

## PRODUCTION AND CHARACTERISATION OF PYROLYTIC OIL DERIVED FROM CO-PYROLYSIS OF SOLID POLYTHENE WASTE AND SAW DUST

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**Abstract-** In this study locally available biomass solid waste polythene and saw dust have been pyrolyzed in laboratory scale 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 (TGA) to investigate their suitability as feedstock. The collected solid polythene waste sized into 2cm×2cm and then mixed with saw dust (600-1600µm) at different ratio. The mixtures of solid polythene waste and saw dust were then fed into the reactor. The products obtained are pyrolytic oil, solid char and gases. The liquid oil and solid char products were collected separately but the gases were flared into the atmosphere. The process conditions were varied by the percentage of polythene in the mixture at reactor temperature 450°C-550°C. The product yields and feedstock to oil energy conversion efficiency (FOECE) were varied significantly with the variation of polythene waste in feedstock. The maximum liquid yield was 33 wt. % for mixture ratio 3:1 at a temperature 450°C while the minimum liquid yield was 23 wt. % for mixture ratio 1:3 at a temperature 500°C. On the other hand, about 50 wt. % and 20 wt. % liquid were produced for individual feed of polythene and sawdust. The wt. % of liquid was decreasing while the wt. % of char and gas were increasing with the increasing amount of sawdust in the feedstock. The condensed pyrolytic oil was collected and characterization of the pyrolytic oil was carried out by means of density, viscosity, higher calorific value, pour point, flash point etc. The heat value of the liquid oil obtained from 50% polythene and 50% sawdust blend is 33700 kJ/kg. From the study it is clear that the biomass solid waste polythene and saw dust have the potential to be converted into liquid oil as a source of renewable energy with some further upgrading of the products.

**Keywords.** Polythene waste; Saw dust; Co-pyrolysis.

### 1. INTRODUCTION

Now-a-days the demand of energy and crisis of it is the serious issues around the world. Because, the storage of conventional sources of energy (oil, gas, coal, etc.) is limited in the world, which is alarming for the modern world. By the year 2100, the world population is expected to be in excess of 12 billion and it is estimated that the demand for energy will be increased by five times from what it is now. Also it is estimated that petroleum reserve of the world will be exhausted by (2040) recent future [1]. So, our focus is on the alternative energy source. Biomass is the third most common energy source in the world after coal and oil. In the perspective of increase in energy demand, the high costs of fossil fuels and disposal problem, the environmental concern about emission levels of CO<sub>2</sub>, SO<sub>2</sub> and NO<sub>x</sub> in the atmosphere etc., the use of biomass providing partial substitution of fossil fuels for power generation is of continuing and increasing our attention. Biomass is a potential source of renewable energy. From total energy consumption, we get 6.9% from renewable energy and get only 3.3% from biomass that is about half of the total renewable energy [2]. In Bangladesh there are huge amount of biomass solid wastes from agricultural by products or industrial

wastes which are not effectively and efficiently using. 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. So 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 [3]. There are various parameters which plays a great role for optimizing liquid oil production in pyrolysis such as temperature, type of reactor, residence time, pressure, type and rate of fluidizing gas etc. If gaseous or char product was preferred, higher temperature more than 500 °C was suggested and if liquid was preferred instead, lower temperature in the range of 300-500 °C was recommended for all plastics [4]. Different plastic have different degradation temperature which depend on their structure. For common plastics such as PET, HDPE, LDPE, PP, PS, the thermal degradation temperature started at 350 °C but for PVC, the degradation started at 220 °C [5]. The bio-oil obtained from pyrolysis has some disadvantages like lower high-heat value (HHV), higher oxygen content, lower volatile and delayed ignition time in engine etc. The high oxygen content of bio-oil (usually

45 to 50 wt. %) prevents its use as fuel [3]. In this work, co-pyrolysis of high density polyethylene (HDPE) and saw dust mixtures have been performed in a fixed bed co-pyrolysis reactor. By up gradation of co-pyrolysis processes, it can play a great role parallel to other conventional fuels. The co-pyrolytic 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 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 Equation (1).

Conversion efficiency (FOECE)

$$\eta = \frac{Q_0 \times W_0}{Q_p \times W_p + Q_s \times W_s} \quad (1)$$

Where  $Q_p, Q_s, Q_0$  represent the heating values of polythene waste, saw dust and product oil.  $W_p, W_s$  and  $W_0$  are the mass fractions of the 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. 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. The original materials were crushed and pulverized to a size of <2 mm before they were analyzed. The TG/DTG plots for polythene and saw dust are presented in Figure. 1. from Figure. 1 it can be seen that decomposition is completed for both of the samples around 500 °C and decomposition rate is maximum at 250°C and 450°C for polythene and saw dust, respectively.

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	-

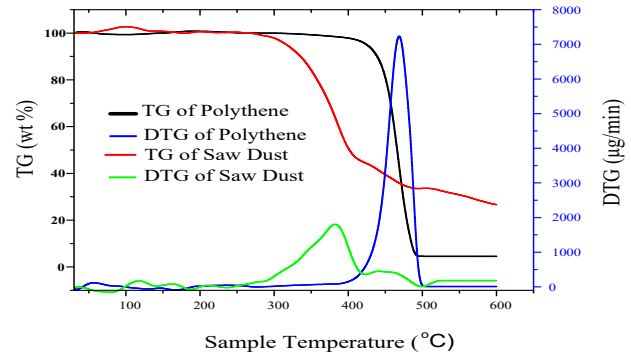
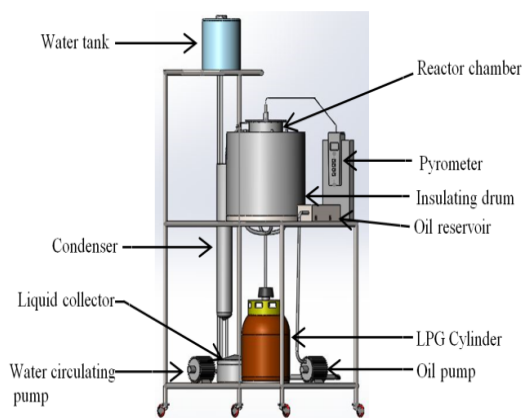


Fig. 1: TG/DTG plots of polythene and saw dust

## 3. METHODOLOGY

The main components of the experimental set-up have been presented in FIGURE 2. (a) The experimental unit consists of major components- a fixed-bed reactor chamber, condenser, LPG cylinder with burner, K-type thermocouple, water tank, liquid collector, oil reservoir, water circulating pump and oil pump. The reactor is made of stainless steel for its less corrosiveness having vapor residence time of 5s. The reactor is placed on the bed and covered by 7 LPG burner, each of them are 0.5 inch in diameter and 28 inch length. To reduce heat loss two layer of glass wool (insulating material) was used around the reactor. The temperature inside the reactor was measured by means of a K-type thermocouple which was inserted into the reactor chamber. A condenser pipe made of stainless steel having 5 turns of diameter 0.5 inch and length mm was connected upward portion of the reactor and placed into the water inside a condenser chamber which condensed the pyrolytic vapor passing through it. The water is circulate through a water circulating pump of .75 HP. The condenser pipe was inserted into the condenser chamber.



(a)



(b)

Fig. 2: (a) Main components of the fixed bed LPG heating co-pyrolysis system (b) Existing co-pyrolysis set up

The prepared sample waste polythene and sawdust were mixed together at a mixture ratio of 4:0, 3:1, 2:2, 1:3 and 0:4 and the reactor was fed with the blended feed materials. The reactor was closed tightly by means of nut, bolt and gasket so that the pyrolytic vapor could not get outside before condensed. The reactor was heated till no further visible vapor product coming out from the reactor and heated through a LPG burner at a temperature range 450-500°C which was predicted by means of TG/DTG results. The liquid products were condensed inside the condenser chamber and stored into the liquid collector. On the other hand, gases were flared to the atmosphere. The reactor was cooled and bio chars inside the reactor were collected. By subtracting the weight of liquid and char from feedstock the weight of gas product was determined. Several experimental runs were done by varying the operating conditions and every time the pyrolytic liquid was collected and measured. The proximate analysis was carried out according to the American Society for Testing Materials (ASTM) Standard D3172-73 (1984) test procedures for solid fuel and the ultimate analysis was carried out by an Elemental Analyzer of model EA 1108 according to the ASTM D3176-84 standard test

procedures in Bangladesh Council of Science and Industrial Research (BCSIR) laboratory, Dhaka, Bangladesh. The technique used for the determination of CHNS was based on the quantitative “dynamic flash combustion” method. The amount of carbon, hydrogen and nitrogen was determined and the oxygen content was calculated by difference. Some physical properties of pyrolytic liquids like density, viscosity, pour point, flash point and HHV were determined by using the following standard method: ASTM D189, ASTM D445, ASTM D97, ASTM D92 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 SATARAM-TG/DTG/DSC according to ASTM D2887-89 standard test method. The calorific value of the pyrolysis oil was measured using an oxygen bomb calorimeter.

#### 4. RESULTS AND DISCUSSION

The obtained major pyrolytic yields are presented in figure 3. It is clear from Fig.4 that the maximum pyrolytic oil (50 wt. %) and minimum char (0 wt. %) and gas (50 wt. %) were produced from 100% polythene.

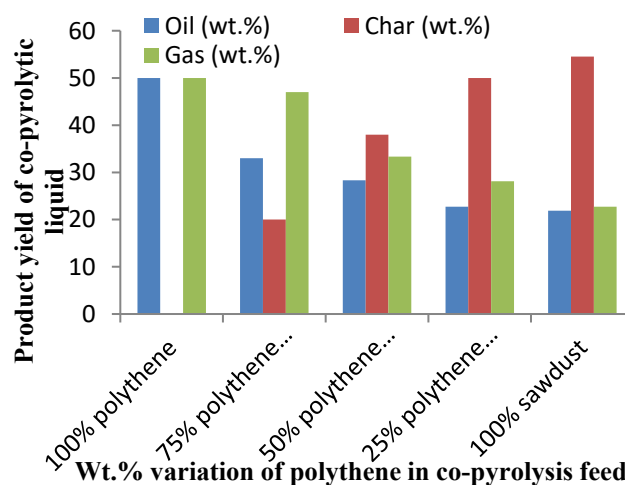


Fig. 3: Pyrolysis product yield distribution for different blends of polythene and sawdust

On the other hand, the minimum liquid (22 wt.%) and maximum char (54.54 wt.%) and gas products (22.72 wt.%) were obtained from 100% sawdust. 75% polythene and 25% saw dust blend can be considered optimum feed mixture as 33 wt.% liquid, 20wt.% char and 47 wt.% gas were produced. Finally without any hesitation it can be said that, the amount of pyrolytic oil increases as well as the char and gas products decreases with the increase of polythene in the feedstock blends.

#### 5. ANALYSIS OF FUEL PROPERTIES OF THE PRODUCT LIQUIDS

The oil obtained from co-pyrolysis of polythene and sawdust was homogeneous and there is no phase change occur in the storage bottles. The characterization of the co-pyrolytic oil was characterized in terms of density, viscosity, calorific value, pour point and flash point. The storage and utilization of the co-pyrolytic oil is greatly influenced by the moisture content in the feed stocks and pyrolysis conditions. The water content of the pyrolytic oil usually varies from 15 to 30 wt. %, depending on the initial moisture content in the feed stocks [6]. On the one hand, it increases ignition delay, lowers heating values, causes phase separation, and reduces combustion rates during the combustion process [3]. Besides, it also causes premature evaporation and subsequent injection difficulties during the preheating process and also create problem for atomization during combustion. The variation of density with wt. % variation of polythene in the blend is shown in Fig. 5. From Fig. 5, the highest density of the pyrolytic oil was obtained from 100% sawdust and it was 790 kg/m<sup>3</sup>. As the wt. % of sawdust increases in the blend, the density of the pyrolytic oil is also increases.

Similarly, from table 2 the maximum viscosity (7.4 CST) of the liquid yield was obtained from 100% polythene. The increase of the wt. % of sawdust in the blend decreases the viscosity of the pyrolytic liquid. The Fig. 6 represents the variation of calorific value with the wt. % variation of polythene and sawdust in the blend.

The highest calorific value (37500 kJ/kg) obtained from 0 wt. % sawdust and 100 wt. % polythene feed stoke blend. The wt. % increases of sawdust in the feedstock blend decreases the calorific value of the liquid. The fuel properties of the co-pyrolysis liquid are compared with various petroleum products are presented in Table 2. The comparison of pyrolytic liquid obtained from co-pyrolysis of polythene and sawdust with conventional fuel indicates its suitability whether it can be used as alternative fuel or not. The density of co-pyrolytic liquid was found lower than that of petrol, diesel and other alternative fuels. Besides, the viscosity of the co-pyrolytic liquid was higher than that of diesel and gasoline fuels but lower than the palm oil. The blends 0 wt. % polythene and 100 wt. % have the lower viscosity (4.8 cSt) which is considered as more suitable for handling and transporting of the liquid. Again the HCV of the co-pyrolytic liquid is lower than the conventional fuels. The HCV of the co-pyrolytic liquid of the polythene and sawdust is 37.5 MJ/kg. The substance which will burn, ignite and catch fire easily is considered as more flammable. Flash point is the lowest temperature at which vapors of the material will ignite in air, when given an ignition source. The flash point of the co-pyrolytic liquid is 84°C which is quite near to the flash point of the petroleum refined fuels. For example diesel fuel has the flash point of 75°C.

Table 2: The fuel properties of the pyrolytic oil compared to petroleum products

Feed Materials (wt. %)	Density (Kg/m <sup>3</sup> )	Calorific Value (kJ/kg)	Viscosity (cSt)	Pour Point (°C)	Flash Point (°C)
100% polythene & 0% sawdust	710	37500	7.4	<-6.2	79
75% polythene & 25% sawdust	728	33400	6.5	<-6.2	80
50% polythene & 50% sawdust	760.5	33700	5.8	<-6.2	84
25% polythene & 75% sawdust	775.5	24400	5.2	<-4	88
0% polythene & 100% sawdust	790	6620	4.8	<-6.2	98
RTP pyrolysis oil of wood	800-900	22100-24300	-	-	-
Palm oil [7]	830	22100	41	20	250
Diesel [8]	827	45180	2.61	-33 to -15	60-80
Gasoline [9]	710-790	47700	<1	-	-45

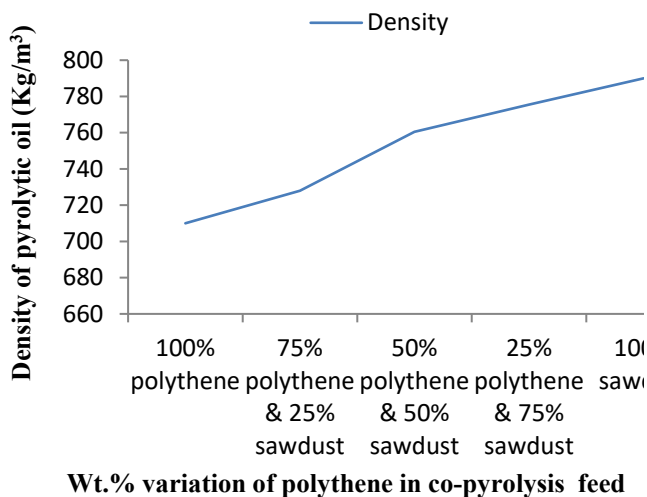


Fig. 4: Variation of density with the wt. % variation of polythene in the feedstock

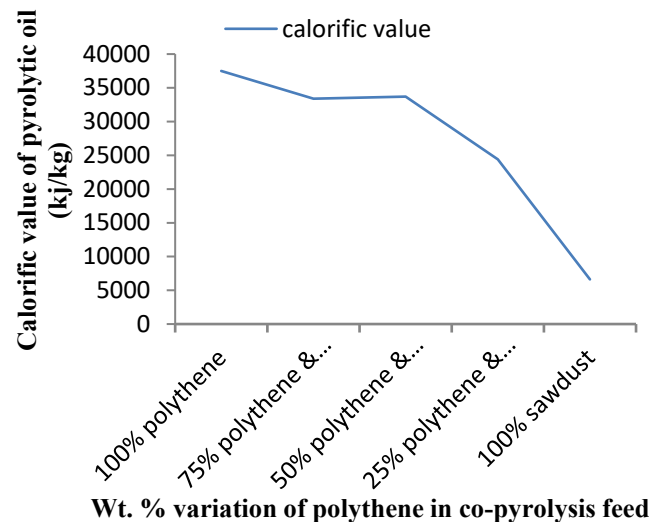


Fig. 5: Variation of calorific value with the wt. % variation of polythene in the feedstock

## 6. CONCLUSION

The variation of wt. % of polythene and sawdust has a great influence on the product yield as well as FOECE. In this study about ten experimental runs were made by varying the proportion of the feed materials. The liquid product yield increases while the char and gases product decreases with the increase of the wt. % of polythene in the feed stock blends. The maximum liquid yield 50 wt. % was obtained from the feed stock blends 100% polythene at a reactor temperature 500°C for zero N<sub>2</sub> gas flow. A temperature 500°C is suggested as the best co-pyrolysis temperature for the co-pyrolysis of polythene waste and sawdust. The maximum calorific value of the pyrolytic liquid was 37.5Mj/kg obtained from co-pyrolysis of polythene waste with sawdust. From the results it can be said that by applying various treatment the obtained co-pyrolytic liquid can be used as a potential sources of renewable energy sources.

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