Production of Liquid Fuel from Pyrolysis of WasteTires

Md. Shameem Hossain*, Dr. A. N. M. Mizanur Rahman*

ABSTRACT— Worldwide energy crisis forced the researchers to explore for new and alternate sources of energy. For the developing countries this problems are acute. Generation of any kind of waste is a problem to the environment. Some wastes have the characteristics of producing energy by different thermochemical conversion. In the present work, waste tires were pyrolysed in a fixed bed reactor. The influences of pyrolysis temperature, heating rate, operating time, sample size etc. on yield were investigated. The pyrolysis of tire was carried out within the temperature range of 300ºC to 600ºC. The optimum pyrolytic oil of 42.0% was obtained for tire pyrolysis at 450ºC. Higher temperature and smaller particle size increases the heating rate that resulting a decreased char yield. The cracking of hydrocarbons, resulting increased H_2 content in the gaseous product, is favored by a higher temperature and smaller particle size. The physical properties of the pyrolytic oil were examined. The oil obtained was analyzed for their fuel properties compared with other petroleum products. The density and viscosity of the liquid was 935.1 kg/m^3 and 6.95 cSt at 40°C, respectively. The higher calorific value of the liquid was about 37.98 MJ/kg. The properties of pyrolytic liquid were much closer to that of conventional furnace oils. It could be concluded that pyrolysis of waste tires may be a potential source of alternative fuels.

Keywords — Mini Pyrolysis plant, Fixed bed Reactor, Tire pyrolysis, Electrical heater, Pyrolytic oil, Non-biodegradable material, Condenser.

1. INTRODUCTION

BANGLADESH is a developing and most densely populated country in the world with a total population of about 156.6 million. Her per capita energy consumption is much below the world average. Energy consumption mix is estimated as: indigenous biomass 60%, natural gas 27.45%, oil 11.89%, coal 0.44% and hydro 0.23%. More than 77% of the country's population lives in rural areas and meeting most of their energy needs from traditional biomass fuels. Around 32% have access to electricity, while in rural areas the availability of electricity is only 22%. Only 3–4% of the households have connection of natural gas for cooking. About 2–3% households use kerosene for the same and the rest (over 90%) depend on biomass for their energy needs [1]. Thus, it is crucial to find out alternative and sustainable resources to mitigate the energy crisis.

Recent environmental issues and energy security have been emerged as public and political concern which led to alternative way of thinking and renewable energy sources may be an indigenous source of that kind of thinking [2]. As energy demand is becoming acute day by day, scientists are giving efforts on the potentials of utilizing appropriate technologies to recover energy and useful by-products from domestic and industrial solid wastes. Researchers have been conducted for biodegradable and non-biodegradable waste materials. Rubber and plastics are non-biodegradable. About 20.50 million bicycle/rickshaw tires become scrap every year and wait for disposal which is about 37%(wt) of total tire waste production in Bangladesh. It is estimated that 30,750 tons bicycle/rickshaw tires, 5160 tons motorcycle tires, and 28,900 tons bus/truck tires become scrap and are disposed of every year [3]. Disposal of waste tires causes typical problems for environment. Dumped scrap tire in massive stockpiles is one of the possible causes of ideal breeding grounds for disease carrying mosquitoes and other vermin with the aid of rain water deposited in the free space of tire wall. On the other hand, if tires are left in open air may result in significant disturbances and dangerous situations like risk of fire. If the scrap tires burn directly in brick fields or any other incineration plant then various harmful gases such as, CO2, CO, SOx, NOx, etc. will produce which cause environmental pollution. Thus, an environmental friendly and economic technology should be developed for effective dispose of waste tires as well as to recover energy from it if possible. Different alternative techniques have been using for recycling the waste tires such as retreating, reclaiming, incineration, grinding, etc. However, all of them have significant drawbacks and limitations [4]. Different means are available for disposal of waste tires and one relatively effective way is pyrolysis of there.

Pyrolysis, an attractive method to recycle scrap tires, has recently been the subject of renewed interest. Pyrolysis of tire can produce oils, chars, and gases. The oil from pyrolysis is known as pyrolysis oil or pyrolytic oil orpyrolytic liquid in addition to the steel cords, all of which have the potential tobe recycled. Tire pyrolysis liquids (a mixture of paraffin's, olefins and aromatic compounds) have been found to have a high gross calorific value of around 41–44 MJ/kg, which would encourage their use as replacements for conventional Liquid fuels [1]. Roy et al. [5-7] compared the derived oil from tire pyrolysis with petroleum naphtha; the conclusion was

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that the naphtha from the derived oil had a higher octane number than petroleum naphtha but must be hydrofined and reformed in order to be used as a clean fuel. However, the high concentration of aromatic hydrocarbons [8-9] limited the derived oil from tire pyrolysis to be used as fuel.

Pyrolysis is a thermochemical process and is generally described as the thermal decomposition of the organic wastes in the absence of oxygen at temperature about 400°C. Three products are typically obtained from the organic solid wastes: liquids, solid char and gases. The pyrolysis of solid tire wastes has received increasing attention because the process conditions may be optimized to produce high energy density liquids, char and gases [10].The main purpose of this research work is to design a self-sufficient pyrolysis pilot plant for production of liquid fuel from solid tire waste by using pyrolysis technology.

2. Materials and methodology

The raw materials used, their preparation and the methodology of the experiment are briefly discussed in the following subsections.

2. 1 Preparation of Feed Materials Preparation

The raw materials used as feedstock for the pyrolysis were waste bus-tire. The tires were collected from the nearby bus repairing garage at Ferighat, Khulna, Bangladesh. In order to maintain the uniformity of the components in the representative samples of tire, same brand tires were chopped cross-section wise into four different sizes, such as, 1.00×1.00×0.75cm; 1.00×1.75×0.75cm; 2.00×1.00×0.75cm and 2.00×1.50×0.75cm. These small pieces could be considered as the representative of the whole sample. They does not contain any steel cords but the textile fabrics. Before loading to the reactor, the samples were washed properly to remove any mud or foreign materials.

2.2 Experimental Set-up

Batch type fixed-bed pyrolysis reactor was selected for the study. The main reactor chamber was constructed from 0.7 mm thick MS sheet having a length of 56 cm. The outer diameter of the chamber was 16.7 cm. Fig.1, shows the schematic view of the experimental set up. The major components are fixed-bed reactor chamber, the electrical heating elements for maintaining the temperature inside, the water cooled condensing coil to convert the condensable vapour to pyrolytic liquid, the gravity feed type reactor feeder, the liquid collecting steel bottle, N_2 cylinder with connection pipes; K-type thermocouples with temperature indicator. A distributor plate was fitted to support the feedstock, which is at a distance of 30 mm from the bottom of the reactor chamber. The distributor plate was made of stainless steel having 90 holes of 2.5 mm diameter each. The N_2 gas inlet was below the distributor plate. Four 10 mm diameter tube-heater of 500W each is used in the heating element. These heaters can be controlled with separate switches. The reactor surface was thermally insulated with glass wool and asbestos rope.

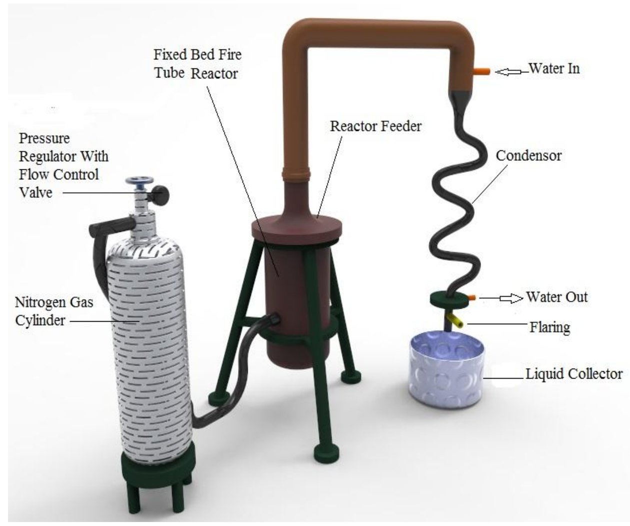

Fig.1: Shows the schematic view of the experimental set -up

2.3 Experimental Procedure

The experiments were conducted by varying the temperature within the range of 300-600°C at every 50°C interval for different feed sizes of the raw material. The thermocouple sensors were protruded inside the reactor chamber to record the temperatures inside. A mass of 1.5 kg of the sample was taken in the reactor in each run. The loading of samples were made by gravity. Before the start of the experiment, the reactor was purged by flowing N2 for 2 minutes to remove the inside air. The reactor heater was switched on and the temperature of the reactor was allowed to rise to a desired value of 300°C indicated by the temperature indicator. The temperatures were noted from the digital display during the experiments. During pyrolysis of tire, a reddish/bright brown visible vapor usually flared into atmosphere. Nitrogen gas supply was continued in order to maintain an inert atmosphere inside the reactor and also to sweep away the pyrolysed vapor product to the condensers. Pyrolytic vapor then passed through the condenser pipes to condense them into pyrolytic liquid and then collected in the bottles. The uncondensed gases were flared to the atmosphere. When the bottles were completely filled up with liquid so that no air was trapped inside the bottles they were taken out. When the decomposition was completed, colorless gas came out from the reactor. The colorless flaring was the significance of the completion of thermal decomposition of the tire sample inside the reactor. When pyrolysis was completed, the vapor exit port was closed and the reactor heater was switch off and N_2 gas supply was also stopped .After cooling down the system, the char product was brought out from the reactor chamber. The char was collected in the collection bagand weighed. The liquid was taken then

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weighed and uncondensed gas weight was determined by subtracting the sum of the liquid and char weight from the total weight of feedstock. Afterwards, the system was made ready for next run.

3. Result & Discussion

The result and discussion are described in the following section.

3.1. Effect of Temperature on Product Yield

For the pyrolytic conversion of waste tire in batch type fixed-bed reactor, as mentioned before, the experiments were conducted in the temperature range of 300°C to 600°C. The experiments were conducted to examine the effect of pyrolysis temperature on product yield. The effects of temperature on pyrolytic products obtained from waste tire are shown in Fig. 2 to 5.

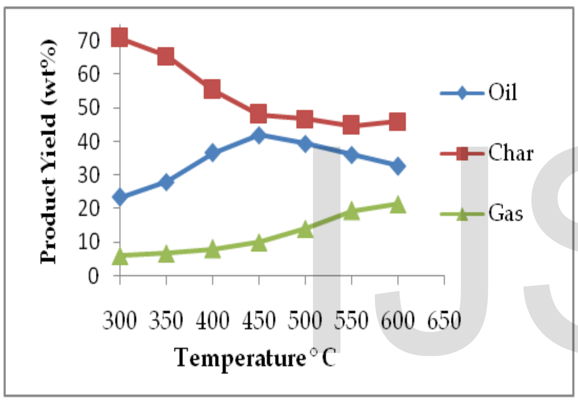

Fig.2. Effect of temperature on product yields for tire pyrolysis with feed size 0.75 cm3

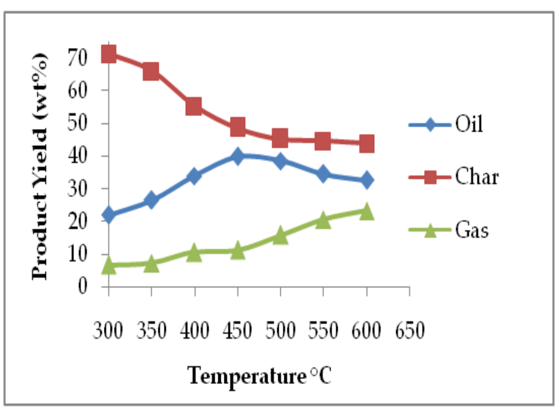

Fig 3: Effect of temperature on product yields for tire pyrolysis with feed size 1.31 cm3

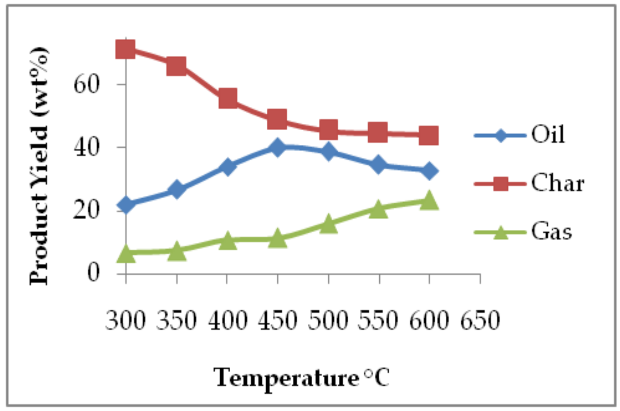

Fig 4: Effect of temperature on product yields for tire pyrolysis with feed size 1.50 cm3

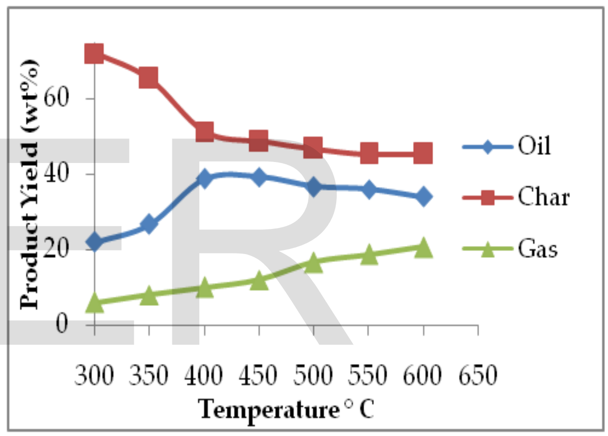

Fig 5: Effect of temperature on product yields for tire pyrolysis with feed size 2.25 cm3

The three types of products i.e., liquid oil, solid and gas were obtained. It is observed from figures that with the increase in temperature the liquid production rate increases until it reaches a maximum and then decreases. All the curves from Figs. 2 to 5 show similar nature. Among the four samples the best result was obtained with feed size of 0.75 cm3 (i.e., 1cm ×1cm×0.75cm). The result of which is shown in Fig. 2. The maximum oil yield of about 42.0% (wt) was obtained at 350oC from pyrolysis of waste tires. The yield then decreases to 32.67 % (wt) at a temperature of 600°C.

The gas yield increases over the whole temperature range to a maximum value of 21.33% at 600°C, while char yield decreases up to 450°C and then remains almost constant. This is probably due to better cracking of the tire at this temperature and rubber of the tire is not completely decomposed (pyrolysis is not complete) at a temperature less

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than 450°C. Further it was observed that solid yield decrease, liquid and gas yields increases. This is probably due to complete thermal decomposition of rubber. It was apparent that at lower temperature the tire was partially pyrolysed to produce less oil and volatiles with maximum retention of material in solid form as char.

3.2 Effect of Sample Size on Product Yield of Tire

The effect of sample size on product yield of tire pyrolysis under optimum reactor temperature (450°) is presented inFig.6. The weight fractions of liquid oil, char and gas produced were plotted together with sample size. The figure shows that liquid yield from tire first slightly increases up to a maximum value of 42.0% (wt) for sample size of 0.75cm3 and then decreases for larger sample while the char yield increases and gas yield decreases through all the sample sizes from 1.31 to 2.25cm3. Smaller sample size provides more reaction surface causes high heating rate and too quick decomposition of the rubber sample. From Fig. 6 it is also observed that liquid yield is a maximum for sample size of 0.75 cm^3.

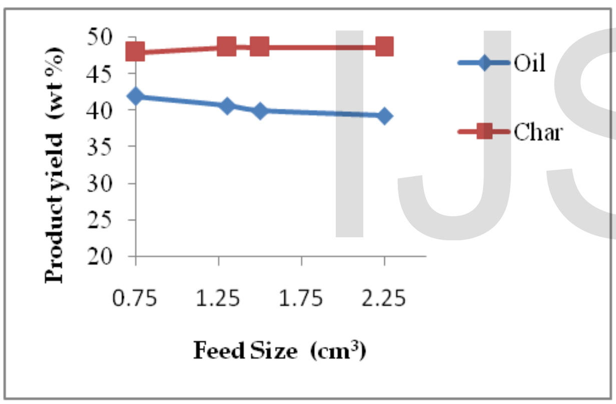

Fig 6: Effect of feed size on product yields at 450°C of pyrolysis of waste tire

The oil vapor comparatively get enough time for secondary reaction in the reactor and consequently increase gas yields and decrease the liquid and char yields. On the other hand, the heating rate in larger sample size is low due to its lower thermal conductivity and heat can flow only to a certain depth in the available pyrolysis time compared to Thus, the rubber core of the larger pieces becomes carbonized and/or cannot be decomposed completely resulting increase in char yields and decrease in liquid and gas yields. This confirms the results obtained in [11].

3.3 Effect of Operating Time on Product Yield

The effect of operating time on product yield is shown in Fig. 7. From Fig.7, it is observed that more operating time was required to complete the conversion which results in incomplete deploymerisation of the sample that leads to production of more char and less amount of oil. As less operating time was required to complete the conversion, that leads more oil and less char. There is no obvious mechanism for gas loss with operating time. It was also observed that low temperature and longer operating time contributes to secondary pyrolysis of primary products, which leads less oil and more char products as obtained in [12].

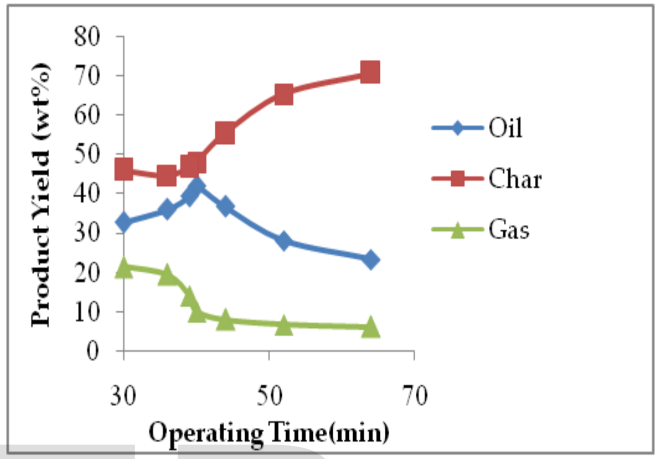

Fig 7: Effect of operating time on product yield for tire pyrolysis with feed size 0.75 cm3

3.4 Elemental Analysis of Pyrolytic Oil

Elemental analysis of pyrolytic oil is very important to find out various properties. Elemental analysis of pyrolytic oil is carried out and the results are shown in Table 1.

TABLE 1
ELEMENTAL ANALYSIS (C, H , N, S) OF PYROLYTIC OIL

Elemental Analysis	Pyrolytic oil
Carbon (wt %)	87.46
Hydrogen (wt %)	1.173
Nitrogen (wt %)	3.91
Sulfur (wt %)	5.669
Others	1.788

3.5 Comparison of Pyrolysis Liquid with Petroleum Products

The fuel properties of oil derived from waste tire were analyzed and compared with that of furnace and diesel oil is presented in Table 2.

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TABLE 2
COMPARISON THE PROPERTIES OF PYROLYTIC OIL WITH CONVENTIONAL DIESEL AND FURNACE OIL

Physical Properties	Pyrolytic oil	Reference with	
		Diesel	Furnace oil
Density (kg/m3), 30°C	935.1	820 to 860	890 to 960
Kinematic Viscosity @40°cSt	6.59	3 to 5	45
Flash Point °C	37	≥ 55	70
Pour Point °C	-7	-40 to -1	10 to27
Gross Calorific Value (MJ/Kg)	37.98	42 to 44	42 to 43

The table shows that the density of pyrolytic oil was found 935.1 kg/m3 for tire and commercial furnace oil is (890 to 960 kg/m3) which is higher than that of commercial diesel (820-860 kg/m3) and petrol (700-800 kg/m3). This is attributed to the presence of heavier compounds in both the pyrolysis oil. The viscosity of liquid products from the waste tire (6.59 cSt @40°C) was slightly higher than that of the diesel (3 to 5 cSt @ 40°C) but too much lower than that of furnace oil (45 cSt@40°C). Low viscosity of the liquids of 4.62-4.90 cSt at30°C is a favorable feature in the handling and transporting of the liquid. But the flash and pour point is slightly higher than that of diesel fuel. Gross calorific value (GCV) of the pyrolytic oil is 37.97MJ/kg respectively is slightly less than that of diesel and gasoline.

3.6 Compositional Group Fourier Transform Infra-Red (FTIR) Spectroscopy

The functional group compositions of the pyrolysis liquids were analyzed by Fourier Transform Infra-Red (FTIR) spectroscopy to identify the basic compositional group. The standard FTIR spectra of hydrocarbons were used to identify the functional groups of the components of the pyrolysis oil, The FTIR results are shown in Table: 3.

4. CONCLUSION

Under this study, the recovery of value added products, i.e., pyrolysis oil from waste tire was investigated. A few trial runs have been made at various operating condition for the maximum liquid production. The maximum yield of pyrolytic oil from the waste tire was 42.0 % (wt) at a temperature of 450°C with the tire size of 0.75 cm3for total load of 1.5 kg. Physical properties of pyrolytic oil are comparable with that of diesel and furnace oil. It was found that some properties were much closer to diesel fuels and other conventional fuels. The pyrolytic oil obtained from waste tire was investigated with FTIR four groups: alkane, alkenes, alkynes and aromatic compound. Considering all these results, it can be concluded that the oil obtained from pyrolysis of wastes tire can be used as an alternative fuel.

TABLE 3
FTIR FUNCTIONAL GROUPS AND THE INDICATED COMPOUND OF PYROLYTIC OIL

Absorbance Range (cm-1)	Functional Group	Class of Compound	Without Catalyst
3200-3650	O-H	Alcohol, phenol, Carboxylic acid	3300-3700
3300-3500	N-H	Amines	
2850-2960	C-H	Alkanes and Alkyl group	2800-3000
1660-2000	C=C	Aromatic	1600-1700
1450-1600	C-H	Alkanes	1450-1600
1325-1425			1300-1450
1175-1300	C-O	Primary, esters and ethers	1030-1370
1000-1150	C-H	Alkanes	966-1030
875-950	HC≡CH	Alkynes	812-966
600-950		Aromatic compound	752-812

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