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Biofuels Extraction through Pyrolysis of Banana Waste

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ABSTRACT
Demand for energy is increasing at an alarming rate. To overcome this problem pyrolysis of biomass can be counted as an alternative option. Banana waste is a very good source of Banana waste. The aim of the work was finding the worthiness of banana waste as a biomass source for pyrolysis process and extraction biofuels from it. Banana waste is a very common type of bio-mass. Banana waste was collected from tea stalls and hotels, then dried and prepared for pyrolysis. To extract fuel from banana waste, a fixed bed type pyrolysis apparatus was designed and constructed. The pyrolysis apparatus was contained a fixed bed type reactor, dry heater, condenser mechanism, vacuum pump, thermocouple. After extracting liquid fuel, physical properties were measured and compared with various pyrolytic oils. The average amount of biofuel extraction from banana wastes was obtained 3.6% (wt) and it is relatively low in comparison with other waste available in the literature.

Keywords: Pyrolysis, Biofuel, Banana Waste, Pyrolytic Oil.

1. Introduction:

The demand for energy is increasing day by day due to the rapid growth of population, urbanization, and industrialization. The majority of the demand is fulfilled by the fossil fuel, which source is very limited, also it is harmful to the environment. So, an alternative fuel should be thought to overcome the energy crisis and reduce environmental threats. On the other hand, the standard of living and quality of life of a nation depend on its per capita energy consumption. Bangladesh is a developing country and is one of the most densely populated countries in the world with a total population of 164.67 million. Estimated final consumption of total energy is around 46.43 MTOE.Average increase of energy consumption is about 6% per annum. Per capita consumption of energy in Bangladesh is on an average 285 KgOE (Kilogram Oil Equivalent) and per capita generation of electricity is 371 kWh with an access to electricity 76%, which is lower than those of South Asian neighboring countries. The known energy sources in Bangladesh are natural gas, coal, imported oil, hydro-electricity, and traditional biomass source. Natural gas, coal, imported, hydro-electric energy sources are known as a commercial energy source. Biomass accounts for about 29% of primary energy and rests the rest 71% is being met by commercial energy. Natural gas accounts for about 68% of the commercial energy and rest the rest 32% is being met by imported oil. Currently, about 213MW power is generated by using the solar system. Moreover, in off-grid areas power is also being generated by using the Solar Home System (SHS). In addition, there are some poultry and dairy farms in which biogas plants are being set up and this biogas is used for cooking and power generation which is currently producing about 1MW power. Imported oil accounts for the lion's share of the rest. Every year Bangladesh imports about 5.4 million metric tons of crude and Refined Petroleum Products. Apart from natural gas and crude oil, coal is mainly used as fuel in the brick-fields and Thermal Power Plant. To generate electricity by Bio-Mass Gasification Method, some steps have been taken in the country. [1] Thus, it is a crucial time to find a sustainable resource to mitigate the energy crisis of Bangladesh.

The different thermo-chemical process that includes combustion, liquefaction, hydrogenation, and pyrolysis has been used to convert the waste into various energy products. Pyrolysis can convert waste directly into solid, liquid and gaseous products by thermal decomposition of waste in the absence of oxygen. To obtain biodiesel from green solid waste the Pyrolysis process is preferred mostly.

Bangladesh is an agriculture-based country. The banana is one of the most common agricultural products. In 2016, banana production in Bangladesh was 798,012 tons. Though Bangladesh banana production fluctuated substantially in recent years, it tended to increase through 1967 - 2016 period ending at 798,012 tons in 2016 [2].

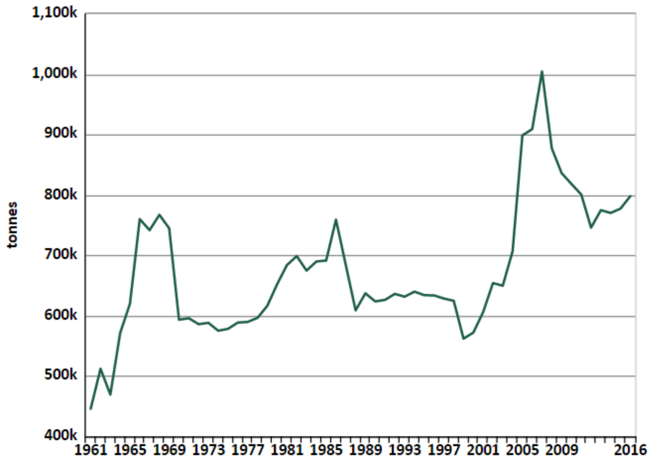

Fig 1: Annual production of banana for the fiscal year 1961 to 2016 [2]

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Every year a huge amount banana, as well as banana waste, is produced. Very common use of Banana waste is the food of domestic animals. There is a very negligible number of commercial uses of banana waste, but the maximum amount of waste is wasted. Waste banana should be managed because this waste may become harmful for the environment.

The banana waste can be used as a bio-degradable bio-mass to recover biofuel as it is cheap and highly available. Dry waste can be a source of energy and valuable chemical product, and their thermal decomposition makes the recovery of useful compounds possible. For recovering biofuel from banana waste Pyrolysis can be a good option. This work investigates the effectiveness of banana waste as biomass for the pyrolysis process. Finding banana waste suitable for producing biofuel through pyrolysis or not is a major objective of this work.

To fulfill is an investigation, a fixed bed pyrolysis reactor was designed and constructed, biofuel was extracted, fuels properties (density, viscosity, gross calorific value, flash point, pour point) were determined. The properties of pyrolytic oil were also compared with fossil fuel and other pyrolytic oil.

2. Experimental Procedure:

Pyrolysis is a thermochemical decomposition process which is found to be the best suited for conversion of biomass to carbon-rich solid and liquid fuel. The process of pyrolysis of organic matter is very complex and consists of both simultaneous and successive reactions when organic material is heated in a non-reactive atmosphere. In this process, thermal decomposition of organic components in biomass goes up to 700^{o}C - 800^{o}C in the absence of air/oxygen. The long chains of carbon, hydrogen and oxygen compounds in biomass break down into smaller molecules, in the form of gases, condensable vapors (tars and oils), and solid charcoal under pyrolysis conditions. Rate and amount of decomposition gases, tars and char depend on the process parameters of the reactor (pyrolysis) temperature, heating rate, pressure, reactor configuration, feedstock's variation. The following figure shows a schematic diagram for a pyrolysis process. By condensing condensable gasses from those decomposition gasses bio fuel is obtained [3].

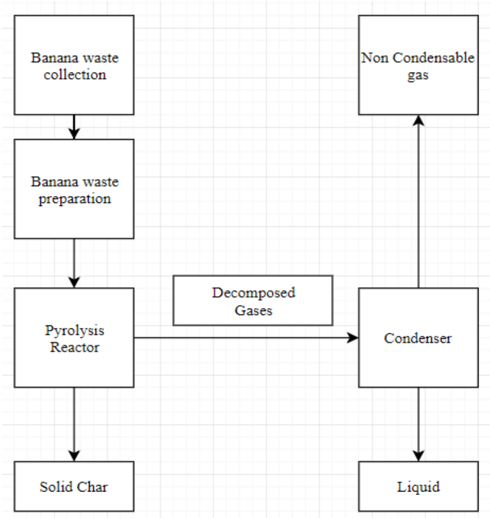

Fig. 1: Flowchart of Pyrolysis process

2.1 Feed material:

The most common types banana waste are banana fruit peel and fruit bunch stem as shown in Fig. 2. At normal condition, banana waste contains a large amount of moisture. Moisture is one of the biggest disadvantages of banana waste for the pyrolysis process. So, drying of banana waste as much as possible is very important. Banana waste is highly cheap and available but a high amount of moisture is one of the biggest limitations. Banana wastes are also made as small as possible for quick decomposing.

Fig. 2: Raw Banana waste

Fig. 3: Dry Banana waste

2.2 Pyrolysis apparatus:

Batch type fixed-bed pyrolysis apparatus was selected for the experiment. CAD model of the experimental apparatus is shown in Fig. 4. The main components of the pyrolysis apparatus are pyrolysis reactor and condenser. Temperature measuring instrument is used to measure the temperature and vacuum pump is used to perform the experiment without oxygen. Asbestos rope is used to insulate the reactor.

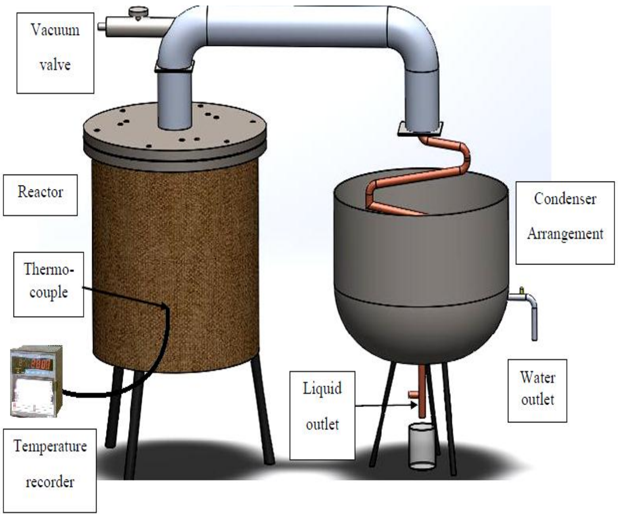

Fig 4: Experimental apparatus

2.2.1 Pyrolysis reactor:

The pyrolysis reactor is designed for pyrolysis of waste materials like biomass, agricultural wastes, forest residue etc. The reactor is a cylindrical, fixed bed reactor made of mild steel as shown in Fig. 4. The top side of the reactor can be open for feeding the raw material and solid residue (char) can be removed at the end of the experiment.

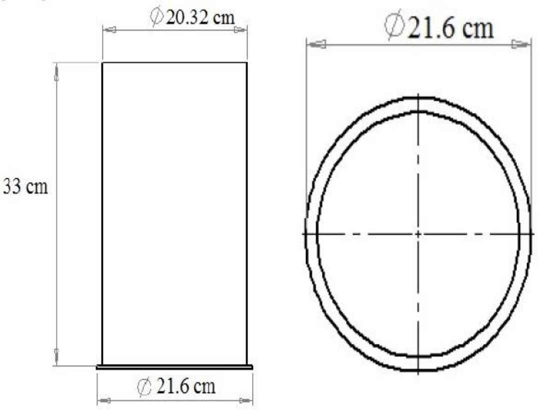

Fig 5: Drawing of reactor shell

An exit pipe at the top carries away the evolved gases during pyrolysis. During the reaction, the top side is kept closed by a cover plate tightly secured to the flanged opening. This prevents ingression of atmospheric air into the reactor, thereby achieving pyrolysis conditions.
Three U shaped electrical dry heaters each of 500W capacity are mounted on the top part of the reactor. The heater provides heat for thermal decomposition.

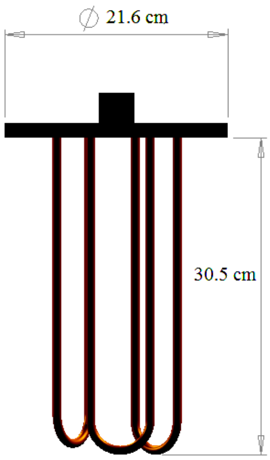

Fig 6: Electrical Heaters

The temperature inside the reactor is measured by a K type thermocouple. K type thermocouple is very inexpensive and highly available. It is normally used in the temperature range -200^{o}C to +1350^{o}C. The range of thermocouple used for this experiment is 0^{o}C to 800^{o}C.

2.2.2 Condenser:

A simple gas to water heat exchanger type condenser is provided to condensed the volatile gases produced from thermal decomposition. Gas is carried by copper tube and incondensable gases are passed through a bypass pipe under the condenser. Bended copper tube is merged in water which is contained by a container.

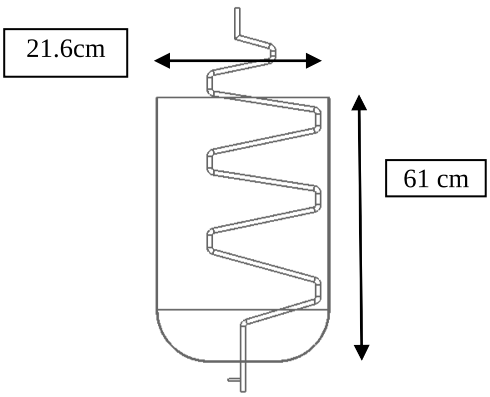

Fig 5: Schematic diagram of Condenser arrangement

2.2.3 Construction of the Apparatus:

An apparatus was constructed according to the design as shown in Fig. 6. Three heaters are mounted on the top part of the apparatus. Reactor and condenser are connected with a U-shaped mild steel pipe. Two flanges joint is used in the connection of reactor and condenser. A copper tube with several bending is used to carry the gas and which acts as a condenser. There is a bypass path at the end side of the tube which helps to pass the extra uncondensed gas. To decrease heat loss and gas leakage asbestos ropes and silicone gasket are used. To make the reactor oxygen free initially a vacuum pump is used so a vacuum valve is mounted on the top side of the U shape pipe. The constructed apparatus is installed in the Heat Engine Laboratory at Khulna University of Engineering & Technology, Khulna, Bangladesh.

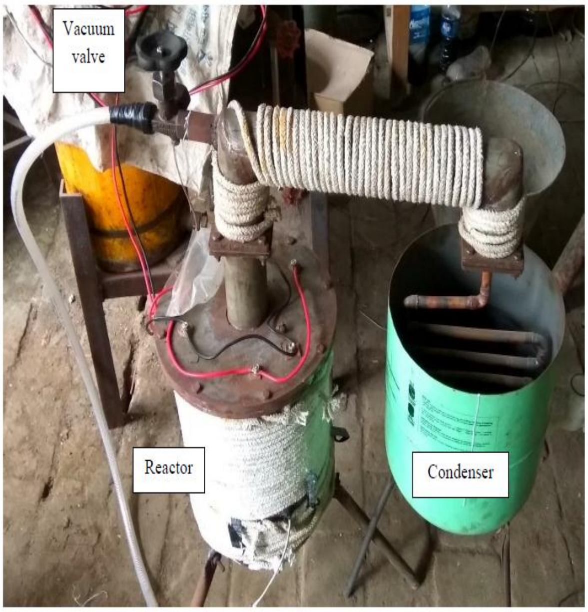

Fig 6: Final constructed apparatus

3. Results and Discussion:

Pyrolytic conversion of Banana waste is performed in the constructed fixed-bed reactor system. Temperature readings inside the reactor were taken by using a K-type thermocouple and water temperature of the condenser was taken by using a thermometer. After each observation, the amount of products from the process were measured. Table 1 shows the experimental data were taken during the experiments and Table 2 and 3 show the amount of products were obtained from the process.

Table 1 Experimental data

Mass of feed (gm)	Starting temperature (^oC)	Final Temperature (^oC)	Pyrolysis time (min)
865	60	435	45
1100	68	477	60
950	63	448	52
900	60	450	50
1050	70	475	55

Table 2: Amount of products obtained from the experiment

Incondensable Gas (gm)	Amount of Ash (gm)	Mass of Liquid including moisture (gm)	Mass of liquid without moisture (gm)
380	320	135	30
475	421	164	40
390	373	155	32
370	365	135	30
455	410	140	45

Table 3: The Relative amount of the products

Percentage of incondensable gas	Percentage of ash	Percentage of liquid (without moisture)
43.93	36.99	3.46
43.18	38.27	3.63
41.052	39.26	3.36
41.11	40.55	3.33
43.33	39.04	4.28

3.1 Yields of pyrolysis products in weight percentage:

The main products of banana waste pyrolysis are liquid fuel, ash, and non-condensable gases. The amounts of products are yielded from banana waste pyrolysis are shown in table 4 in comparison to the amount of the products of pyrolysis of bagasse, jute stick [4] waste tire [5] and waste plastic [6]. In average 42.5% incondensable gas, 38.8% ash and 3.6% liquid fuel were obtained from banana waste. It is clearly indicated that the amount of fuel extracted from banana waste is very low compared with others.

Table 4: Yields products comparison with others biomass pyrolysis

Bio mass	% of Liquid	% of Ash	% of Gas
Banana Waste	3.6	38.8	42.5
Bagasse	69.5	19.4	10.9
Jute Sticks	68.2	21.7	9.8
Waste tire	49	38.3	12.7
Waste Plastic (PVC)	12.3	0	87.7

The liquid obtained from pyrolysis of banana waste contained a high amount of water content. Dehydrating of fuel was one of the biggest challenges and fuel amount was very low. Percentage of non-condensable gas and ash is too high than liquid fuel. The input energy is too high than output energy. So the efficiency of this is system is too low. Although banana waste is highly available and very cheap, but it contains a very high amount of moisture. After drying very well total moisture are not possible to remove which decrease liquid fuel quality. Due to the high moisture in a banana waste high amount of water content was found in fuel. Dehydrating of fuel was a very big challenge and fuel amount was not satisfactory.

3.2 Properties of obtained fuel:

The properties of the obtained fuel such as flash point, pour point, density, gross calorific value and the kinematic viscosity are measured in the Heat Engine and Fluid Mechanics lab of Mechanical Engineering department, KUET. Gross calorific value was measured by using bomb calorimeter. Kinematic viscosity was measured by using Saybolt viscometer.

Table 5: Fuel properties of the pyrolytic oil in comparison with other commercial diesel fuels, furnace oil and pyrolytic oil obtained from tire scrap

Property	Pyrolytic Oil	Diesel	Furnace Oil	Pyrolytic Oil [8]
Density (kg/m^3) at 30^{o}C	720	820 to 860	890 to 960	912
Flash point (^{o}C)	50	55	70	37
Gross Calorific Value (MJ/kg)	25.5	42 to 44	42 to 43	39
Kinematic Viscosity at 40^{o}C (m^2/s)	7.56×10^{-6}	2 to 4.5×10^{-6}	45×10^{-6}	5.55×10^{-6}
Absolute Viscosity at 40^{o}C (Ns/m^2)	5.44×10^{-3}	1.64 to 3.87×10^{-3}	0.04 to 0.0432	5.016×10^{-3}

The pyrolytic liquid obtained from pyrolysis of Banana wastes appears dark brown with a strong acrid smell. No phase separation was found to take place in the storage bottles. The fuel properties of the extracted pyrolytic oil are shown in Table 5 and compared with diesel, furnace oil and a pyrolytic oil from motor cycle tire scrap [8]. Flashpoint was 50^{o}C, Pour point was -6^{o}C, Density was 720kg/m^3 at 30^{o}C, Gross calorific value was 25,551 KJ/kg, at 40^{o}C Kinematic viscosity and Absolute viscosity were 0.00000756 m^2/s and 0.0054432Ns/m^2 respectively. Where for Diesel, Density is 820 to 860 Kg/m^3, Kinematic Viscosity at 40°C is 2 to 4.5 CeSt, Flash Point is ≥ 55°C, Pour Point is -40 to -1°C, Gross Calorific Value is 42 to 44 MJ/Kg.

4. Conclusion:

Banana waste is a common biomass in Bangladesh and its consumption is creasing day by day. The main objective of this work is extracted biofuel from banana waste using pyrolysis technique. A fixed bed pyrolysis apparatus was designed and constructed. Several experiments were performed to extract biofuel from banana waste. The liquid obtained from pyrolysis contained a high amount of water. Among the pyrolytic product, 3.6% was pyrolytic oil and rest were ash, incondensable gas and moisture. It is clear that fuel can be extracted from banana waste. However, amount of fuel is quite low in comparison with other waste and properties of fuel were average quality.

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