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Biofuel from Co-pyrolysis of Solid Polythene Waste and Saw dust

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ABSTRACT

This study focused on the conversion of solid polythene waste and saw dust into biofuels and chemicals by externally heated fixed-bed co-pyrolysis reactor. The solid polythene waste and saw dust were characterized through proximate and ultimate analysis, gross calorific values and thermo-gravimetric analysis to investigate their suitability as feedstock for this consideration. The collected solid polythene waste chipped and then mixed with saw dust at different blends. The mixtures of solid wastes were fed into the reactor and the products were oil, char and gases. The liquid and char products were collected separately while the gas was flared into the atmosphere. The process conditions were varied by the percentage of polythene in the blends at reactor temperature 450°C. The variation of polythene waste in feed blends was found to influence the product yields and feedstock to oil energy conversion efficiency (FOECE) significantly. The maximum liquid of 80wt% was obtained from 100% polythene and minimum liquid of 36 wt% from 100% sawdust. The percentage of liquid was decreasing with increasing amount of sawdust in the blends at the same time the wt % of char and gas were rising with the fraction of saw dust within the blends. The condensed pyrolytic oil was analyzed for its fuel properties. The heat value of the liquid oil obtained from 50% polythene and 50% sawdust blend is 33600 kJ/kg. The analysis results showed that the oils have compatible viscosity and high heat value which are comparable with the conventional petroleum oil.

Keywords: Biofuels; Polythene waste; Saw dust; Co-pyrolysis.

1. Introduction

The propeller of the modern civilization and its development depends mainly on energy. Now a day “Energy” has become a global concern. Energy can be obtained from various sources among them fuel is the most common. The main focus of this study is to explore the alternative source of fuel which will be manufactured from polythene and sawdust. In Bangladesh there is a huge amount of biomass solid wastes from agricultural by products or industrial wastes that are not effectively and efficiently using.

Bio mass and thermo plastic materials constitute an important fraction of municipal solid waste. In twelve European countries the municipal solid wastes show an average composition of 65% lignocellulosic materials and 15% polymeric materials. The residues produced by intensive agriculture in green houses are also a mixture of vegetable and plastic materials, basically polyethylene and polypropylene [1].

Important amounts of agricultural and forestall residues are generated which industrial activities do not take advantage of and which could constitute an important source of energy. Plastic residues are not bio degradable and only a small fraction is recycled by the industry in question. Most of these products are buried in garbage dumps and in some cases incinerated, although the recycling of these materials is now an important alternative to landfill. Moreover, poly-olefins show very convenient characteristics for use in the production of composite materials such as polymers reinforced with natural fibers. The increasing use of these materials poses some important challenges for the thermal treatment of biomass plastic mixtures.

Thermo chemical recovery processes allow the obtainment of combustible gases and/or energy. Gasification and pyrolysis do not create the environmental problems caused by incineration, although the low energetic content of the gas obtained is a significant disadvantage [2]. The thermal decomposition of saw dust and other lignocellulosic residues has been studied in previous works, which indicate that the thermal decomposition ranges from approximately 200 °C to 400 °C in an inert atmosphere [3-5]. The co-pyrolysis of wood biomass–polyolefins was carried out in a rotating autoclave where it was found that, at 400 °C, more than 50% (in mass) of final products are found in the liquid phase for a 1:1 (in mass) mixture. The obtained liquids are separated in a distillable liquids fraction and in an extracted liquids fraction [6]. Aromatic hydrocarbons can be produced by the catalytic co-pyrolysis of biomass and high density polyethylene [7]. Numerous studies on the thermal decomposition of poly-olefins and in particular, polyethylene have been carried out especially in vacuum or inert atmosphere [8-11]. Poly-olefinic materials such as high density polyethylene (HDPE) show a different behavior to lignocellulosic materials. Under pyrolysis conditions, the material decomposition starts at approximately 400 °C and progresses very rapidly up to 450-470 °C without producing solid residue that could be used as combustible for supplying energy to the global process. The use of mixtures of bio mass with other fuels of greater energetic content (coal or petroleum derived) in these processes (co-pyrolysis or co-gasification) substantially increases the value of the gas produced and the thermal efficiency of the process. In addition, the use of a mixture of renewable fuel with

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fossil or fossil derived fuels reduces the total carbon-dioxide emissions and the environmental impact.

In this work, co-pyrolysis of high density polyethylene (HDPE) and saw dust mixtures have been performed in a fixed bed reactor. The upgrading of co-pyrolysis processes, it can play the role parallel to other conventional fuels. Since the conventional fuels have been diminishing very swiftly at a risky rate day by day the focus on alternative renewable sources of energy has been ever increasing. As a result biomass has been getting continued and increased attention. Biomass is a potential source of renewable energy. Besides it is a fact that the whole world is generating a significant amount of polythene and saw dust. Mostly these are underutilized and unutilized. In many places it is creating environmental and disposal problems as well. An attempt has been taken to convert these wastes into value added materials and energy by co-pyrolysis process. Pyrolysis is the thermal degradation of the organic components of solid wastes, at typical pyrolysis temperatures of 300°C-600°C to produce oil, gas and char products. The oil may be used directly as a fuel, added to petroleum refinery stocks, upgraded using catalysts to a premium grade fuel or used as a chemical feedstock. The gases from polythene pyrolysis are typically composed of C₁-C₄ hydrocarbons and hydrogen with a high calorific value, of sufficient energy content to act as fuel to provide the heat for the pyrolysis process. The solid char may be used as a solid fuel, as carbon black or upgraded to produce an activated carbon.

In general most urban wastes are a mixture of variety of waste components, which adds to the complexity of their treatment separately and also add additional cost in waste to energy recovery processes. It would be easier and cost effective if the waste mix would be converted into energy together.

The feedstock to oil energy conversion efficiency (FOECE) is one of the performance indicators for evaluation of successful pyrolysis techniques.

Feedstock-to-oil energy conversion efficiency (FOECE) is defined as the ratio of pyrolysis oil energy to the total energy of the feedstock, which is calculated using Eq. (1).

Conversion efficiency (FOECE)

$$\eta = \frac{Q_o \times W_o}{Q_p \times W_p + Q_s \times W_s} \times 100 \quad (1)$$

Where Q_p , Q_s and Q_o represent the heating values of rice husk, polythene waste and product oil; W_p , W_s , and W_o are the mass fractions of the rice husk, polythene waste, saw dust and product oil, respectively.

The objective of the presented study is to determine the optimum process condition for co-pyrolysis of polythene waste and saw dust blends. The influence of process parameters, on the yield and FOECE from the pyrolysis of different blends of wastes are studied. The liquid products from the co-pyrolysis of organic wastes are characterized for their fuel properties.

2. Materials and Methods

2.1 Feed Materials

Waste Polythene was collected locally from dumped site in Rajshahi City Corporation of Bangladesh. Polythene was then chopped and sized of 2cm×2cm. The sawdust sample was collected from a saw mill near Rajshahi city and used as feedstock. The sawdust contains some amount of moisture. The sawdust was sun-dried and finally oven-dried by an oven at a temperature of 110°C for 2 hours to remove moisture. The proximate and ultimate analysis and higher heating values of the waste polythene and saw dust are presented in Table 1.

Table 1. Proximate and elemental analysis, heat value of solid polythene waste and saw dust.

Proximate analysis [wt%]	Polythene Waste	Saw dust	Elemental analysis [wt%]	Polythene Waste	Saw dust
Moisture content	0.41	6.3	Carbon [C]	83.93	47.1
volatile	96.88	74.3	Hydrogen [H]	12.84	5.9
Fixed carbon	0.28	18.2	Nitrogen [N]	-	0.1
Ash content	2.43	1.2	Oxygen [O]	0.80	46.9
HHV [MJ/Kg]	47.74	20	Others	2.43	-

The TG/DTG plots for polythene waste and saw dusts are presented in Fig.1. From Fig.1 it can be seen that decomposition is completed for both of the samples around 550°C and decomposition rate is maximum at 360°C and 460°C for polythene and saw dust, respectively.

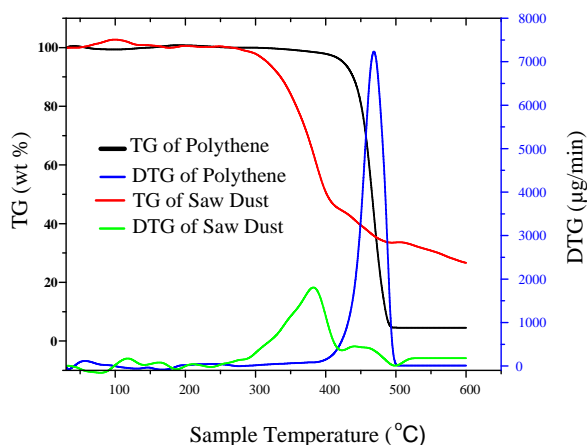


Fig. 1: TG/DTG plots of polythene waste and saw dust at heating rate 15°C/min.

2.2 Experimental section

The main components of the experimental set-up have been presented in Fig. 2. The experimental unit consists of major components: (i) a fixed-bed reactor chamber; (ii) condenser; (iii) a N₂ gas cylinder with a pressure regulator and gas flow meter; (iv) LPG cylinder with burner; (v) K-type (chromel-alumel) thermocouples with a temperature controller; (vi) water tank; (vii) liquid collector; (viii) oil reservoir; (ix) water circulating pump; (x) oil pump. The solid polythene waste and saw dust were blended together at weight ratio of 100:0; 75:25; 50:50; 25:75; and 0:100. By the action of gravity force the blended feed material was supplied into the reactor chamber. Then the reactor was purged before experiments by the flow of N₂ gas at 6 L/min for 5 min to remove air inside. The reactor heated by switching on LPG burner, and the sample was heated to a desired value of temperature of 460°C and hold at that temperature for 60 min, or no further visible vapor product coming out.

The TG/DTG results (Fig.1) give idea to run the reactor at an operating temperature of 460°C for the selected feed material blends.

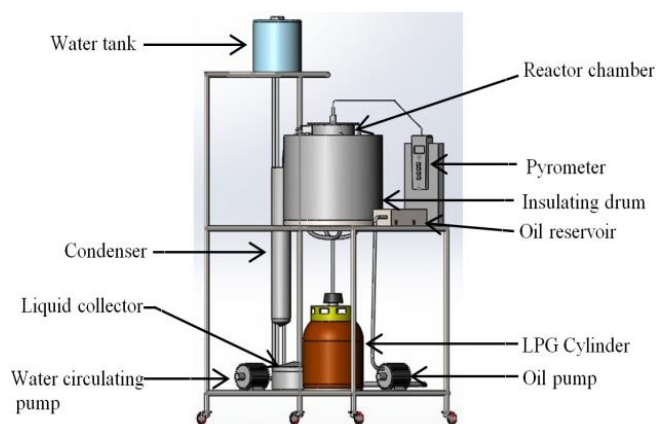


Fig. 2: Main components of the fixed-bed LPG heating pyrolysis system.

Nitrogen gas was supplied in order to maintain the inert atmosphere in the reactor and also to sweep away the pyrolyzed vapor product to the condensers. Pyrolysis vapor product were passed through the condenser to quench into liquid and then collected in the liquid collector. The uncondensed gases were flared to the atmosphere. When pyrolysis of the feed material in the reactor was completed, the vapor exit port was closed and, LPG burner was switched off. N₂ gas supply was also stopped. After cool down the system, the char product was taken out from the reactor chamber by opening char exit port. Char was collected in the char collection bag and weight. The liquid was then weighted and gas weight was determined by subtracting the liquid and char weight from feedstock. Afterward, the system has been made ready for next run. Before analyzing the liquid product was centrifuged at 3000 rpm for 15 min to remove heavy condensate and impurities.

2.3 Pyrolytic product liquid analysis

Pyrolytic liquids obtained under the maximum liquid yield conditions were well mixed and homogenized prior to analysis being made. Some physical properties of pyrolytic liquids: density, viscosity, flash point, pour point and HHV were determined by using the following standard method: ASTM D189, ASTM D445, ASTM D92, ASTM D97 and ASTM D240 respectively. The boiling point range distribution of hydrocarbons in the pyrolytic liquids was determined by using Thermo-gravimetric Analyzer (TGA) of model SATERAM-TG/DTG/DSC according to ASTM D2887-89 standard test method. The sample (15-20mg) was heated from ambient temperature to 550°C at a heating rate of 10°C/min in a high purity helium atmosphere at a flow rate of 100ml/min. The data obtained from TGA was used to evaluate the simulated distillation curves.

3. Results and Discussion

3.1 Pyrolysis product yields

From Fig. 3 it is shown that maximum liquid product of 80 wt% was obtained by using 100% polythene waste feed. On the other hand minimum amount of liquid product of 36 wt% was obtained from 100% saw dust feed. Consequently the maximum char and gas of 38 wt % and 26 wt% respectively were found from 100% saw dust feed.

The optimum blend of 50% polythene and 50% saw dust yielded 62.5 wt% liquid, 22 wt% gas and 15.5 wt% char. The liquid product yield decreases whereas char and gases product increasing with the increase of saw dust in the blends. It is also found from Fig. 3 that FOECE decreases with the increase of saw dust in the feed blends. 50 wt% polythene and 50 wt% saw dust mixture may be considered as optimum feedstock blend. Because, higher amount of saw dust than this blended feed results decrease of the liquid product very sharply. More or less similar results were found for co-pyrolysis

of polythene rubber and biomass by previous research groups [12].

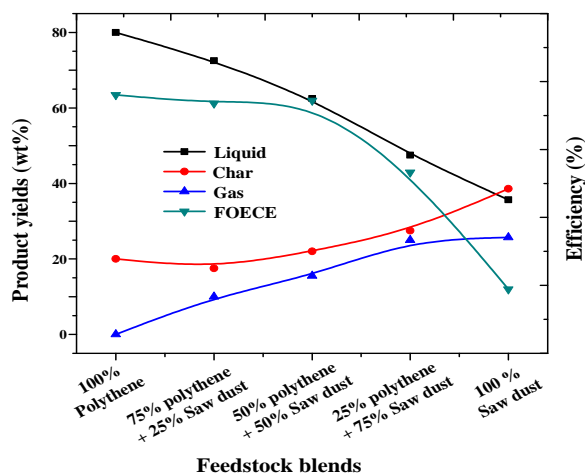


Fig. 3: Pyrolysis product yield distribution for different blends of polythene waste and saw dust

Navarro et al. [13] studied pyrolysis of three types of waste: They reported that the increase of reaction time increased alkane content both in gas phase from 53% to 70v% and in liquid fraction from 48% to 60wt%. The rise of reaction temperature led to a decrease of liquid yield (from 82% to 73wt %), which was followed by the increase of solids and gases. The increase of reaction temperature also allowed the increase of the alkane content in gas phase from 39% to 70v%. The parameter that most affected products yield and composition was plastics content on the wastes initial mixture. The enhancement of this parameter increased liquid yield from 33% to 92wt%, at the expense of solids and gases contents and also decreased aromatic contents from 52% to 28wt%.

Li et al [14] investigated co-pyrolysis of discarded rubber and plastics in a tube furnace. They observed that compared with the pyrolysis of rubber or plastics separately, the co-pyrolysis of rubber and plastics produced a higher oil yield with a higher oil heating value. When the mass fraction of the rubber was 60 wt%, the pyrolysis oil yield and reached their maximum values. When adding 10% stalk additive at a rubber-to-plastics ratio of 4:1, a higher oil yield was achieved, and the oil yield increased by 10.3 wt%, where the heating value of the pyrolysis oil reached 39.93 MJ/Kg. They concluded that the stalk additive only had a slight impact on the solid residue and the completeness of the pyrolysis reactions. The stalk additive increased the FOECE and postponed the highest yield point to the 80 wt% rubber blend because the greater volatility promoted the pyrolysis reaction and the production of condensable gaseous components.

3.2 Fuel properties of the liquid

The pyrolytic liquids obtained from co-pyrolysis of polythene wastes and saw dusts were characterized in

terms of fuel properties. Some properties of pyrolytic liquids obtained at reaction temperature 460°C in comparison to petroleum-refined fuels are shown in Table 2. Remarkably, only one phase is found in the liquid fraction, which is not achieved by mixture of the pure liquids. Density of pyrolytic liquids was found higher than that of the commercial diesel fuel but lower than that of heavy fuel oil. The viscosity of liquid products from co-pyrolysis was slightly higher than that of commercial diesel fuels. Low viscosity of the liquids of 5.80 cSt at 30°C is a favourable feature in the handling and transporting of the liquids. Flammability is the ease with which a substance will ignite, causing fire or combustion. Materials that will ignite at temperatures commonly encountered are considered flammable, with various specific definitions giving a temperature requirement. The flash point is the important characteristic. The flash point of co-pyrolysis derived liquids was 85°C. The flash point of the polythene-derived liquids is low when compared with petroleum-refined fuels. For example, kerosene has a required flash minimum point of 23°C, diesel fuel of 75°C and light fuel of 79°C.

The low flash point of the derived liquids are not surprising since the product liquids represents unrefined liquids with a mixture of components having a wide distillation range. A volatile liquids substance may have sufficient vapor pressure to form flammable mixture with air in tem. As low as -10°C, so ignition can occur even without direct contact. Examples of flammable liquids are gasoline, ethanol and acetone. The pH value of the limonene-rich is 4 to 5, which is in weak in acidic nature. It is found that there is very little contamination with some metals (V, Mn, Mg, Ba, Ni, Ti, Cu, Cr, Cd and Co), and does not contaminate with glass and PET plastic and/or other plastics. The pH value of soft drinks like Cola and Pepsi of Coca Cola Company is 2.5 and they use PET plastic bottles for its storage and handlings. Thus, storage and handling of the pyrolysis liquids are little problematic in industrial usage in regard. The pyrolytic liquids have higher calorific value (33 MJ/kg) than the used polythene and rice husk from which it is recovered (30 and 17 MJ/kg). The oil has a higher calorific value than that of bituminous coal (28MJ/kg) and wood charcoal (30MJ/kg). Table 3 shows that the polythene derived liquids exhibit a high content of carbon, leading to the production of high value carbon materials that are used in various industries (i.e. production of calcium carbide, steelworks, etc.) the important requirements for diesel fuel are its ignition quality, viscosity, water, sediment and sulfur contents. Using pyrolytic liquids as a fuels require preliminary treatments such as decanting, centrifugation filtration. The treated pyrolysis oil could be used alone or blended with other fuels such diesel, which will reduce viscosity and increase the pH value of the resulting blend. Consequently, the atomization will be improved, ensuring a complete burnout of the fuel. Based on its fuel properties, polythene-derived pyrolytic

liquids can be considered a valuable component for use with conventional fuels.

Table 2: Characteristics of the pyrolytic liquids in comparison to petroleum products

Analysis	polythene waste pyrolysis liquid	Saw dust pyrolysis liquid	Co-pyrolysis liquid	Diesel
Density [Kg/m ³]	708	798.75	662.5	803
Viscosity [cSt]	7.3	4.7	5.8	2.6
Flash point[°C]	80	99	85	60-80
Pour point [°C]	<-6.2	<-6.2	<-6.2	-33 to -15
HHV MJ/Kg	37.8	6.72	33.6	45.8

3.3 Boiling point distribution of the co-pyrolysis Liquids

The boiling point distribution of hydrocarbons in pyrolytic liquids from pyrolysis of heavy automotive polythene wastes at the temperature of 450⁰C is presented in Fig.4 as simulated distillation curve. For comparison purpose the simulated distillation curves of commercial gasoline and diesel fuel are also presented in Fig.4.

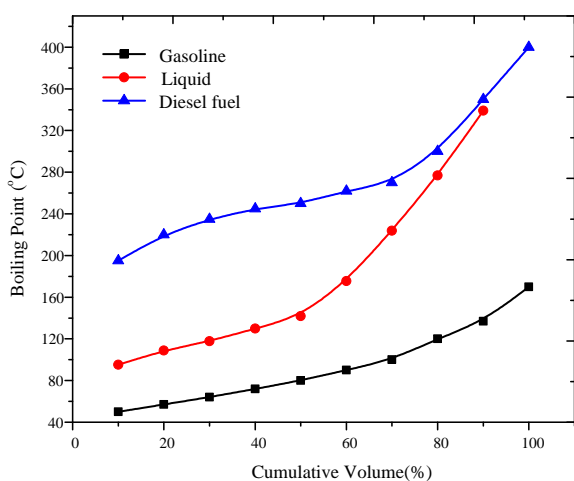


Fig. 4: Simulated distillation curve co-pyrolysis liquids compared to petroleum product.

The data shows that the pyrolytic liquids have a wide boiling point range. Pyrolytic liquids extracted from heavy automotive polythene waste contained about 20% gasoline fraction (boiling point range < 160⁰C). It showed be note that the boiling point of pyrolytic liquids throughout distillation is lower than the diesel fuel. Fig. 4 also shows that 10% of co-pyrolysis oil remains as residues due to presence of impurities.

4. Conclusions

The variation of polythene waste in feed blends was found to influence the product yields and FOECE significantly. The liquid product yield decreases whereas char and gases product increasing with the decrease of polythene waste in the blends. The FOECE decreases quickly with the increase of saw dust in the feed blends. The maximum liquid yields were 62.5 wt% for 50% polythene and 50% saw dust at reactor temperature 460⁰C for zero N₂ gas flow. Remarkably, only one phase is found in the liquid fraction, which is not achieved by mixture of the pure liquids. The results show that it is possible to obtained liquid products that are comparable to petroleum fuels from the selected wastes if the pyrolysis conditions are chosen accordingly.

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