Production of Liquid Fuel and Activated Carbon from Mahogany Seed by Using Pyrolysis Technology

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Abstract

The renovation of biomass waste in the form of Mahogany seed waste into bio-fuel as well as activated carbon by fixed bed pyrolysis reactor has been taken into consideration in this study. The mahogany seed in particle form is pyrolyzed in an enormously heated fixed bed reactor with nitrogen as the carrier gas. The reactor is heated from 400^0C to 600^0C using a external heater in which rice husk and charcoal are used as the heater biomass fuel. Reactor bed temperature, running time and feed particle size have been varied to get the optimum operating conditions of the system. The parameters are found to influence the product yields to a large extent. A maximum liquid and char yield are 49 wt. % and 35 wt. % respectively obtained at a reactor bed temperature 500^0C when the running time is 90 minutes. Acquired pyrolyzed oil at these optimal process conditions were analyzed for some of their properties as an alternative fuel. The oil possesses comparable flame temperature, favorable flash point and reasonable viscosity along with somewhat higher density. The kinematic viscosity of the derived fuel is 3.8 cSt and density is 1525 kg/m^3. The higher calorific value is found 32.4 MJ/kg which is significantly higher than other biomass derived fuel. Moderate adsorption capacity of the prepared activated carbon in case of methyl blue & tea water was also revealed.

Keywords: Renewable energy, Activated carbon, Pyrolysis oil, Fixed bed, Mahogany seeds.

1.Introduction

Biomass has been recognized as a major renewable energy source to supplement declining fossil fuel sources of energy [1]. It is the most popular form of renewable energy and currently bio-fuel production is becoming very much promising [2]. Besides, commercial activated carbon is a favored adsorbent for the elimination of micro pollutants from the aqueous phase; however, its extensive use is restricted due to high associated costs. To reduce treatment costs, attempts have been made to find economical alternative activated carbon (AC) precursors, such as mahogany seed waste. From the view point of energy transformation, pyrolysis is more attractive among various thermo chemical conversion processes because of its simplicity and higher conversion capability of biomass and its solid wastes into liquid and solid product. Pyrolysis is generally described as the thermal decomposition of the organic components in biomass wastes in absence of oxygen at mediate temperature (about 500° C) to yield tar (bio oil, bio fuel, bio crude), char (activated carbon) and gaseous fractions (fuel gases). Pyrolysis may be either fixed bed pyrolysis or fluidized bed pyrolysis. In fixed bed pyrolysis, a fixed bed pyrolyser is used. The feed material in the reactor is fixed and heated at high temperature. As the feed is fixed in the reaction bed (reactor), it is called fixed bed pyrolysis. In this process, the feed material is fed into the reactor and heat is applied externally. Usually nitrogen is used as inert gas for making inert condition and for helping the gaseous mixture to dispose of the reactor. A possible pathway of pyrolysis process is shown in Figure1. This technology is spreading with research and experimental work in many countries of the present world [3]. Energy is the major requirement of modern society, its development and management carries a lot of significance in the economic development of any country. There is a close relationship between the level of energy consumption in a country and its economic development. The energy consumption in the world has been growing at an alarming rate. By the year 2100, the world population is expected to be more than 12 billion and it is estimated that the demand for energy would increase by five times the current demand [4]. Under such circumstances, man has to find out some sources of energy for his survival that be able to meet considerable part of the energy demand in future. Several reviews on the subject are available, with applications including removal of heavy metals, organic compounds and dyes [5]. Currently, there are many studies on the development of low-cost adsorbents, namely by using waste materials for that purpose. Also, several reviews report a great deal of work done on their application for the removal of specific pollutants from aqueous phase, mainly heavy metals and dyes [7-8] presented are view on the use of saw dust for the removal of contaminants from water. Despite the satisfactory results obtained using some of these low-cost adsorbents, activated carbon (AC) are known to be more efficient in adsorbing a greater amount of pollutants. AC production costs can be reduced by either choosing a cheap raw material or by applying a proper production method [9-10]; nevertheless, it is still a challenge to prepare AC with very specific characteristics, such as a given pore size distribution, and using low-cost raw materials processed at low temperature (less energy costs) . Therefore, it is of extreme relevance to find suitable low-cost raw materials that are economically attractive and at the same time present similar or even better characteristics than the conventional ones. The use of waste materials for the preparation of AC is also very attractive from the point of view of their contribution to decrease the costs of waste disposal, therefore helping environmental protection. In this contest, fixed bed pyrolysis system from the mahogany seed is one of the promising sources of energy. Mahogany are grown extensively in the whole world especially in Middle East and Asia.The seeds of these mahogany fruits are almost wastage. This waste may be used for energy recovery as fuel.

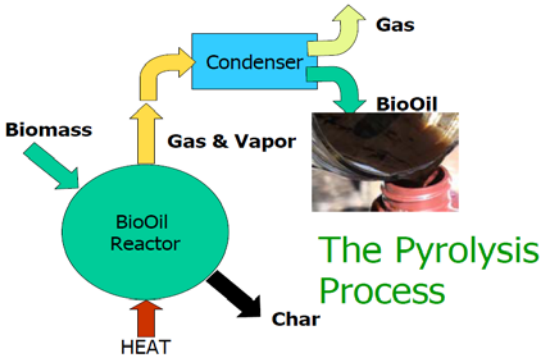

Figure 1: A possible pathway of pyrolysis of organic solid waste

The pyrolysis oil is of moderate heating value, is easily transported, can be burnt directly in the thermal power plant, can possibly be injected into the flow of a conventional petroleum refinery, burnt in a gas turbine or upgraded to obtain light hydrocarbons for transport fuel [11]. Besides these, there are scopes to upgrade the oil to obtain high grade fuel and valuable chemicals.

2. Materials and methods

2.1 Preparation of feed material

Mahogany seeds were collected locally in Rajshahi (Bangladesh). The size of raw seeds was almost 1.5 cm^3. The seeds were crushed and sieved to three different sizes and finally oven dried for 24 hours at 110°C prior to pyrolysis. The mahogany fruit in a tree and seeds are shown in fig. 2 and 3 respectively. The higher heating value of seed is found to be 24.936 MJ/kg.

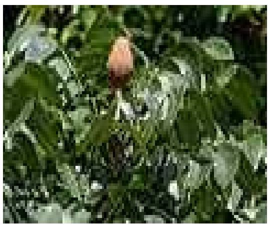

Fig.2 Mahogany fruit

Fig.3 Mahogany seed

2.2 Characterization of raw materials

The raw materials were characterized according to their proximate and ultimate analysis. Proximate analysis identified the % of moisture, oil, crude fiber, carbohydrates and ash content in the samples and the ultimate analysis carried out in CHNSO elemental analyzer (Variael CUBE Germany) to provide the elemental composition. The proximate and ultimate analysis of mahogany seed is presented in Table 1 and Table 2 respectively.

Table 1: proximate analysis of mahogany seed [12]

Moisture	Oil	Crude fiber	Carbohydrates	Ash
6-11%	7-10%	10-20%	53-63%	1-2%

Table 2. Ultimate analysis of Mahogany seed. [12]

C	H	N	S	O
48.14%	6.40%	0.28%	0.03%	45.15%

2.3 Experimental section

Mahogany seed is pyrolyzed in an externally heated stainless steel fixed bed reactor system. The main components of the system are fixed bed reactor, liquid condenser and ice cooled liquid collectors. The effective length of the reactor is 46 cm and the diameter is 7.60 cm. The schematic diagram of the fixed bed pyrolysis system is shown in Figure 4. The reactor is heated externally by a biomass heater at different temperatures (450, 500, 550 and 600^{0}C) and this temperature is measured by means of a mercury thermometer. Nitrogen gas is supplied in order to maintain the inert atmosphere in the reactor, and to dispose of the pyrolyzed vapor products to the condenser. Pyrolysis vapor is condensed into liquid in the condenser and then is collected in the liquid collectors. The non-condensed gas is flared to the atmosphere.

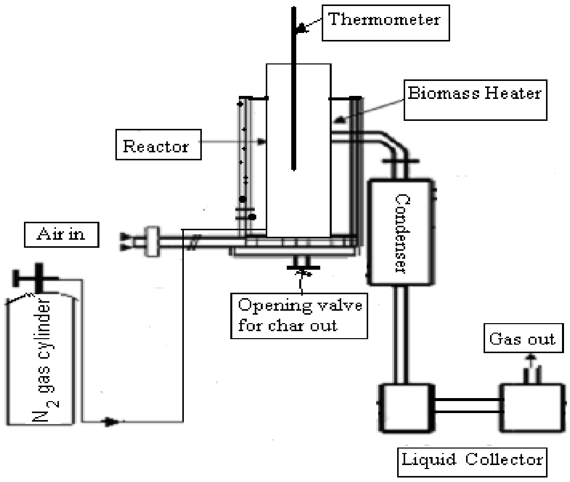

Figure 4: Schematic diagram of fixed bed pyrolysis system

3. Result and discussion

3.1 Product yield

The products obtained from the pyrolysis of mahogany seed are liquid oil, solid char and gas. At an operating temperature of 550 ^{0}C for a feed size 1 mm diameter at a gas flow rate of 5 liter/min with a running time of 90 minute, liquid production is found to be the maximum (49 wt%) of the dry feedstock.

3.2 Effect of feed particle size

Figure 5 represents the percentage weight of liquid and solid char products for different particle size of feed at a bed temperature of 550°C and an operating time of 90 minutes. It is observed that at 550°C the percentage of liquid collection is a maximum of 49% of total biomass feed for particle size of smaller than 1.18 mm. A less amount of liquid is obtained from the larger particle size feed. This may be due to the fact that the larger size particles are not sufficiently heated up so rapidly causing incomplete pyrolysis that reduced liquid product yield. This may be due to the fact that the smaller particles were overheated or too quick devolatilization occurs producing more gases, on the other hand, the larger size particles were not adequately heated up so rapidly causing incomplete pyrolysis rendering less liquid product yield. With the increase of feed particle size, gas yield was decreasing from 28 to 8 wt% of feed. Smaller feed size provides more reaction surface causes high heating rate and too quick decomposition of crushed mahogany seeds. The product oil vapors comparatively get enough time for secondary reaction in the reactor and consequently increase in gas yield and decrease in liquid and char yields. On the other hand, the heating rate in larger feed is low due to its lower thermal conductivity and heat can flow only to a certain depth in the available pyrolysis time compared to almost complete thermal decomposition of the smaller particles. Thus the feed of larger pieces becomes carbonized and/or cannot be decomposed completely resulting increase in char yield and decrease in liquid and gas yields. In the presented study it may be concluded that the optimum feed size is 1.18 mm for which decomposition of mahogany seed is complete and has less possibility of secondary cracking at the optimum reactor temperature. Evan et al. [8] pyrolyzed wood waste in a fixed bed reactor and showed maximum liquid product 54 wt% of biomass waste was obtained for temperature 450°C with 0.8 to 1.2 mm feed size. The feedstock size of 0.25 to 1 cm and 1 to 2 cm produced a maximum percentage of liquid of 45 wt% and 52 wt%, respectively. Islam et al. [13] pyrolyzed municipal solid waste in a fixed bed reactor and reported that the maximum liquid yield 55 wt% of solid waste at temperature 450°C for feed size 1-2 cm.

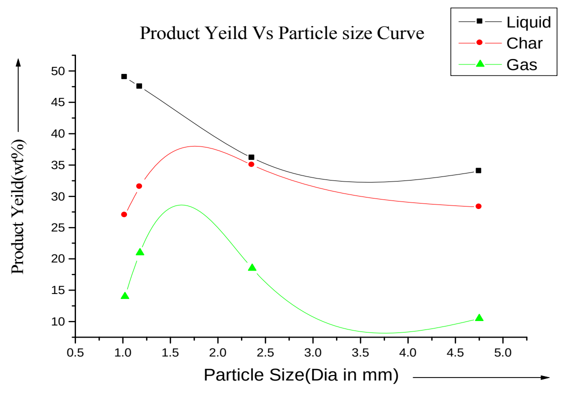

Figure 5: Effect of feed particle size on product yield.

3.3 Effect of operating temperature

Figure 6 shows the variation of percentage weight of liquid, char and gaseous products at different bed temperature with particle size of smaller than 1.18mm. From this it is found that the maximum liquid products yield is obtained at a temperature of 550°C, and this is 49 wt% of total biomass feed. At lower temperature the liquid product yield is decreasing while with the increase of temperature above 550°C, the liquid product yield is again deteriorating. With the increase of temperature the solid char yield is decreasing above 550°C and increasing below 550°C. It may be caused at lower temperature less than 550°C, complete reaction cannot be taken place.

The reason behind this was that the lower temperature was not sufficiently high enough for the pyrolysis devolatilization reaction to take place completely rendering reduced amount of liquid and gaseous products. Again the higher temperature was causing secondary cracking reaction of the vapors yielding more gas at the cost of the liquid product yield. However, the intermediate temperature was sufficient enough for complete pyrolysis reaction to take place and at the same time this temperature was not high enough for secondary reaction rendering maximum quantity of liquid product with less amount of char residue and gaseous products.

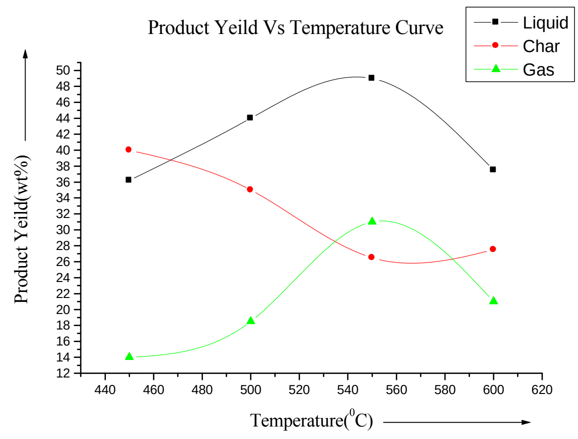

Figure 6: Effect of Reaction Temperature on product yields

Islam et al. [14] pyrolyzed jute-stick in a fluidized bed reactor and reported that the yield of liquid at maximum level up to 50 wt% at 425°C with 300-600 µm feed particle size and 30 l/min fluidized gas flow rate. Onay et al. [15] pyrolyzed rapeseed in a fixed bed reactor and reported that the maximum liquid yield 51.7 wt% of solid waste at reactor temperature 550°C for particle size 0.6-1.80 mm and gas flow rate 100 cm^3/min. Acikgoz et al. [16] pyrolyzed linseed in a fixed bed reactor and reported that the maximum liquid product yield 57.7 wt% of solid waste at 550°C for gas flow rate 100 cm^3/min and particle size 0.6-1.80 mm with heating rate 300°C/min.

3.4 Effect of running time on product yield

Figure 7 shows the variation of product yield (wt%) of liquid, solid char and gas products at a temperature of 550°C for feed particle of size of smaller than 1.18mm. The maximum liquid product is 49wt% of biomass feed while the solid char product is 35 wt% of dry feed at 90 minutes. It is observed that lower and greater running time than of that of 90 minutes the liquid product yield is not optimum that may be due to insufficient pyrolysis reaction and higher rate of gas discharge respectively. Secondary cracking reaction taken place by which the amount of permanent gas product is increased. So at temperature higher than 550^{0}C liquid product is decreased.

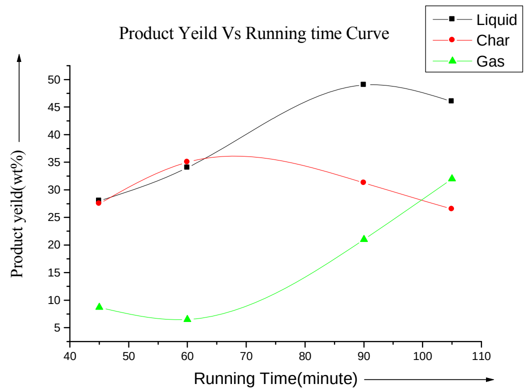

Figure 7: Effect of Running Time on product yield.

4. Analysis of products yield:

Products have been analyzed to obtain different physical properties.

4.1 Physical properties of pyrolysis oil

The energy content of the oil is 32.40 MJ/kg. The oil is found to be slightly heavier than water with a density of 1525 kg/m^3 at 35 ^{0}C. The flash point of the oil is 60 ^{0}C and hence precautions are not required in handling and storage at normal atmosphere. The low viscosity of the oil of 3.8 cSt at 35^{0}C is a favorable feature in the handling and transportation.

Table 3: Comparison of date seed pyrolysis oil with biomass derived pyrolysis oil

Analysis	Mahogny seed oil	Date seed oil [17]	Sugarcane bagasse oil [18]	Jute stick oil [14]
Kinematic viscosity at 35^{0}C (cSt)	3.8	6.63	89.34	12.8
Density (kg/m^3)	1525	1042	1198	1224
Flash Point (^{0}C)	60	126	105	>70
HHV(MJ/kg)	32.4	28.6	20.072	21.091

4.2 Comparison with other biomass derived oil and diesel fuel

Table 3 and 4 shows the characteristics of the pyrolysis oil derived from mahogany seed in comparison with other biomass derived oils and diesel fuel. It is evident that the density and viscosity of mahogany seed oil is favorable than other pyrolysis oils and very much closer to diesel. The higher heating value of mahogany seed oil is found to be higher than other biomass derived oil.

Table 4: Comparison of mahogany seed pyrolysis oil with diesel fuel

Analysis	Mahogany seed oil	Diesel [19]	Heavy fuel oil [19]
Kinematic viscosity at 26^{0}C (cSt)	3.8	2.61	200
Density (kg/m^3)	1525	827.1	980
Flash Point (^{0}C)	60	53	90-180
HHV(MJ/kg)	32.4	45.18	42-43

4.3 Observation of different oil flame and compare the variation of temperature with time

Figure 8: Flame of Mahogany seed oil, Diesel fuel & kerosene fuel

Figure 9: Measurement of different flame temperature by Digital Pyrometer.

In figure 10 the graph shows the change of flame temperature of mahogany seed oil, diesel fuel & kerosene fuel with time. On the following graph it is seen that the flame temperature of diesel fuel is maximum and it is about 1008^{o}C and the flame temperature of Mahogany seed oil is minimum and it is about 491^{o}C .The kerosene is in between two. This is due to the calorific value of the particular fuel. As the calorific value of diesel is higher so, the flame temperature is higher but the calorific value of mahogany seed oil is lower so, the flame temperature of product oil is lower.

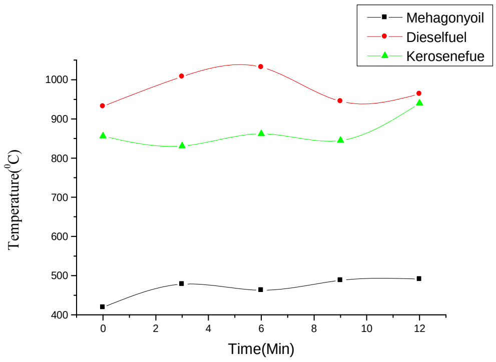

Figure 10: Different flame temperature curve varied with time.

5. Preparation of activated carbon

Activated carbon, also called activated charcoal, activated coal or carbo activates, is a form of carbon that has been processed to make it extremely porous and thus to have a very large surface area available for adsorption or chemical reactions. To produce activated carbon the pyrolysis product char were cooled to ambient temperature. Then the char was ground and sieved into different sizes. The pyrolysis product char and activated carbon are shown in figure 11 and 12 respectively.

5.1 Observation the effect of activated carbon

To observe the activated carbon into the solid char two process liquid methyl blue and tea water were prepared and then visual inspection was done. Weight, feed particle size and concentration have been varied to realize the adsorption performance of activated carbon in case of methyl blue. Weight and particle size have been varied in case of tea water. The parameters are found to influence the activation performance significantly for both methyl blue and tea water.

Fig.11 Char derived from mahogany seed

Fig.12Activated carbon

5.2 Influence of particle size on the adsorption process

To evaluate the effect of particle size on the adsorption process, the activated carbon was ground and sieved into different size fractions: It is clear that methyl blue uptake increased with the decrease in particle size, due to the corresponding increase in surface area and better accessibility to pores. According to [20], breaking of large particles into smaller ones can also open some tiny sealed channels, which might then become available for adsorption. Based on the results, the remaining experiments were conducted employing the smaller particle size activated carbon.

6. Conclusion

The biomass solid waste in the form of mahogay seed is successfully converted into liquid, char and gas by fixed bed pyrolysis system. The heating value of the pyrolysis oil is found to be 32.4 MJ/kg, which is higher than other biomass derived pyrolysis oils and also significantly higher than that of solid mahogany seed waste. The maximum liquid yield is found to be 49 wt% of dry biomass feedstock at the temperature of 500 $^{\circ}$C. The density and viscosity of the liquid are greater than that of diesel. However, the oil from the mahogany seed may be considered as an important candidate of potential source of alternative fuel. Moderate adsorption capacity of the prepared activated carbon in case of methyl blue & tea water.

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8. Nomenclature

Symbol	Meaning
cm	Centimeter
^{0}C	Degree Celsius
wt%	Weight Percentage
MJ	Mega Joule
Kg	Kilogram
cSt	Centistokes