DUJASE Vol. 2(1) 17-20, 2011 (July)

Bio-oil from pyrolysis of bagasse

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Received on 19. 08. 2010. Accepted for publication on 02. 08.2011

Abstract

Pyrolysis is one of the most important routes for thermo-chemical conversion of biomass to fuels. Pyrolysis of bagasse for the production of bio-oil was taken into consideration in this study. Pyrolysis was performed at different temperatures ranging from 400^{0}C to 600^{0}C under vacuum. The optimum temperature of bagasse pyrolysis was 500^{0}C and reaction time was 30 minutes. The products of the bagasse pyrolysis were bio-oil, bio-char and gaseous mixture. The maximum oil yield was 56 wt% of dry bagasse. The fuel properties such as calorific value, viscosity, density, pour point, flash point, water content etc. were determined for the bio-oil and compared with the typical bio-oil characteristics. The physico-chemical characterizations of bio-oil were carried out by FT-IR spectroscopy, ICP-OES and TG analysis. The bio-char was characterized for its suitability to be used as fuel and adsorbent by measuring the calorific value, surface area and by methylene blue adsorption test.

Key words: Renewable energy, Bagasse, Pyrolysis, Bio-oil, Bio-char.

1. Introduction

The world's fossil fuel reserves are limited and in fact nearly exhausted, but the energy consumption has increased. Therefore high demand for fuel is obvious. Thus increasing attention is being paid to the alternative or renewable energy sources. Biomass, a material derived from recently dead organisms such as plants, animals and their residues, is one of the main focused raw materials for renewable fuel (bio fuel) production. Bio-fuel is defined as solid, liquid or gaseous fuel derived from relatively recently dead or alive biological materials while fossil fuels are derived from long dead biological materials. The bio-oil can be produced from any biological carbonaceous sources; although the most common sources are photosynthetic plants [1]. Various plants, plant-derived materials and residues are used for bio-oil production around the world according to their availability in the specific zone [2]. Needless to say, sugar cane is one of the most produced crops in the world. About 30 wt% of sugar cane generates bagasse during the extraction of juice from cane [3]. It is estimated that over 80 million metric tons of bagasse is generated annually in the world from which 90% is from the developing countries [4]. Mostly this is either under-utilized or unutilized as a source of heat energy. Bangladesh is an agricultural country, produce huge sugar cane as well as bagasse. Thus clean energy recovery from this bagasse waste may be worthwhile. The thermo gravimetric analysis (TGA) study of bagasse [5] shows that bagasse may be utilized for energy recovery as a fuel. The pyrolysis oil may be used as a fuel in boiler, dedicated diesel engines and industrial gas turbines for the purpose of power generation [6]. In addition to this, there are scopes to upgrade the oil to obtain high grade fuel and valuable chemicals [7]. The solid char can be used for making activated carbon, reinforcing fillers in plastics, rubber goods and as fertilizer and soil conditioner [8]. The energy obtained from bio-oil is a form of renewable energy. Utilization of this energy does not add any extra carbon dioxide to the atmospheric environment in contrast to fossil fuels [9]. Due to the lower contents of sulfur and nitrogen in the bagasse pyro-oil, its energy utilization also creates less environmental pollution and health risk than fossil fuel combustion.

2. Materials and Methods

2.1. Materials

In this study, the bagasse sample was collected from Zeal Bangla Sugar Mill, Jamalpur, Bangladesh. The physical impurities of the sample were separated out. The sample was then solar dried and stored in the laboratory under dry condition. The main characteristics of bagasse raw materials were determined and are shown in Table 1.

Table 1: Characteristics of bagasse raw materials

Characteristics	Values
Moisture, % wt.	17.43
Ash , % wt.	2.76
Combustible matter, % wt.	85.34
Carbon residue, % wt.	12.88
Average bulk density, kg/m^3	377.56

2.2. Pyrolysis

An electrically heated fixed-bed tubular reactor was designed for this experiment. The length of the reactor was 0.61 m and the inner diameter was 0.08 m. Pyrolysis experiments were performed at 710-720 mmHg pressure. Moisture free bagasse sample was taken into a stainless steel mesh and was introduced into the tube furnace. The furnace was heated electrically and the reactor temperature was recorded using a YOKOGAWA digital thermometer (model 2455). A centrifugal pump was set to create and maintain the vacuum inside the pyrolyser. The temperature of pyrolyser was varied from 400 to 600°C for several experiments. The mixture of liquid and gases came out through the vacuum line of the pyrolyser. The fluid from the pyrolyser was condensed in a series of ice-cooled condenser and raw bio-oil was obtained. Uncondensed gas was blown off. The solid bio-char was collected from the pyrolyser as residue at the end of each batch of pyrolysis.

3. Results and Discussion

3.1 Product yields

The products obtained from the pyrolysis process were liquid oil, solid char and gaseous mixture. The liquid was found to be a single phase greenish-white color. From the several experiments it was observed that the yields of liquid product and solid char vary with process conditions. With the increase in temperature up to 500°C, the liquid yield increased. The liquid product yield decreased with the further increase in temperature. The maximum oil yield was 56 wt% of dry bagasse sample at 500°C. At a temperature lower than 500°C, the liquid yield decreased and char yield increased. On the other hand, at a temperature higher than 500°C, the char and oil yields were found to be lower while the gas yield was observed to be higher. The reason for lower amount of liquid yield at lower temperature may be due to the fact that the temperature was not enough for complete pyrolysis. At higher temperature there is a possibility of decomposition of reaction products to lighter gaseous products giving lower liquid and char yields. The variation of product yields with reactor temperature is presented in Table 2.

Table 2: Effect of pyrolysis temperature on product yield (Pyrolysis time was 30 minutes)

Temperature, °C	Bio-oil yield, %	Bio-char yield, %	Gas yield, %
400	15.7	61.75	22.55
425	18.5	52.67	28.83
450	25.0	46.24	28.76
475	35.5	42.78	21.72
500	56.2	37.02	6.78
525	41.6	32.35	26.05
550	40.0	24.71	35.29
575	37.5	22.58	39.92
600	26.8	22.19	51.01

It was observed that the yield of oil product increased with time. After 30 minutes,
the increase in the liquid yield was insignificant. The effect of time on the liquid yield at 500°C is presented in Table 3.

Table 3: Effect of pyrolysis time on liquid product yield

Temperature, °C	Time, minute	% Bio-oil yield
500	10	16
	15	26
	20	35
	25	41
	30	56
	35	58
	40	60
	45	61

3.2 Bio-oil analysis

3.2.1 Physico-chemical Characteristics

Biomass pyrolysis oil is not standardized product. This can exhibit in a wide range of properties and composition based on the feedstock and pyrolysis techniques employed. Product characteristics may also vary with the process conditions. However, the pyrolysis liquid product is highly acidic having high water content, moderate heating value and very low sulfur content [10]. The most prominent is the acidic nature of the oil due to high oxygen content. The pH value of bagasse derived pyro-oil was found to be less than 3 and it is therefore, very corrosive. The high water content of pyro-oil is due to formation of water in pyrolysis process and moisture content of the raw materials [11]. The lower heating value of the oil is due to the high water content and presence of carbonyl compounds [12]. The ash content in the oil is very negligible. Table 4 shows the characteristics of the bagasse oil in comparison to the typical bio-oil.

Table 4: Physical / Fuel properties of bagasse pyrolytic oil

Properties	Method of testing	Bio-oil derived from bagasse	Typical bio-oil
Density @ 15°C, g/cc	IP-131/57	1.01	1.12
Viscosity @ 40°C, cSt	ASTM-D 445-65	4.19	5-20
pH value	pH meter	2.7	2-5
Water content, % wt.	ASTM-74/57	32	20-50
Heating value, MJ/kg.	Bomb calorimeter	14	12-25
Flash point, °C	ASTM-D 93-62	67	85
Pour point, °C	ASTM-D 97-57	-7	-15
Cetane Number	D 613-86	54	~

Ash content, % wt.	IP 4/58	0.07	0.10
Sulfur content, % wt.	ASTM-D 129-64	not detected	trace
Nitrogen content, % wt.	IP 74/57	not detected	trace
Corrosion	IP 154/59	drastic	drastic
Carbon residue, % wt.	ASTM-D 189-65	0.34	0.40

3.2.2 TGA of bio-oil

Thermogravimetric analysis (TGA) indicates the volatility of bio-oil constituents at different temperature. The TGA graph (Fig. 1) gives the information of high water content in bio-oil. The TGA graph becomes almost horizontal after 150^{0}C. This indicates that most of the bio-oil constituents have the boiling point below 150^{0}C.

Fig. 1. TGA graph of bagasse derived bio-oil

3.2.3 FT-IR analysis

The functional groups and the indicated compounds of bagasse derived bio-oil from the Fourier Transformed-Infrared (FT-IR) spectroscopy (Fig. 2) are presented in Table 5.

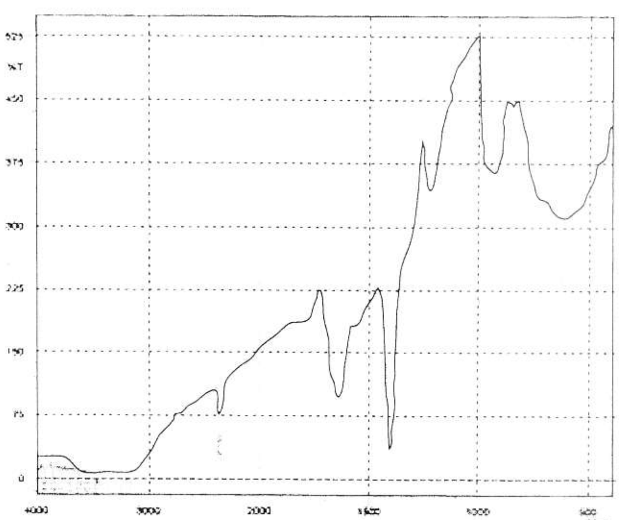
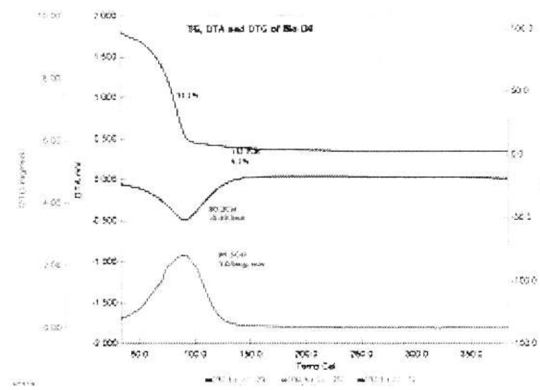


Fig. 2: FTIR spectrum of bagasse bio-oil

Table 5: FT-IR functional groups and the indicated compounds in bagasse derived bio-oil

Frequency range (cm^{-1})	**Group**	**Class of compound**
3650-3100	O-H stretching	Polymeric O-H, water impurities
2800-2300	C-H stretching	Aldehydes
1750-1640	C=O stretching	Ketones, aldehydes, carboxylic acids
1475-1350	C-H bending	Alkanes
1300-950	C-O stretching O-H bending	Primary, secondary and tertiary alcohols, phenols, ethers and esters
900-500	Out-of-plane bending	Aromatic compounds



The high fraction of oxygenated compounds reduces the calorific value of the oil since C=O bonds do not release energy during combustion. The presence of C-H; C=C; and alcohols indicates that the liquids have a potential to be used as fuel.

3.2.4 Analysis of heavy metals in bio-oil by ICP-OES

The bio-oil samples were digested by acid mixtures in a microwave digestion system and analyzed by inductively coupled plasma-optical emission spectrophotometer (ICP-OES model: Varian 720-ES). The heavy metals impurities in bio-oil were analyzed and shown in Table 6. Heavy metals content in the bio-oil were very low and within the acceptable limits.

Table 6: Heavy metal contents in bagasse derived bio-oil

Name of Heavy Metals	**Amount in ppm**
Antimony (Sb)	2.00
Arsenic (As)	4.00
Barium (Ba)	0.05
Cadmium (Cd)	not detected
Chromium (Cr)	5.50
Lead (Pb)	7.25
Mercury (Hg)	not detected
Selenium (Se)	1.50

3.2.5 Bio-char analysis

Calorific value of bio-char was measured by a JULIUS PETERS Berlin NW21 model bomb calorimeter and the value was found to be 22.55 MJ/kg. The high calorific value of char indicates its suitability to be used as fuel. The surface area of bio-char was 214. 32 m^2/kg, obtained by

Blain air-permeability apparatus. Large surface area indicates that the bagasse derived char would be an effective adsorbent. The adsorption capacity of chars was measured by methylene blue (MB) solution test. Bagasse derived bio-char was found to adsorb 5.5 mg/g methylene blue (MB).

4. Conclusions

The bio-oil was single-phase liquid product of greenish-white color with acrid smell. The hazardous creating agents sulfur and nitrogen were not detected in the oils. FT-IR analysis showed that the liquid was dominant with oxygenated species. Hence, it is important to deoxygenate the liquid by some upgrading technology. The physical properties analysis showed that the oil was acidic in nature with lower viscosity. The oil possessed favorable pour and flash points. The heating value of the oil was moderate & the value is similar to other biomass derived pyrolysis oil. From this study, it is found that the pyrolysis of bagasse may be a future potential alternative source of liquid hydrocarbon fuels and chemical compounds feed stock. Further characterization studies on pyrolysis liquid product from the solid wastes should be conducted to provide ways of utilizing the liquid as fuels in boiler; internal combustion engines etc. Catalytic upgrading of the liquid product to higher utility fuels, using various types of catalyst may also be studied.

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