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Experimental Characterisation of Bagasse Biomass Material for Energy Production

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ABSTRACT

A number of persistent problems have been associated with the supply of traditional domestic fuel products in Nigeria particularly in rural areas including deforestation, wood-fuel shortage and high cost of fossil fuel. The use of bio-fuels from agricultural waste biomass which are usually available in large quantities was advocated. This paper therefore presents the experimental determination of fuel performance parameters of sugarcane bagasse after two weeks of sun drying. Samples were prepared and analysed for bulk density, moisture content, ash content, volatile matter, chemical and calorific values. The results indicate that fuel performance properties are affected by moisture content. The bulk density and volatile matter decrease with decrease in moisture content. After 14 days of drying; the moisture content, bulk density and the volatile matter decreased from 30%; 320kg/m^3 and 81.7% to 7%, 280kg/m^3 and 69.4% respectively. The ash contents, carbon contents and the calorific values increased from 3.30%; 12%; and 5.57 MJ/kg to 7.21%, 16% and 14 MJ/kg respectively. The proximate analyses results and mineral elements in bagasse were in agreement with those found in wood-fuel. The results suggest that the disposed off bagasse could be developed as a source of energy for domestic and industrial purposes.

Keywords: *Bagasse, moisture content, drying, fuel performance properties, energy*

1. INTRODUCTION

Large quantities of biomass residues are generated from agricultural processing in Nigeria yearly and these had been poorly utilized which invariably become menace to the environment. Research efforts are currently being geared towards effective management of these enormous wastes. Presently, sugarcane is grown on 25-30 thousands hectares in the country, of which industrial cane covers about 12 thousands hectares. (Wada *et al*, 2004). With an average yield of 80 to 100 tons cane per hectare, the annual yield of sugarcane in Nigeria is two to three million tons; about 45% of which ends up as bagasse, a ligno-cellulose material left after the removal of fluids (sugar and moisture) from sugarcane.

Biomass has been defined by Hollie, 2011, as organic plant materials which do not directly go into foods or consumer products. Biomass is not only of interest as a fuel source, it is also readily becoming a raw material option for power and bio-based products such as chemicals, building materials and plastic production (Hollie, 2011). Other advantages of using biomass as a source of energy include the fact that are available in large quantites from renewable energy source; and are not associated with environmental hazards such as acid rain, mine spoils, open pits, radioactive waste disposal or the damming of rivers. Also biomass fuels are sustainable as the green plants from which the fuels are derived use the carbon dioxide during growth. The use of waste biomass as a fuel avoids pollution and other landfill disposal problems (Nishan Sriram and Mohammad Shahidehpour, 2005)

The amounts of sugar, lignin, and lignin-like compounds increase with age of the plant until the flowering time, therefore it is essential to determine the amount and mineral compositions before they can be used as fuel (Ma *et al.*, 2000). Senthilnathan *et al*, (2014) characterised coconut coir-glass-human hair-coconut coir hybrid composite to determine the mineral content by using hand layup method. Biren *et al* (2013) evaluated the mechanical properties of red mud filled coir fiber reinforced polymer composites using the Bayer process of extraction.

Activated carbon was also characterised by Ash *et al* (2006) using SEM, particle size analyzer and proximate analyzer to determine its relevance when used as a purifier. Raju *et al* (2012) also investigated the properties of groundnut shell particles reinforced polymer composite by testing for their physical and mechanical properties to determine their relevance as a filler material. Another research also was conducted by carbonisation and activation of activated carbon which was produced from agricultural waste materials to replace commercial ones used for taste and odour removal in water treatment (Chipofya and Mcconnachie, 2000). With such a wide range of biomass sources and production process variables, the need to understand the composition of the bagasse fibre becomes an important issue hence the essence of this study.

2. MATERIALS AND METHODS

2.1 Bagasse Fibre Preparation

Bagasse was obtained from Bodija Market in Ibadan, Oyo State. The raw bagasse was received at about 30% moisture content. It was sun-dried for 14 days, manually depithed and finely ground by hammer milled. The hammer-milled particles were sieved through 600 μm and bagged.

Plate 1: Preparation of sugarcane bagasse for analyses

2.2 Determination of the properties of the biomass

The bagged samples were analyzed for density, moisture content, volatile matter, organic and ash contents, calorific values and chemical analyses during the drying period of 14 days.

2.2.1. Density Analysis

The bulk density was determined by calculating the ratio of the mass to the volume occupied. A container of known volume was weighed. The container was filled with each sample and reweighed. The difference between the initial weight of the container and the final weight was the weight of the sample. The bulk density was calculated from the relationship:

$$Bulk\ density = \frac{W_{bc} - W_c}{V_{bc}}$$

Where:

W_{bc} = Mass of the sample and the container
W_c = Mass of th container
V_{bc} = Volume occupied by the bagasse

2.2.2 Determination of moisture content

The moisture content of sugarcane bagasse was determined by the oven drying method. This was carried out at temperature of 103 ± 2ºC in accordance with the ASTM D 1037 (1991)

The moisture content was calculated by using the equation:

$$M_{bagasse} = \frac{(W_i - W_f) \times 100\ \%}{W_i}$$

Where:

W_i = initial mass of bagasse
W_f = final mass of bagasse

2.2.3 Determination of Ash Content

Ash content was determined using the ASTM D 2017 (1998) 0. 3 g of bagasse placed in a pre-weighted crucible was incinerated in a muffle furnace at 760^0 C until complete ashing was achieved. The crucible was then transferred into a desiccators for cooling. Three replicates were made. The cooled samples were then weighed. The ash content was calculated by using the equation:

$$Ash\ content\ (\%) = \frac{(W_2 - W_0) \times 100\ \%}{W_1 - W_0}$$

Where:

W_0 = Weight of the crucible, W_1 = Weight of the crucible + sample before incineration and W_2 = Weight of the crucible + sample after incineration

2.2.4 Determination of Volatile Matter

The volatile matter was determined according to ISO 562/1974. 2g of the samples of the bagasse was incinerated in crucible at temperature of 800^0 C for 5 minutes and allowed to cool down in a desiccators. The volatile matter content was calculated by using the equation:

$$\%\ Volatile\ Matter\ Content = \frac{(initial\ weight - final\ weight) \times 100}{initial\ weight}$$

2.2.5 Determination of Fixed Carbon

The fixed carbon of bagasse was determined as reported by Debdoudi et al. (2005) using the relationship below:

$$FC = 100 - \%Ash - \%VM$$

Where:

FC = fixed carbon; %Ash = % Ash content and % VM =% Volatile Matter

2.2.6 Determination of Calorific Value

The net calorific value was determined by using the relationship below:

$$NCV = 18.7\ (1.0 - AC - MC) - (2.5MC)$$

Where:

NCV = net (lower) calorific value
AC = ash content
MC = moisture content

2.2.7 Determination of Protein Content

The crude protein content was determined using Kjedhal method (AOAC, 1989). 10 g of bagasse sample were digested using 5.5 g of the combined catalyst of CuSO4 and K2SO4 (ratio 1:10) and 15 ml of conc. H_2SO_4. A control sample was also prepared without the specified chemicals. It was digested at a temperature of 400°C until the solution became colourless. The titre values were obtained for the blank. Three replicates were produced. Protein content was calculated by multiplying the total nitrogen content obtained from Kjeldahl experiment by Kjeldahl factor of 6.25, since on the average 16% of most protein are nitrogen (AOAC, 1990).

$$\%N = \frac{(titre - blank) \times N \times N_f \times D_f \times 100}{S_w}$$

$$\%\ Protein = \%N\ \times 6.25$$

Where:

N = Normality of the HCI, N_f = Nitrogen factor 14/1000, D_f = Diluted factor (100),
S_w = Sample weight and N = Nitrogen

2.2.8 Determination of Proximate and Chemical Analyses

This study was carried out to evaluate the proximate and chemical components of the bagasse of *Saccahrum officinarum* at oven dried condition.

2.2.8.1 Determination of Cellulose + Lignin

1g of dried ground sample was weighed into a 250 ml fibre flask and 100 ml of cold sulphuric acid-CTAB solution and 2 ml of decaline were added. The mixture was gently boiled for 1 hr. The mixture was filtered while still hot and the residue was washed with boiling water and acetone. The crucible and content were dried in an oven at 100°C overnight and allowed to cool in a desiccator and weighed. Percentage ADF was calculated using the formula:

$$\%ADF = (\frac{W_{cr} + dryADF) - W_{cr}}{Wt.ofSample} \times 100$$

Where:

% ADF = Acid Detergent Fibre

2.2.8.2 Determination of Lignin Content

The ADF residue as obtained in the preceding experiment was soaked in cold sulphuric acid. The mixture was stirred to a smooth paste to break all the lumps. The process was repeated three times. The residue was washed with hot water until free from acid. The residue in the crucible was dried for 24h at 100°C and then cooled. It was then weighed (W_1). The crucible plus oven dried residue was transferred to a muffle furnace set at 550°C to ash for three hours till a white grayish ash was obtained, cooled in a desiccator and weighed (W_2).

% ADL was calculated using the formula:

$$\%ADL = (\frac{W_1 - W_2}{Wt.ofSample}) \times 100$$

2.2.8.3 Measurement of Percentage Hemi-Cellulose and Percentage Cellulose

Percentage hemi-cellulose and cellulose were determined in accordance with ASTM D 2017– 98

$$\%Hemicellubse = \%NDF - \%ADF$$
$$\%Cellulose = \%ADF - \%ADL$$

Where:

%NDF = the percentage of the neutral detergent fibre which is the measure of the total percentage of cell wall constituents.

%ADF= the percentage of the acid detergent fibre which is the measure of the sum total by percent of cellulose and lignin.

%ADL= the percentage of the acid detergent lignin which is the measure of the percentage of lignin only.

2.2.8.4 Determination of Mineral Analysis

5 g of bagasse was ashed in the furnace at 500°C and allowed to cool to room temperature. The ashes were digested in digestion flask with IN-HCI at 90°C for 5 minutes. The content was transferred into a 100 ml volumetric flask and made up to mark with IN-HCI and properly mixed. The content was then filtered and kept in a polyethylene bottle. The digests were then transferred to Atomic Absorption Spectrophotometer (AAS) where the minerals were automatically quantified. All the minerals except for phosphorus were determined by the use of AAS. The phosphorus content was determined using the Vanado-Molybdate method as recommended by AOAC, (1990)

NOTE: All the experimental work was carried out in three replications. The data obtained were subjected to statistical analysis.

RESULTS AND DISCUSSIONS

3.1 Bulk Density

The average bulk density of bagasse reduced from 320kg/m^3 to 280kg/m^3 after 14 days of drying. The bulk density reduced as the moisture content reduced as indicated by increasing the drying time as shown in Fig. 1. The effect of drying on bulk densities of bagasse was significant at 85.49%. Low density improves handling and transportation of the material. The information is useful in the design of energy conversion process and facility.

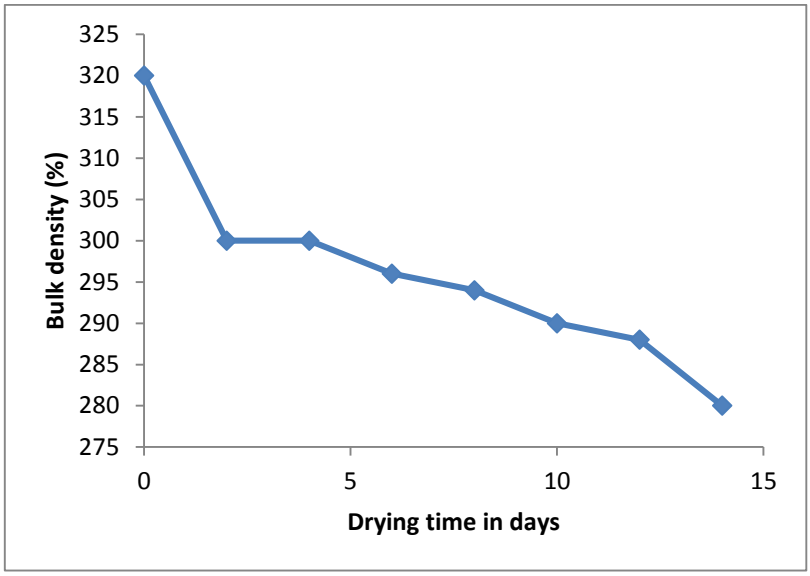

Figure 1: Effect of drying time on bagasse bulk density

3.2 Moisture Content

The moisture contents of crushed bagasse samples as received from the mill were found to range from 28 to 31%. The overall average moisture content of the randomly selected bagasse from different sources was 30%. The moisture migration pattern within the 0 – 14 days of drying is shown in figure 2. It was observed that the moisture contents dropped rapidly within the first four days of drying. The average moisture content reduced from 32% at the first day to 7.0% after 14 days of drying. It was significant at 94.45%.

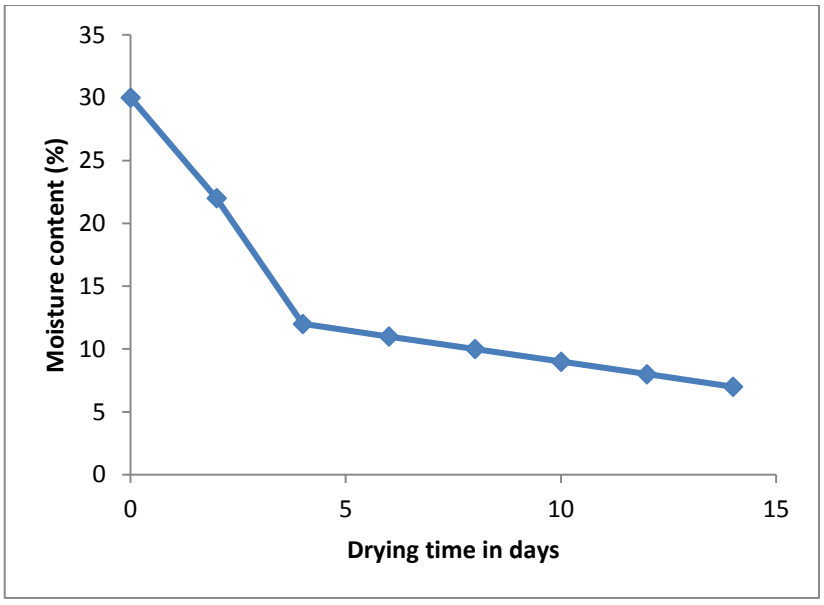

Figure 2: Effect of drying time on bagasse moisture content

3.3 Ash Content

The effect of drying on the ash content of bagasse is shown in Fig. 3. The average ash content increased from 3.30 to 7.21% during the periods of drying. Drying was observed to significantly affect the ash content of bagasse. The result obtained for the ash content compared adequately with what was observed for fuel material by Chow *et al.* (2008). The ash content of pinewood has also been reported to have increased with reduction in moisture content (Szemmelveisz 2009).

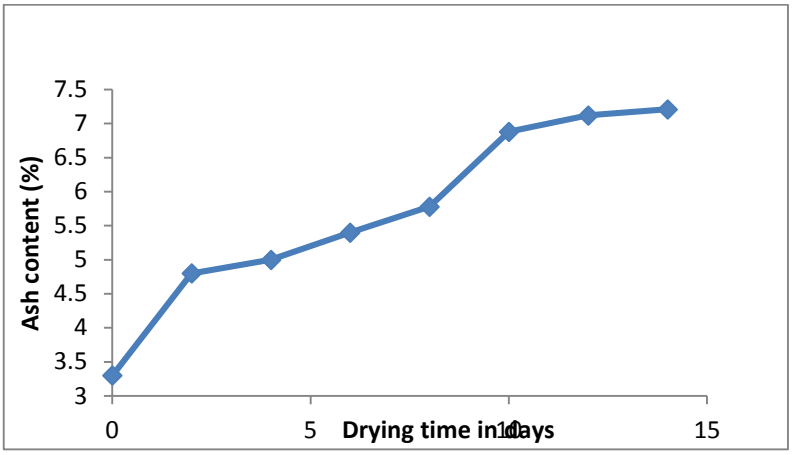

Figure 3: Effect of drying time on bagasse ash content

3.3 Volatile Matter

The volatile matter decreased with decrease in moisture content. The highest volatile matter was obtained at the commencement of drying. The value decreased from 81.7 to 69.4 % from first day to the fourteenth day of drying as shown in figure 4. The results agreed with that of Chow *et al.* (2008) and Szemmelveisz (2009) for palm fruit and pinewood respectively.

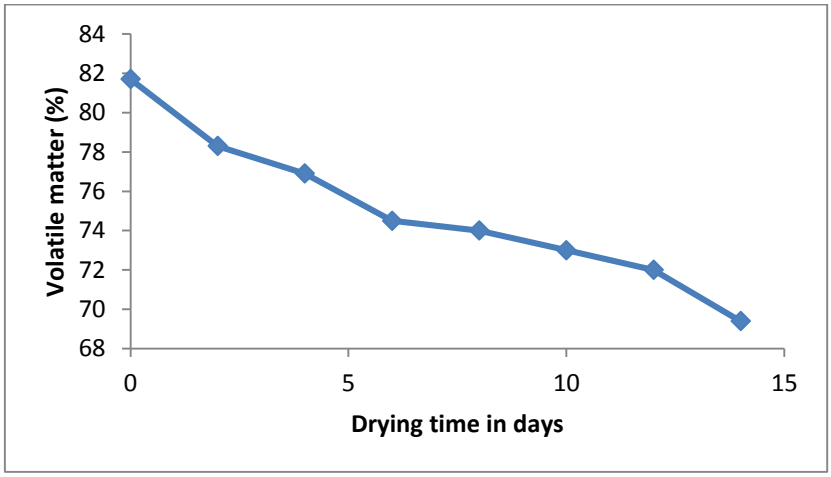

Figure 4: Effect of drying time on bagasse volatile matter content

3.4 Fixed Carbon Content

The average fixed carbon of bagasse increased from 12% from the first day of drying to 16% at the end of drying. The optimum fixed carbon content was observed at about of 12 days of drying. This is shown in figure 5.

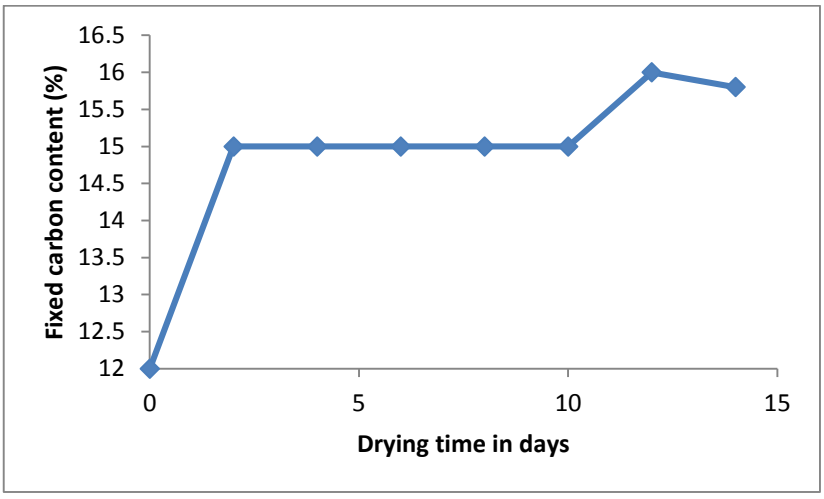

Figure 5: Effect of drying time on bagasse fixed carbon content

3.5 Calorific Value

The net calorific value increased from 5.57 MJ/kg at the onset of drying to 14 MJ/kg as shown in figure 6. Calorific value is very important in the numerical simulations and choice of thermal conversion system for biomass materials.

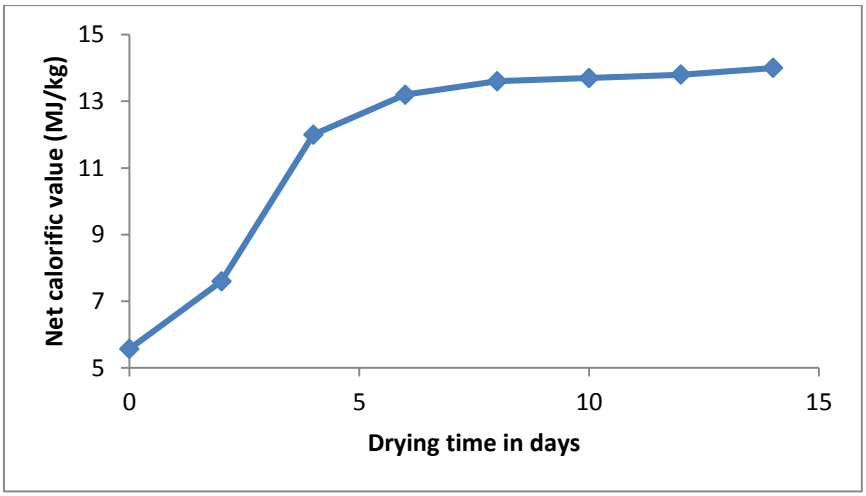

Figure 6: Effect of drying time on bagasse net calorific content

3.6 Mineral Analysis of Bagasse

The mineral elements of bagasse are given in Table 1. Calcium, magnesium and potassium were the major mineral constituents. This was in agreement with the observation of Semple and Evans (2004) as the major minerals found in wood. They estimated that these chemicals may constitute up to 70% of the mineral content of wood. Sodium, manganese, iron, copper, zinc and phosphorus were found in traces in all bagasse samples. The presence of heavy metals in large proportion (over 70.0%), is an indication of toxicity and natural durability. The mineral composition of bagasse could therefore give an indication of the amount of toxic substances in the material.

Table 1: Mineral Composition of Bagasse

Minerals	Parts per million (ppm)	Proportion	Percentage
Ca	-	0.73	72.75
Mg	-	0.01	0.99
K	-	0.22	21.92
Na	11.22	0.001	0.12
Mn	17.22	0.002	2.0
Fe	442.34	0.04	3.99
Cu	238.0	0.0002	0.239
Zn	0.48	0.00005	0.005
PO_4	0.07	0.00007	0.0007

3.7 Proximate Analysis of Bagasse

The proximate composition of bagasse is presented in Table 2. The values obtained indicated that bagasse has nutritional values that can make them attractive to insects. The carbohydrate content was higher than that of rattan (79.44%) while the protein content of bagasse was found to be within the range obtained for rattan (2.94 - 4.62 percent (Dahunsi, 2000). The moisture content was less than 12 percent recommended for good storability and this implies that depithed and dried bagasse can be stored until the need arises. The ash contents of 3.3 ± 0.03 were higher than the range of 0.1 to 0.5 estimated for domestic wood by Semple and Evans (2004). The low natural fat content of 0.5% is a desirable quality. The crude fibre analysis shown in figure 7 revealed that the bagasse consisted mainly of cellulose (43.2%), hemi-cellulose (31.5%) and lignin (22.0%). The relatively high cellulose content of bagasse suggests high fibre per unit weight this would have a positive effect on its combustion characteristics. The pie chart showing the percentage of crude

composition of bagasse is shown in Figure 7. The value agreed with the values of Paturau (2004) having Cellulose, pentosans, lignin and ash contents of 47, 30, 20 and 3% respectively.

Table 2: Proximate Composition of Bagasse

Parameters	Percentage composition
Protein	2.3
Ash	3.3
Fat	0.5
Moisture	7.5
Carbohydrate	86.4

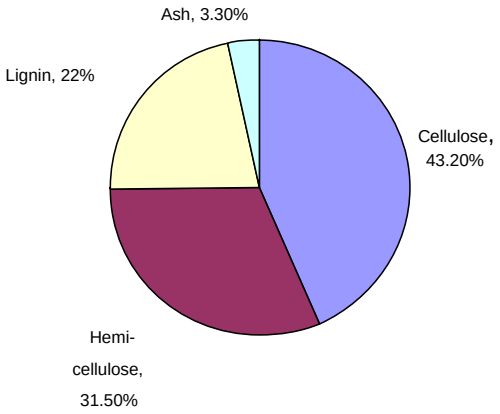

Figure 7: Average crude fibre analysis of bagasse

3. CONCLUSION AND RECOMMENDATION

Energy demand, most especially in the developing nations can be augmented by the use of waste biomass, a renewable energy source which is available in abundance. Ineffective utilization of the biomass residues constitutes environmental hazard and pollution and also emits strong irritating smell due to microbial decomposition activities at dump sites. This calls for quantification, characterization and effective conversion of these readily available by-products for energy production. This study has shown that the calorific value of bagasse can be improved by reducing its moisture content and this can be achieved by sun drying. The calorific value increased from 5.57 to 14 MJ/kg after 14 days of drying. The data generated could be useful in the design of the processes and facilities that will utilize the waste. The results suggest that the disposed off bagasse could be developed as a source of energy for domestic and industrial purposes.

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