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PRODUCTION OF LIQUID FUEL AND OBSERVATION OF ACTIVATED CARBON OF CHAR FROM WASTE MAHOGANY SEED USING FIXED BED PYROLYSIS PROCESS

Md.Afrozzaman[1,*], Anwar Sadat[2], H.M.Farshid[3]

[1]Department of Mechanical Engineering,Rajshahi University of Engineering and Technology, Bangladesh
[2]Department of Mechanical Engineering,Chittagong University of Engineering and Technology, Bangladesh
[3]Department of Chemical Engineering, Bangladesh University of Engineering and Technology, Bangladesh

[1,*]afroz_062107@yahoo.com, [2]sadatcuet07@yahoo.com, [3]hasanfarshid@yahoo.com

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 pyrolysed in a heated fixed bed reactor with Nitrogen as the carrier gas. Reactor bed temperature, running time and feed particle size have been varied to get the optimum operating conditions of the system. A maximum liquid and char yield are 49 wt. % and 35 wt. % respectively obtained at a reactor bed temperature* 550^0C *when the running time is 90 minutes. 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 high. Moderate adsorption capacity of the prepared activated carbon in case of Methyl blue and tea water is also revealed.*

Keywords: Waste Mahogany Seed, Fixed Bed Pyrolysis Reactor, Higher Calorific Value, Activated Carbon.

1. INTRODUCTION

Pyrolysis for energy conversion from carbonaceous waste is defined as the thermochemical decomposition of organic material at elevated temperature either in total absence of air or with a lack of a stochiometrically needed amount of oxygen to the extent where gasification does not occur.

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. Transformation of energy into useful and sustainable forms that can fulfill and suit the needs of human beings in the best possible way. From the view point of energy transformation, fixed bed pyrolysis is more attractive among various thermochemical conversion processes because of its simplicity and higher conversion capability of biomass and its solid wastes into liquid product.

As carbonaceous solid waste is 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 useable and environmentally acceptable. This liquid of high heating value can easily be transported, can be burnt directly in the thermal power plant, can easily be injected into the flow of conventional petroleum refinery, can be burnt in a gas turbine or upgraded to obtain light hydrocarbon transport fuel. The solid char can be used for making activated carbon. The gas has higher calorific value that is sufficient to be used for the total energy requirements of the pyrolysis plant.

2. PYROLYSIS

Pyrolysis is generally described as the thermal decomposition of the organic components in biomass wastes in the absence of oxygen at elevated temperature (about 500° C) to yield liquid (bio oil, bio fuel, bio crude), char (charcoal) and gaseous fractions (fuel gases). For convenience, there are two approaches to the conversion technology. The first approach referred to as conventional pyrolysis is to maximize the yields of fuel gas at the preferred conditions of high temperature, low heating rate and long gas residence time or to enhance the char production at the low temperature and low heating rate.

Another approach referred to as flash or fast pyrolysis is to maximize the yields of liquid product at the processing conditions of low temperature, high heating rate and short gas residence time.

3. SOLID PARTICLE PYROLYSIS

Pyrolysis is the heating of any fuel particle, droplet or gaseous molecule in the absence of oxygen and for solids it can be presented by the following equation:

$$C_aH_bO_3 + heat \longrightarrow H_2O+CO_2+H_2+CO+CH_4+C_2H_6+CH_2O+ \ldots + liquid + char$$

3.1Selected Mahogany Seed as Biomass Waste

Mahogany seeds were selected as the feed material for this study. Switenia mahagoni in the genus Switenia is extensively cultivated in India, Srilanka, Bangladesh etc as avenue tree. It is a semi evergreen tree, about 30-35m tall. Fruit shape is oval, fruit length is 3 to 6 inches, fruit

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covering dry or hard, the fruit color is blue or brown with 35-45 seeds per fruit and 3300-3500 seeds per kg [2].

3.2 Reasons for Selecting Mahogany Seeds as Biomass Waste

1. A large amount (250000 tons/yr) of mahogany seed is not utilized which is grown in Bangladesh.
2. The production of oil from mahogany seed may provide the use of a renewable resource, and at the same time adding value to agricultural products.

3.3 About Mahogany Seed

Table 1: Approximate composition of mahogany seeds [3]

Moisture	12%
Protein	5-7%
Oil content	47-62%

4. POSSIBLE REACTION PATHWAY

A possible reaction pathway of pyrolysis process is shown below:

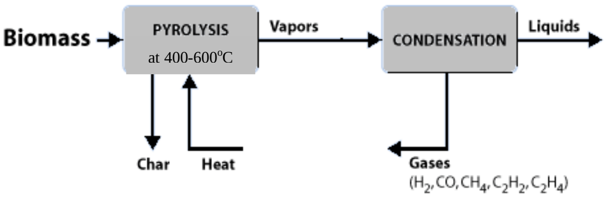

Fig. 1: A possible reaction pathway of pyrolysis of organic solid waste

5. FIXED 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. The feed material is fed into the reactor and heat is applied externally. Inert gas is used for making inert condition and for helping the gaseous mixture to dispose of the reactor. The losses in fixed bed pyrolysis are relatively less than fluidized bed pyrolysis. Moreover, fluidized bed pyrolysis is more complex.

6. FEED PREPARATION

The mahogany seed is collected and dried. It is then crushed into smaller sizes. These are <1.18mm, 1.18mm, 2.36mm, and 4.75mm in dia. It is dried with the help of oven maintaining 110°C to drive away adsorbed water from seed surface. Thus the feed material is prepared.

Fig. 2: Pyrolysis oil from Mahogany seeds

Fig. 3 : Char derived from Mahogany seeds

6.1 Experimental Setup of Pyrolysis System

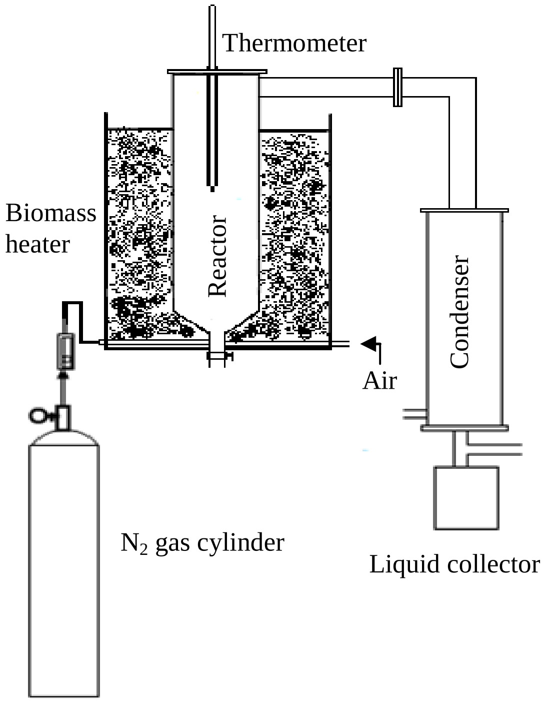

Fig. 4: The Schematic Diagram of Fixed bed pyrolysis system

6.2The Fixed Bed Pyrolysis Set up

- **Reactor:** Reactor is the enclosure where the biomass feed material is pyrolysed in the absence of oxygen. The biomass heater is surrounded by the reactor. The heat gets the reactor from the biomass heater. The N_2 gas cylinder provides N_2 for the inert atmosphere inside the reactor. The bio mass are decomposed in the absence of O_2.
- **Condenser:** Condenser is the hollow shaped cylinder through which a small diameter pipe goes through. The gas from the feed material goes through the pipe and outside the pipe water flow through the hollow cylinder. The hollow shaped cylinder has two opening. A pipe is attached through the upper opening which supplies water and there is a pipe in the lower opening which rejects water from the condenser. So, the entire condenser remains cool by the flow of water.
- **Biomass Heater:** The biomass heater is the confinement by which the reactor is surrounded. In the biomass heater the solid fuel such as cow dung, rice husk and liquid fuel Kerosene are given for producing heat and the heat is utilized in the reactor.
- **Liquid Collector:** The liquid collector is attached with the condenser and the liquid is reserved in the collector. The gas is condensed through the condenser and the condensed gas that is liquid is collected in the collector. The liquid collector is submerged in the icy water for well liquidation.

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- **N_2 gas cylinder:** The N_2 gas cylinder is used for providing N_2 gas in the reactor .The gas attain inert atmosphere inside the cylinder as the process must be happened in the absence of O_2 .

7. EXPERIMENTAL PROCEDURE

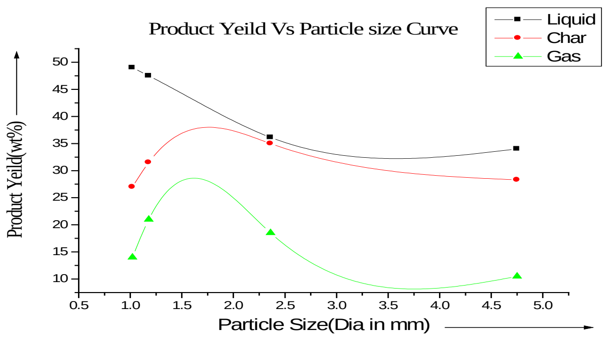
In this experiment, feed material is weighed and filled into the reactor. The experimental set-up is assembled. High temperature adjustable gaskets are used to seal the joints and fittings of the hot parts of the connecting pipe, reactor and condenser. Ice is placed into the condenser. The reactor is heated externally by a biomass heater at different temperatures and these temperatures are measured by mercury thermometer (capacity range -0°C to 610°C). The N_2 gas is passed through reactor through a heated pipe and this flow (4-10 liter/min.) is controlled by the use of a gas flow meter valve (capacity 0-40 liter/min). The operation time is recorded by means of a stopwatch. When the operation is completed a small flow of N_2 gas is allowed to pass through the system to prevent back flow of air which might react with hot gases when the reactor is still hot. It is dismantle when the rig is cooled enough to be handled. The char is collected from the reactor bed and weighed. All data are recorded in tabular form. All the parts of the system are cleaned and the heating value of the liquid and char is measured by a bomb calorimeter before reassembling for the next run.

8. EXPERIMETAL RUN

A total of 6 experimental run has been taken firstly in this study. Four sizes of mahogany seeds are used here. To obtain these sizes, three meshes sieve are used. These are mesh no. 4 that can separate particle of 4.75mm, mesh no. 8 that can separate particle of 2.36cm and mesh no. 16 that can separate particle of 1.18cm. The forth size particle is of less than 1.18cm. The experimental results of the run at different conditions with their effects are presented here.

8.1Effect of Feed Particle Size

Fig. 5 shows that the product yield is higher for lower particle size. The lower the particle size the higher the surface area which provides high heating rate. For smaller particles quick devolatilization occurs producing more gases which turn into liquid by condensation. In case of gas and char production, with the variation of particle size, product yield increases, reaches a peak value and then decreases with a relatively slow rate



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

8.2Effect of Reaction Temperature

Fig. 6 shows that liquid and gas product yield increases with the increase of temperature and rise to a peak point and then decreases, for char the curve shows just opposite behavior.

The reason behind this is that the lower temperature is 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 is causing secondary cracking reaction of the vapors yielding more gas at the cost of the liquid product yield. However, the intermediate temperature is 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.

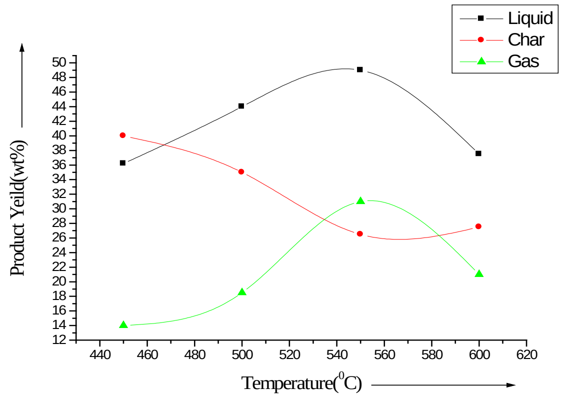


Fig. 6: Effect of reaction temperature on product yield

8.3Effect of Running Time

It is observed from Fig. 7 that, lower and greater running time than 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. It is observed that for running time less than that of 30 minutes the liquid yield is not optimum that may be due to incomplete pyrolysis reaction of the whole feed.

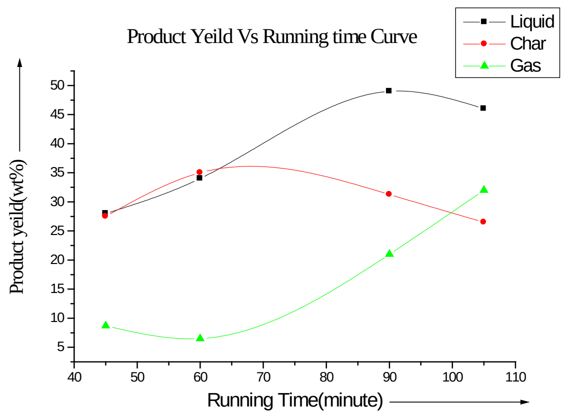


Fig. 7: Effect of running time on product yield

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9. PHYSICAL CHARACTERISTICS

The physical characteristics of the obtained pyrolysis oil are shown in Table 2.The energy content of the oil is 32470 KJ/kg. The oil is found to be heavier than water. The flash point of the oil is 38^{0}C and hence precautions are required in handling and storage at normal atmosphere. The low viscosity of the oil is 3.8 cSt at 35^{0}C is a favorable feature in the handling and transportation of the liquid.

Table 2: Physical characteristics of mahogany seed oil.

Analysis	Mahogany seed oil
Kinematic viscosity at 35^{0}C (cSt)	3.8
Density(kg/ m^3)	1525
Flash Point(^{0}C)	38
Fire Point (^{0}C)	42
HHV of liquid(MJ/kg)	32.4
HHV of char(MJ/kg)	23.2

10. COMPARISON OF MAHOGANY SEED OIL WITH BIOMASS DERIVED PYROLYSIS OIL AND CONVENTIONAL PETROLEUM FUEL

The comparison of physical characteristics of mahogany seed oil with other biomass derived pyrolysis oil and petroleum products is shown in Tables 3 and 4.

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

Analysis	Mahogany Seed oil	Date Seed oil [4]	Waste paper oil [5]	Sugar cane bagasse oil [6]	Jute stick oil [5]
Kinematic viscosity at 35^{0}C (cSt)	3.8	6.63	2.00	89.34	12.8
Density (kg/m^3)	1525	1042.4	1205	1198	1224
Flash Point (^{0}C)	38	126	200	105	>70
HHV(MJ/kg)	32.4	28.636	13.10	20.072	21.091

Table 4: Physical characteristics of the mahogany seeds pyrolysis oil with other conventional fuel

Analysis	Mahogany Seed oil	Fast Diesel [7]	Diesel [8]	Heavy Fuel Oil[9]	Kerosene Fuel [10]
Kinematic viscosity at 35^{0}C (cSt)	3.8	1.3-3. 3.3$^#$	2.61*	200$^#$	1.3
Density (kg/m^3)	1525	780	827.1*	980*	780
Flash Point (^{0}C)	38	75	53	90-180	37-65
HHV(MJ/kg)	32.4	45-46	45.18	42-43	46.2

10.1 Experiment on Flame Characteristics

The three types of fuel were used in the experiment:

- Mahogany seed pyrolysis oil.
- Diesel.
- Kerosene

10.2 Different Types of Flame Observation

In the Fig. 8, it is seen that the flame temperature of Mahogany seed oil is significantly close to Diesel and Kerosene .The higher calorific value of the Mahogany seed oil might be of huge potentiality and demand in near future

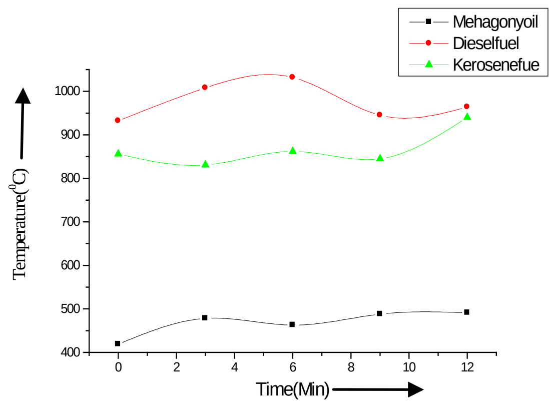

Fig. 8: Different flame temperature curve varied with time

10.3 Activated Carbon

Activated carbon, also called activated charcoal or activated coal 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.

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10.4 Experimental Observation of Activated Carbon

To observe the activated carbon into the solid char two process liquid is prepared and then visual inspection is done. Two process liquid are Methyl Blue and Tea water.By the Methyl Blue three type of observations are made b y varying weight(0.1gm.0.15gm,0.2gm,0.3gm), by varying particle size (0.1mm, 0.16mm, 0.25mm), by varying concentration. By the Tea water two type of observations are made b y varying weight. (0.1gm., 0.15gm, 0.2gm) and by varying particle size (0.1mm, 0.16mm, 0.63mm).

10.5 Methodology of Observation of Activated Carbon

Four beakers are taken to make the observation of activated carbon. First the methyl blue is taken into 100 ml of water and different weight of solid char is mix with process liquid. Then the solution is kept for 60 minute. A little change can be observed in the color of solution. Then in the same way different size of solid char is taken into the beakers. Different concentration of methyl blue is taken into the beaker and kept for 60 minute for observation. In the same way the process liquid, Tea water is taken and repeated the processes.

11. CONCLUSION

The physical properties analysis showed that the oil is heavy in nature with moderate viscosity. The heating value of the oil is quite satisfactory. The fuel properties of pyrolysis liquids such as density, viscosity and HHV are found almost comparable to other biomass derived pyrolysis oils. The flame temperature of mahogany seed oil is satisfactory and it was burn smoothly. The observation of Activated carbon is moderate as very little change occurs.

12. RECOMMENDATION

- The process bed temperature would be easier to control at uniform value if the system could be well insulated and supplied uniform rate of air by the blower.
- The char products from pyrolysis of mahogany seed are reasonably high. The high char yield has a potential values a solid fuel or as activated carbon or further characterization of the char are suggested. The energy content of the char could be utilized.
- The external heating system (heater) should be insulated to reduce heat loss.
- After upgrading the fuel can be get the flame with little or no vapor which makes complete combustion.

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14. NOMENCLATURE

Symbol	Meaning
%	Percent
^oC	Degree Celsius
T	Temperature
HHV	Higher Heating Value
GCV	Gross Calorific Value
L/min	Liter per minute
cSt	Centistokes
KJ/kg	Kilojoules per kilogram
Wt%	Weight percent

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