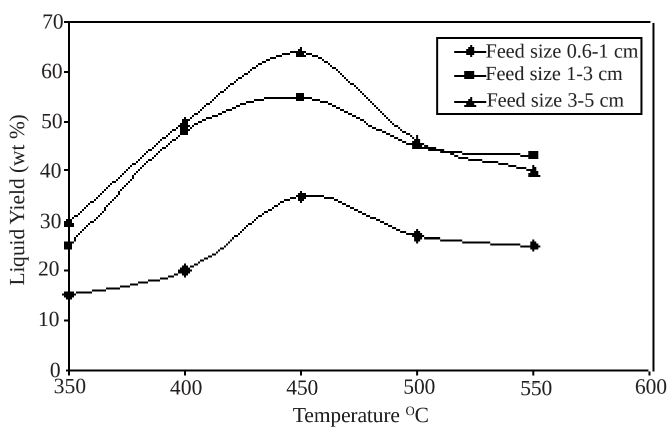

Fig. 4. Effect of feed particle size on the liquid yield for pyrolysis of scrap tyre

from the finest feed might be lower due to fact that the finer feed was blown out of the reactor in a shorter time, too quick for the total devolatilization to be completed.

3.3.3 Effect of Running Time

The effect of variation of running time on liquid yield is presented in Figure 5. The plotted result shows that the liquid yield increases with the increase of running time. It reaches the maximum value of liquid yield at 75-80 min. After this, the liquid yield remains constant. It may be concluded that at this running time the volatile content in the feedstock was fully disposed gap of.

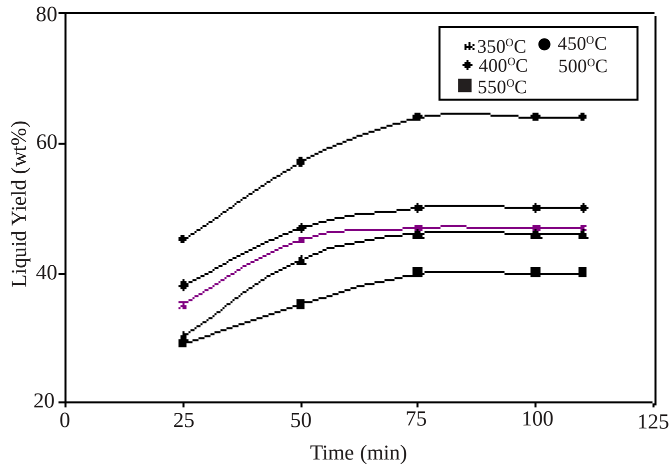

Fig. 5. Effect of running time on liquid yield for pyrolysis of scrap tyre

3.4 Oil Product Analysis

3.4.1 FTIR Analysis

The absorption frequency spectra representing the functional group, composition analysis of the scrap tyre pyrolysis oil is presented Table 2. The strong absorbance peaks of C-H vibrations between 3000-2800 cm^{-1}, 1150- 1000 cm^{-1} and the C-H deformation vibration between 1425- 1325

Frequency range (cm^{-1})	Group	Class of compound
3000-2800	C-H stretching	Alkanes
1775-1680	C=O stretching	Ketones, Aldehydes, Carboxilic acids
1680-1575	C=C stretching	Alkenes
1575-1425	$-NO_2$ stretching	Nitrogenous compound
1425-1325	C-H bending	Alkanes
1300-1175	C-O stretching O-H bending	Primary, secondary and tertiary alcohols, phenol, esters and ethers.
1150-1000	C-H bending	Alkanes
950-875	C≡C stretching	Alkynes
900-650		Aromatic compounds

Table 2 The FTIR Functional Groups and the Indicated Compositions of Pyrolysis Oil

cm^{-1} indicate the presence of alkanes. The absorbance peaks between 1775-1680 cm^{-1} represents the C=O stretching vibration, indicating the presence of ketones and aldehydes. The possible presence of alkenes are indicated by the absorbance peaks between 1680 - 1575 cm^{-1} and 1300-1175 cm^{-1} presenting C=C stretching vibration and the presence of alkynes between 950 - 875 cm^{-1} representing C=C stretching vibrations. Absorbance peaks between 900 - 650 cm^{-1} indicate the possible presence of single, polycyclic and substituted aromatic groups. The presence of nitrogenous compound of $-NO_2$ stretching may be due to the absorbance peaks range 1575-1425 cm^{-1}. From the FTIR analysis it is found that oil obtained from scrap tyre consists most of the hydrocarbon compounds. The presence of hydrocarbon groups C-H; C=C; and alcohols indicate that the liquid has a potential to be used as fuel.

3.4.2 Physical and Chemical Properties Analysis and Its Comparison

The oil obtained from fixed bed pyrolysis of scrap tyre was analysed for some physical and fuel properties. Table 3 shows the characteristics of scrap tyre pyrolysis oil in comparison to petroleum fuels such as diesel and heavy fuel oil. The elemental analysis shows that the carbon and hydrogen content of the derived oil is close to that of the petroleum fuels. The ash content in the oil is very low which is 0.06% and there is no sulfur and nitrogen in the oil, suggesting that it does not produce hazardous SO_x and NO_x emissions after combustion. The low viscosity of the oil of 4.89 cSt at 35°C is a favorable feature in handling and transportation of the oil. The density of the derived oil is in between that of diesel fuel and heavy fuel oil. The most significant property is the heating value of the oil that is 41.50 MJ/kg, closer to that of diesel fuel reflecting the high potential of the oil for utilization as a fuel.

Table 3 Characteristics of the Scrap Tyre Oil in Comparison to Petroleum Products

Analysis	Scrap tyre oil	Fast diese [1]	Diesel [2]	Heavy fuel oil [3]
Elemental (wt%)				
C	80	86.1	86.58	85 to 86
H	6.33	12.8	13.29	11 to 1.5
N	-	-	65 ppm	0.3 to 0.5
S	-	0.5	0.11	1.0 to 2.6
Ash	0.06	0.01	0.0	0.1
O	13.67	-	0.01	-
Viscosity at 35°C (cSt)	4.89	1.3 to 3.3#	2.61*	200#
Density (kg/m³)	965.0	780	821.1*	980*
Moisture (wt%)	0.1	-	79 ppm	0.1
PH value	4.25	-	-	-
Flash point (°C)	32	75	53	90 to 180
Pour point (°C)	-25	-	-	25 to 30
HHV (MJ/kg)	41.5	45 to 46	45.18	42 to 43

@ 50°C; * @ 20°C;

4. CONCLUSIONS

- Fixed bed pyrolysis of scrap tyre produces a maximum oil yield of 64 wt% of dry feedstock at an operating temperature of 450°C at atmospheric pressure with a sample size of 3-5 cm.
- The elemental composition of the oil is almost similar to that of diesel fuel.
- FTIR analysis of the scrap tyre pyrolysis oil indicate the presence of alkanes, alkenes, ketons/ aldehydes, aromatic and substituted aromatic groups.
- The physical properties analysis shows that the oil is acidic in nature with kinematic gap viscosity and density in between that of diesel and heavy fuel oil.
- The heating value of the oil is almost similar to that of petroleum products suggesting that the oil

may be used as a fuel.

5. ACKNOWLEDGEMENTS

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6. NOMENCLATURE

CHNOS	=	Carbon, Hydrogen, Nitrogen, Oxygen and Sulfur
FTIR	=	Fourier Transform Infrared
ASTM	=	American Society of Testing Materials
TGA	=	Thermo Gravimetric Analysis
TG	=	Thermo Gravimetric
O-H	=	Hydroxyl Stretching
C-H	=	Carbon Hydrogen Stretching and Bending
C=O	=	Carbonyl Stretching
C=C	=	Carbon carbon double bonding stretching
C=C	=	Carbon carbon triple bonding stretching
$-N_2O$	=	Nitrogen dioxide stretching
C-O	=	Carbon oxygen stretching

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