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FIXED BED PYROLYSIS OF SUGARCANE BAGASSE FOR LIQUID FUEL PRODUCTION

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ABSTRACT

The conversion of sugarcane bagasse into pyrolytic oil by fixed bed reactor has been taken into consideration in this study. The bagasse in particle form was pyrolyzed in an externally heated 7cm diameter and 34cm high fixed bed reactor with nitrogen as a carrier gas. The reactor and gas-preheater were heated by means of a renewable energy biomass source cylindrical heater. At a reactor bed temperature of 450°C for a feed particle size of 300-600μm and at a gas flow rate of 4 l/min, an oil yield of 49wt% of dry feed was obtained. The pyrolysis process temperature was found to have influenced on the product yields. The product oil was analyzed for their properties as an alternative fuel and compared with other biomass derived pyrolysis oil and petroleum product. The fuel properties compared were physical properties, calorific value, elemental (CHNOS) analysis and chemical composition using Fourier Transform InfraRed (FTIR) spectroscopy.

Keywords: Fixed bed pyrolysis, Bagasse, Liquid fuel

1. INTRODUCTION

Pyrolysis for energy conversion from carbonaceous wastes is defined as the thermal degradation of organic matter 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. Pyrolysis processes are usually conducted in a reactor where heat is applied to the feedstock either externally or by the partial combustion of the feedstock. Three products are usually obtained in a pyrolysis process: gas, liquid and char. When the organic matter is heated in a nonreactive atmosphere the primary vapors are first produced, the characteristics of which are most influenced by heating rate. These primary vapors then further degrade to secondary tars and gases if held at high temperature for long enough time for secondary reaction to occur. The proportions and characteristics of the secondary material are a function of temperature and time. Rapid quenching causes the liquid intermediate products of pyrolysis to condense, before further reaction breaks down the higher molecular weight species into gaseous products. A possible reaction pathway of biomass solid waste prolysis process is shown in Figure 1. The conventional sources of fossil fuels have been depleting at an alarming rate and hence the focus on alternative renewable source of energy is increasing. As a result biomass as a renewable energy source has continued to attract increased attention [2]. A lot of work in this area is in progress using different biomass solid waste as the feed material [2, 10]. Sugarcane grows in many part of the world as well as in Bangladesh.

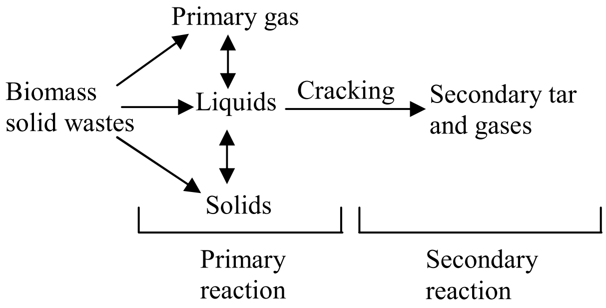

Fig 1. A possible reaction pathway of biomass solid waste prolysis process.

Tropical based climate of the country is suitable for sugarcane production. About 20 wt% of raw sugarcane is generated as biomass solid waste in the form of sugarcane bagasse (sun-dry basis). There are 17 sugar mills in Bangladesh and the bagasse is the major by-product of these mills. Some amount of the by-product is used as fuel for boiler in the millhouse. Mostly this is either under-utilized or unutilized as a source of heat energy. For the past five years the generation of this waste was 1489.2, 1433.0, 1504.2, 1475.8 and 1390.2 thousand metric ton respectively [3]. It is creating waste management problem, specially in the sugar milling sites. Thus, an endeavor from the point of view of the energy recovery from this sugarcane bagasse waste by thermochemical process may be worthwhile.

Recently, characterization studies on solid sugarcane bagasse has been carried out through proximate, ultimate and thermogravimetric (TG) analysis [11]. The results of these analyses showed that the solid biomass has high potentials to provide liquid fuel by pyrolysis conversion process. Amongst the thermochemical processes, pyrolysis has received increasing attention since the process conditions may be optimized to produce high energy density pyrolytic oil in addition to the derived char and gas [2]. The pyrolytic oil may be used directly as a fuel, catalytically upgraded to refined fuel, or added to petroleum refinery feedstocks [2, 4]. The solid char may be useful as fuel, either directly, briquetted or as char-oil or char-water slurries [2]. In addition the derived gas has a high calorific value sufficient to be used for total energy requirements of the biomass pyrolysis plant [2, 5]. Consequently all the derived product streams from the pyrolysis of biomass are available for recovery of energy. Most recently some works have been carried out with the sugarcane bagasse as feedstock at the Heat Engine Laboratory of the Department of Mechanical Engineering, Rajshahi University of Engineering and Technology to obtain liquid fuel using fixed bed pyrolysis technology.

2. MATERIAS AND METHODS

2.1 Biomass

The bagasse was collected from Rajshahi Sugar Mills Limited, Horian, Rajshahi, Bangladesh. It was ground and sieved to the size of 300-600μm and finally dried for 24 hours at 110°C prior to pyrolysis. The gross calorific value of the solid sugarcane bagasse is 16.81 MJ/kg and its bulk density is 177.65 kg/m^3. The proximate and ultimate analysis of the solid biomass is presented in Table 1.

Table 1: Proximate and ultimate analysis of solid sugarcane bagasse

Proximate analysis		Ultimate analysis	
Contents	wt%	Elements	wt%
Volatile	74.98	C	43.77
Fixed carbon	13.57	H	6.83
Moisture	9.51	N	-
Ash	1.94	O	47.46
		S	-

2.2 Fixed Bed Pyrolysis System

The experimental system was a fixed bed pyrolysis unit. Nitrogen was used as carrier gas and also to make the system inert. Flow sheet of the process is given in Figure 2. The reactor was 7cm diameter × 34cm high, constructed of stainless steel with full gas flow and temperature control. The reactor was heated externally. The incoming carrier nitrogen gas was pre-heated before entering the reactor in a pre-heating chamber. The gas flow rate was measured and controlled by nitrogen gas flow meter. The reactor bed and gas pre-heating chamber were heated by means of renewable energy biomass source cylindrical heater. A blower supplied air required for burning biomass in the heater. By varying the air supply that was directly related to the blower speed controlled the temperature of the reactor. The temperature in the fixed bed reactor was measured by a digital pyrometer. The ash of burned biomass in the heater was disposed of through a ash disposal system at the bottom of the heater due to gravity force. Exhaust gas due to burning of heater biomass was exhausted in the atmosphere through a pipeline at the top of the heater. The biomass solid waste particles were packed initially into the reactor. The system was maintained at a pressure slightly above atmosphere by a nitrogen gas pressure regulator. The char was collected from the reactor after completing a run. The vapors and gases were passed through a water-cooled condenser to a series of two ice-cooled collectors to trap the derived liquid product. The carrier gas and noncondensible vapor were flared to the atmosphere. In this experimental study the influence of reactor bed temperature on the liquid and the solid char products yields were studied

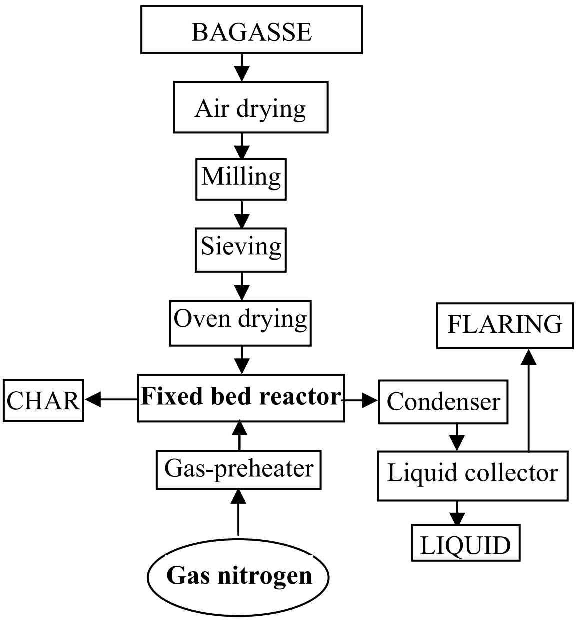

Fig 2. Flow sheet of fixed bed pyrolysis system

2.3 Oil Product Analysis

2.3.1 Physical and chemical analysis

The pyrolytic oil at the maximum liquid yield condition was characterized for its physical properties. These properties were determined according to standard American Society for Testing and Materials (ASTM) test methods. The properties determined were: kinematic viscosity, density, pH value, flash point, pour point and gross calorific value. The elemental composition by ultimate analysis, in terms of carbon, hydrogen, nitrogen, oxygen and sulfur (CHNOS) content of the oil was determined. The test was carried out by an Elemental Analyzer of model EA 1108 according to the ASTM D3176-84 standard test procedures in the laboratory of Analytical Research Division, Bangladesh Council of Science and Industrial Research (BCSIR), Dhaka. The technique used for the determination of CHNS was based on the quantitative "dynamic flash combustion" method. The oxygen content was determined by difference, knowing the ash content

2.3.2 Compositional analysis

The functional groups of the pyrolysis liquid obtained at reactor bed temperature of 450^{o}C was analyzed by Fourier Transform InfraRed (FTIR) spectroscopy to identify the basic compositional groups. The FTIR instrument of model SHIMADZU FTIR 8400 was used to produce the ir-spectra of the derived oil. A thin uniform layer of the liquid was placed between two salt cells and exposed to infrared beam. In the FTIR-8400, the infrared beam from light source was reflected by Collimator Mirror into the interferometer. A parallel beam entered the Michelson interferometer with a 30^{o} incident angle. The beam was then divided by beam Splitter, the resultant beams falling upon moving mirror and fixed mirror. Both beams were reflected back to the beam splitter and joined into one interference beam before proceeding to collecting mirror. From the collecting mirror, the parallel infrared beam created an image of the light source in the center of the sample compartment. Another collecting mirror gathered the beam that passed through the sample and reflected it to detector as the interferogram. After reaching the detector, the interferogram underwent several treatments before being sent to the computer. It was amplified by the preamplifier and the automatic gain amplifier, passed through high-pass and low-pass filters, and was digitized by the 20-bit A/D converter. After the signal was digitized into the interferometer memory, it traveled through the SCSI interface to the PC where Hyper-IR transformed the interferogram into a spectrum. It provided the absorption spectrum in percentage incident intensity, along the wave numbers 4000 to 500 cm^{-1}. The standard ir-spectra of hydrocarbons were used to identify the functional group of the components of the derived liquid. The test was conducted in the laboratory of Department of Chemistry of Rajshahi University, Rajshahi, Bangladesh.

3. RESULTS AND DISCUSSIONS

3.1 Product Yields

Three common products: oil, char and gas were recovered after each run of sugarcane bagasse pyrolysis. Higher percentage of liquid collection makes this biomass potential for liquid fuel extraction. The liquid appeared brownish dark with a strong acrid smell. Careful handling of the liquid was required since the liquid reacted easily with human skins, leaving permanent yellowish brown marks and an acrid smell for a few days, which cannot be removed by bleach or detergent. No phase separation was found to take place. The liquid product was collected in two ice-cooled liquid collectors in series. The char was collected from the reactor. This char were expected to be very reactive, and precautions were required to ensure that it would not be exposed to air when still hot. The gas was diluted by the large flow of nitrogen gas and flared into the atmosphere.

3.2 Effect of Reactor Temperature

Figure 3 shows the variation of percentage mass of liquid, char and gaseous products at different fixed bed temperature for bagasse pyrolysis with particle size 300-600μm. From this figure it is found that the maximum liquid product yield was obtained at a reactor bed temperature of 450°C and this was 49 wt% of total biomass fed. With the decrease of bed temperature at 400°C, the liquid product yield was decreasing (38 wt% of biomass fed) while with the increase of bed temperature at 500°C the liquid product yield was again decreasing (36 wt% of biomass fed). With the increase of reactor bed temperature, the solid char yield was decreasing for the temperature range of 400°C to 500°C. For feed particles of size 300-600μm, a bed temperature of 400°C yielded the maximum percentage mass of char, 50 wt% of biomass fed. At a higher temperature of 500^{o}C, the solid char production was lower, it was found to be 31 wt% of biomass fed. Figure 3 also shows that as the reactor bed temperature was increased the gaseous product yield was increasing. A fluidised bed temperature of 500°C yielded the maximum percentage mass of gas yield of 33 wt% of biomass fed. The gas yields were neat to minimum at the condition of maximum oil production.

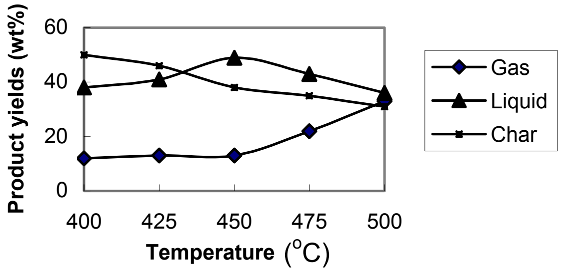

Fig 3. Effect of reactor bed temperature on product yields

This is supported by the thermogravimetric (TG) study of solid sugarcane bagasse, where the complete devolatilization of volatile in bagasse was found to take place at around 450°C. The reason for lower liquid product yield at lower bed temperature may be due to the fact that the temperature rise was not enough for complete pyrolysis to take place yielding less liquid product and higher char production. On the other hand at higher reactor bed temperature there was a possibility of secondary decomposition reactions to take place in the reactor rendering lower liquid and higher amount gas.

3.3 Product Oil Characteristics

3.3.1 Physical and Chemical Characteristics

The elemental composition and the physical characteristics of the bagasse pyrolysis oil obtained at the maximum yield temperature of 450^{o}C is shown in Table 2. The energy content of the oil was 19.185 MJ/kg, due to the presence of moisture and oxygenated compounds. However, it was significantly higher than that of raw bagasse. The oil was heavier than water with density at 30^{o}C is 1160 kg/m^{3} and hence, results higher volumetric energy content. The flash point of the oil was 103^{o}C hence, precautions are not required in handling and storage at normal atmosphere. The oil was easily pourable and the pour point was low, less than –16^{o}C. The oil was found to be moderate in viscosity. The liquid was very acidic with low pH value of 2.98 suggesting its corrosive in nature.

Table 2: The elemental composition and physical characteristics of the bagasse pyrolysis oil and its comparison

Analyses	Standar	Bagasse	Wood waste [6]	Fast diesel [7]
Elemental (wt%)				
C	ASTM D3176-84	45.01	46.24	86.10
H	ASTM D3176-84	6.00	7.55	12.80
N	ASTM D3176-84	-	0.141	-
S	ASTM D3176-84	-	0.03	0.5
Ash	ASTM D482-IP 4	0.25	0.04	0.01
O	By difference	48.74	46.00	-
viscosity @ 30°C (cSt)	ASTM D445-IP71	13.80	66.99#	1.3-3.3§
Density (kg/m^3)	-	1160	1180.20#	780
pH value	Digital pH meter	2.98	2.8	-
Flash point (°C)	ASTM D92-IP 36	103	59	75
Pour point (°C)	ASTM D97-IP 15	-16	-	-
GCV (MJ/kg)	DIN 51900	19.185	19.80	45.00-46.00

@ 40°C; § @ 50°C

The elemental analysis of the oil is an important criterion for the design of a combustion plant utilising the oil with the help of the elemental analysis, the combustion calculation can be carried out from which the quantities of combustion air and flue gas and also the composition of the flue gas can be determined [8]. Bio-crude oils have some properties that are quite different from those of petroleum-drived oils. Biocrude oils contains a large amount of oxygen. The oxygen content of bio-oils (excluding water) is a function of the oxygenated feedstock from which they are made, as well as the residence time and temperature of the pyrolysis step [9]. The oxygen content in the liquid was 48.74%, calculated by difference, was close to that of feedstock composition. The sulfur content of bio-oils is naturally low, due to the low sulfur content of biomass. This low sulfur content is one of the positive aspects of bio-oils [9]. The amount of sulfur in the biomass derived oils will indicate the quantity of the hazardous SO_2 emission in combustion processes. The sulfur was not found and ash content was also found to be low as 0.25% of the oil weight. One of the variables with bio-oils will be the nitrogen content of the oil, which will reflect the variable protein content possible with biomass. Biomass which has a significant content of green, living plant cells (e.g. green grasses) will have a higher nitrogen content than biomass having a large content of dead plant cells (e.g. straw and wood) [9]. The nitrogen content in the bio-oils will contribute to NO_X emissions and it was not detectable in the rice-straw pyrolytic product.

3.3.2 Compositional analysis

From the Fourier transform infra-red spectroscopy of the derived pyrolytic oil, the FTIR functional groups and the indicated compositions of the liquid product were presented in Table 3. The presence of water impurities and other polymeric O-H in the oil are indicated by the broad absorbance peak of O-H stretching vibration between 3600 and 3200 cm^{-1}. The presence of alkanes were indicated by the strong absorbance peak of C-H vibrations between 3050 and 2800 cm^{-1} and the C-H of deformation vibrations between 1490 and 1325cm^{-1}. The absorbance peaks between 1775 and 1650 cm^{-1} represented the C=O stretching vibration, indicating the presence of ketones, aldehydes and carboxylic acids. The possible presence of alkenes were indicated by the absorbance peaks between 1680 and 1575 cm^{-1} representing C=C stretching vibrations. The sharp but less prominent absorbance peaks between 1550 and 1475 cm^{-1} represented $-NO_2$ stretching vibration indicated the presence of small nitrogenous compounds. The overlapping peaks between 1300 and 950 cm^{-1} were suggested due to the presence of primary, secondary and tertiary alcohols, ethers and esters due to the C-O stretching and O-H deformation vibration of these functional groups. Absorbance peaks between 900 and 650 cm^{-1} indicated the possible presence of single, polycyclic and substituted aromatics groups. These functional groups and the indicated composition have been identified in the pyrolytic derived oils from rice-husk from fluidized bed reactor by Islam and Ani [1].

Table 3: FTIR functional groups and the indicated compounds of the pyrolysis oil

Frequency range (cm^{-1})	**Groups**	**Class of compounds**
3600-3200	O-H stretching	Polymeric O-H, water impurities
3050-2800	C-H stretching	Alkanes
1775-1650	C=O stretching	Ketones, Aldehydes, Carboxylic acids
1680-1575	C=C stretching	Alkenes
1550-1475	$-NO_2$ stretching	Nitrogenous compounds
1490-1325	C-H bending	Alkanes
1300-950	C-O stretching O-H bending	Primary, secondary and tertiary alcohols, phenol, esters, ethers.
900-650		Aromatic compounds

The pronounced oxygenated functional groups of O-H; C=O; C-O and aromatic compounds showed that the oil was highly oxygenated and therefore very acidic, as have also been indicated by the elemental composition and the pH value. The high fraction of oxygenated compounds reduce the calorific value of the oil since C=O bonds do not release energy during combustion. The presence of hydrocarbon groups C-H; C=C; and alcohols indicate that the liquid has a potential to be used as fuel.

4. CONCLUSIONS

Fixed bed pyrolysis of solid sugarcane bagasse had given maximum oil yield that was 49 wt% of biomass fed at a reactor bed temperature of 450°C and at a gas flow rate of 4 l/min. With increasing reactor bed temperature, the percentage mass of char production was decreasing while gas production was increasing.

- The pyrolytic oil was a single-phase liquid product.
- The elemental composition of the oil was better than that of solid biomass.
- FTIR analysis showed that the liquid was dominant with oxygenated species.
- The physical properties analysis showed that the oil was heavy and acidic in nature with moderate viscosity. The oil possessed favorable pour and flash points.
- The heating value of the oil was moderate, however, the value is similar to other biomass derived pyrolitic oil. This value was significantly higher than that of solid bagasse.

5. ACKNOWLEDEGEMENTS

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7. NOMENCLATURE

Symbol	Meaning
GCV	Gross calorific value
TG	Thermo
ASTM	American society of testing materials
GOB	Government of Bangladesh
cSt	Centistokes
pH	Negative logarithm of hydrogen ion concentration
O-H	Hydroxyl stretching
C-H	Carbon hydrogen stretching and bending
C=O	Carbonyl stretching
C=C	Carbon carbon double bonding stretching
$-N_2O$	Nitrogen dioxide stretching
C-O	Carbon oxygen stretching
FTIR	Fourier transform infrared