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Integrated Energy Recovery and Sugarcane Waste Management

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Abstract

Sugar industry produces bagasse, molasses and press mud as wastes. Bagasse has high energy content while press mud is rich in nutrients such as phosphates, calcium and nitrates. Where the boiler efficiency is low, and no proper waste management options are adhered to, excess bagasse is stored in heaps and left to decompose, creating adverse environmental conditions. Briquetting is an option that can effectively consume all wastes from the sugar industry by converting them to a denser form. To increase mechanical strength of the briquettes, binders such as molasses, starch, clay, cement and ash are used. Clay as a binder inhibits combustion and produces more smoke and ash, resulting to low heat energy value, furthermore its excavation from wetlands leads to land degradation. This study endeavored to find ways of enhancing heat energy and nutrients recovery from bagasse and press mud by incorporating the latter as a binder in the making of bagasse briquettes by piston press. Physic-chemical characteristics of the briquettes were tested as per the South African Bureau Standards of household fuel. Calorific value was determined using adiabatic bomb calorimeter procedure. From the trial experiments, the formulation with 52.6% bagasse, 26.3% press mud and 21.05% molasses was found to be the best integrated formulation for energy recovery for sugar industry wastes management.

Key Words: Bagasse, Briquettes, Energy, Waste Management

Introduction

Global population growth has given rise to increase in demand of agricultural produce, improved living standards and other needs which in turn leads to increased agricultural biomass. Improper management of agricultural biomass waste contributes towards climate change, water and soil contamination, and air pollution. Furthermore, this waste is of high value with respect to material and energy recovery. Biomass is however underutilised especially in third world countries due to weak regulatory framework on pollution control and cleaner production (UNEP, 2009). Although many countries have realized the need to harness local resources to increase security of energy supply, reverse fossil fuel dependency and improve trade balance (UNDP, 2000), there exist room for improvement. The global environmental agenda, for example in the form of Agenda 21, and the Climate Convention has played a role in this process. Energy alternatives sought especially for third world should be affordable and easy to use. This could in turn increase the income generation from sale of energy materials (UNEP, 2009). Some countries in Africa, such as Sudan and Mauritania, have successfully used sugarcane residues to manufacture important products (Gasmalla, *et al.*, 2012), and even to cogenerate electricity (WEC, 2003). In Kenya, Mumias Sugar Company has successfully installed electricity cogeneration plant that utilizes a portion of cane residues.

Sugarcane wastes comprise of bagasse, tops, press mud and molasses. Immediately after juice extraction, bagasse is estimated to be 30% of cane milled, and typically contains 40-50% moisture content and 1-3% sugar. Bagasse contains 43.8% cellulose, 28.6% hemicellulose, 23.5% lignin, 1.3% ash content and 2.8% other components (Luz, Goncalves, & Del'Arco 2007), that if not used rapidly, storage becomes problematic. Owing to presence of moisture, sugar and microorganisms, fermentation occurs, producing alcohol. Fire is a hazard at the storage site, while storm water runoff from stocked pile causes severe environmental problems. Loose bagasse can be used as fuel, but owing to high moisture content, the energy value can be significantly low especially at household level as compared to when it is carbonised and compacted. Thus, to increase the calorific value, it is desirable to reduce the moisture content and thence compact to increase its density.

Filter mud (filter cake, scum or cachaza), is recovered from press and vacuum filters when sludge from clarification process is dewatered. On average, the percentage of molasses in sulphitation is around 4.5% of cane. Molasses contains around 32-35% sucrose and 6-8 % glucose, along with other lesser components (Ramesh, 2012).

Based on a conversion ratio of 5: 1 raw bagasse to carbonized bagasse (Onchieku Chikamai, & Rao, 2012), briquetting technology is an effective and integrated waste management option especially for third world sugar industry.

Specification for Household Briquettes

The following are permissible specifications of various parameters on quality of charcoal briquettes quality specified by SABS (2000).

- Moisture content: ≤10%
- Volatile matter content: ≤20%
- Ash content: ≤5%
- Fixed carbon content: ≥55%

Methodology

Various concentrations of bagasse, press mud and molasses were varied in formulating bagasse briquettes. Additionally, the physico-chemical properties of resultant briquettes were analysed to derive the ratio that best utilises the wastes from sugar manufacture. During the briquettes formation, the carbonising, pulverisation and mixing steps were simplified in such a way that the technology could be easily reproduced by unskilled persons.

Sample Collection

Samples consisting of about 200 kg of bagasse, 5 kg press mud and molasses were collected from Chemelil Sugar Company in Kisumu, Kenya at Latitude: -.066667 / Longitude: 35.066667. Bagasse and press mud were collected in polyethylene bags, while molasses was collected in 20 litre plastic containers. Bagasse and press mud were sundried to reduce the moisture content. Bagasse was thereafter carbonized in a 200 litre drum kiln (Savanakumar, Haridasan, Bai, & Kasturi, 2006), which was modified by drilling nine, 50mm diameter holes at the bottom and having a fitting lid to enable regulation of oxygen and temperature (Practical action, 2009). Bagasse was arranged in the drum very loosely so as to allow free flow of air. Before lighting, the drum was placed 30cm above the ground using three stones to allow air flow from below. Fire was ignited from below and thereafter from above, resulting in a billow of white smoke that got thicker, yellower and darker. To test the release of volatile matter, a lighted matchstick was thrown on the drum and the smoke caught fire, which was let to burn for eight minutes before sealing with the lid. Once the carbonisation process was complete, the stones were removed, the bottom sealed with sand and the carbonised bagasse was let to cool for an hour and a half. Water was then sprinkled on the carbonised bagasse before being removed from the drum, to reduce dust from escaping to the air. The amount of energy consumed during carbonisation was not evaluated. Sun drying and carbonising was done on site to reduce bulkiness during transportation.

Sample Processing

Screening the residues was the first step to obtain fine particles. A sieve 2mm size was used (Predas, 2006) that enabled bonding, and then four replica samples were obtained. Bagasse and press mud were pulverized (ground), to increase surface area for bonding. Bagasse, press mud and molasses were thereafter blended manually in a drum mixer, and the resultant mixture was pressed at 1.00 N/mm^2 based on Onchieku, *et al*. (2012) and extruded to cylindrical briquettes. The rationale for the amount of pressure used was arrived at owing to Onchieku's *et al*. (2012) study on optimum parameters for the formulation of charcoal briquettes using bagasse and clay as binder. He obtained the best highest calorific energy briquette from the ratio of 1:2:40 of molasses, press mud and bagasse among 0.25 N/mm^2, 0.50 N/mm^2 and 0.75 N/mm^2. In all the trials, they exhibited similar burning characteristics of non-smoky, sweet smell and intact ash remaining after cooling.

The thoroughly blended components in various ratios were compressed into cylindrical briquettes measuring 14 mm diameter, and lengths not exceeding 150 mm. The pressing was carried out using a universal strength testing machine with 500 KN capacities at various pressures and loading rates.

The cross-head of the universal machine was fitted with a piston briquetting press that was designed and fabricated at Kenya Forestry Research Institute (KEFRI), Karura offices workshop. The briquetting press had four struts each with a cross-sectional area of about 1200 mm^2 that fitted very closely with metal tubes containing the components making the briquettes.

Testing and Burning Properties

The trial briquettes produced were kept in stationery drying chambers and dried on direct sunlight to about 18 % moisture content. They were tested in accordance to SABS (2000) for ash content, volatile matter and calorific energy value to evaluate their suitability for household use. Density, ignition and burning characteristics were deduced from previous studies on characterisation of briquettes.

Calorific value was determined using adiabatic bomb calorimeter model 1013-B, having a working power of 100 V. The test samples were ground and weighed to 1 g in triplicate and wrapped with tissue paper of a known calorific value and weight. It was then tied with an ignition wire (platinum) of known calorific value. Both ends of the wire are connected to the bomb calorimeter electrodes (+,-) and placed in a bomb and firmly closed. The bomb calorimeter was calibrated with benzoic acid of a known calorific value.

The firing circuit test plug was inserted and the bomb test switch depressed. The lamp in the switch lights lit up signifying correct fitting of the firing wire. Filling the bomb was achieved by connecting the filling tube to the bomb, tightening the union by hand and filling the bomb slowly with oxygen without displacing the original air content by using pressure of 3 N/mm^2. The calorimeter was adjusted by adding water till a total weight of 3 kg was reached (this corresponds to about 3 N/mm^2).

The bomb was placed on three supports in the calorimeter vessel and it was checked not to be leaking of gas. The calorimeter vessel was placed in the water jacket and then turned on. The cover of the water jacket was lowered completely with thermometer and thermistors. Measurement of the temperature rise was achieved by checking that the initial balance was set to the correct reading and waited until the temperatures of the jackets and the calorimeter stabilized. The thermometer reader was used to read the initial calorimeter temperature to 0.001^{0}C and the sample was ignited, and left for 8-10 minutes to obtain its final equilibrium temperature, to 0.001^0C.

The following formula was used to calculate the calorific value of the test samples:

$$\textbf{CV (Cal/g)} = \frac{\{[\text{water equivalent (g)} + \text{Water quantity of inner cylinder (g)}] \times \text{rise in temperature (ºC)} - \text{Correction Value}\}}{\text{Quantity of sample (g}}$$

Where, CV = calorific value.

The correction value is the sum of the calorific values for the tissue paper and the ignition wire.

The water equivalent was computed as follows:

$$\textbf{Water equivalent} = \frac{[\text{CV of benzoic acid (cal/g)} \times \text{weight of benzoic acid (g)}] - \text{Water quantity of inner cylinder (g)}}{\text{Rise in temperature (ºC)}}$$

Data Analysis and Interpretation

MS-Excel statistical package was used to give measures of central tendency, and graphically represent correlation of parameters.

Optimization of the Results Obtained

This was achieved by using MATLAB® whereby a solver was selected and the optimization problem defined. Optimization options were set, inspected and their default values selected for the solver, and then the problems were run. Intermediate and final results were visualized, problem definitions imported, and algorithm options selected. The results were then exported between the MATLAB® workspace and the Optimization Tool. MATLAB code was automatically generated to capture work and automate tasks. The results were subjected to maximization in two sections:

1) Using percentage ratio from the different bagasse, press mud and molasses ratio.
2) Using the resulting physicochemical results to determine the best formulation.

Results and Discussion

The contribution of each of physic-chemical properties to the different formulation ratios is summarized in Figure 1 and Table 1 below.

Table 1. Summary of Ratios and Respective Physicochemical and Calorific Values

Ratios	**% Bagasse**	**% Press mud**	**% molasses**	**% MC**	**% VM**	**% AC**	**% CC**	**CV (MJ/Kg)**
1	20.0	40.0	40.0	9.5	37.7	21.4	31.3	18.79
2	25.0	50.0	25.0	7.9	34.2	27.1	30.8	16.11
3	25.0	25.0	50.0	11.1	37.5	23.9	27.4	14.64
4	33.3	33.3	33.33	8.0	39.8	22.3	30.0	18.83
5	40.0	20.0	40.0	10.5	30.9	26.5	32.1	17.66
6	50.0	25.0	25.0	7.0	34.2	28.0	31.9	15.73
7	52.6	26.3	21.1	7.0	31.4	28.3	33.3	15.69
8	52.6	21.1	26.3	7.6	32.4	23.7	36.1	17.61
9	55.6	22.2	22.2	7.8	32.5	27.6	32.1	16.48
10	66.7	0.0	33.3	8.9	40.2	22.2	28.7	16.95

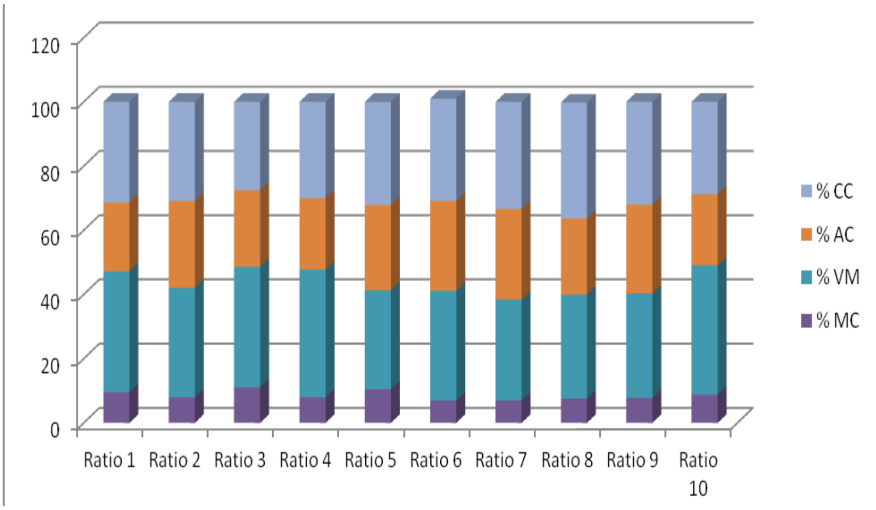

Figure 1. Proportion of Combination of Physicochemical Properties against Various Formulation Ratios

The ratio 4 with equal proportions of 33.3% press mud, 33.3% bagasse and 33.3% molasses had the highest calorific value of 18.83 MJ/Kg. This was followed by ratio 1 with 40% molasses, 20% bagasse and 40% press mud had calorific value of 18.79 MJ/Kg. The ratio 5 with calorific value 17.66 MJ/Kg had 40% molasses, 20% press mud, 40% bagasse. The ratio 8 had 52.6% bagasse, 21.1% press mud and 26.32% molasses that had a calorific value of 17.61 MJ/Kg, carbon content of 36.08%.

Chirchir *et al*. (2013), in a study of comparing cow dung, molasses and clay as binders, concluded that briquettes made using molasses had the best ignition, density and calorific values of the three variables. He also noted that density increased with increase in the binder quantity, with the molasses bound briquette having stronger bonds than clay bound briquettes, hence minimal expansion after extrusion. His study agreed with the finding of Olorunnisola, (2007) and Sotannde, Oluyege and Abah.(2010) where they observed that, the density of briquettes is influenced by binder type and amount. Similarly, Oladeji (2010) and Chirchir *et al*. (2013) noted that ignition time increases with the amount of binder in all types of binders. For an integrated energy recovery of all wastes from Sugar industry, it is important to come up with an optimum briquette that uses all wastes in the sugar industry in a way that bagasse, press mud and molasses are utilized relative to abundance of production and also portions that should bring about the best physic-chemical attributes.

Based on the above previous studies, the briquette that was selected as the best was of formulation ratio 52.6% bagasse, 26.3% press mud and 21.1% molasses that produced press mud briquettes with relatively high calorific values of 15.69 MJ/Kg. The ratios take high amounts of bagasse.

Optimization for Determination of the Best Briquette Ratio

The optimisation equations were obtained subject to the following constraints:

a) The maximum carbonization temperature

$200 \leq T \geq 250$

Where T is in degrees Celsius

b) The percentage bagasse

$20\% \leq X \geq 66.7\%$

c) The percentage press mud

0%≤Y≥50%

d) The percentage molasses in briquettes
21.05%≤M≥50%

e) The moisture content for briquette prior to analysis
10%≤MC≥12%

Optimisation Using Percentage Ratio Bagasse, Press Mud and Molasses Ratio

Coding for model y gave X1: [20, 66.7] → [-1, 1]
X2: [0, 50] → [-1, 1]
X3: [21.05, 50] → [-1, 1]

$$y = 1 + 2x_1 + 12x_2 + 18x_3 + 3x_1^2 + 7x_1x_2 + 10x_1x_3 + 13x_2^2 + 16x_2x_3 + 19x_3^2 + 4x_1^3 + 5x_1^2x_2 + 6x_1^2x_3 + 8x_1x_2^2 + 9x_1x_2x_3 + 11x_1x_3^2 + 14x_2^3 + 15x_2^2x_3 + 17x_2x_3^2 + 20x_3^3 \quad (1)$$

X_1 represent Bagasse, X_2 represent Press mud and X_3 represent Molasses

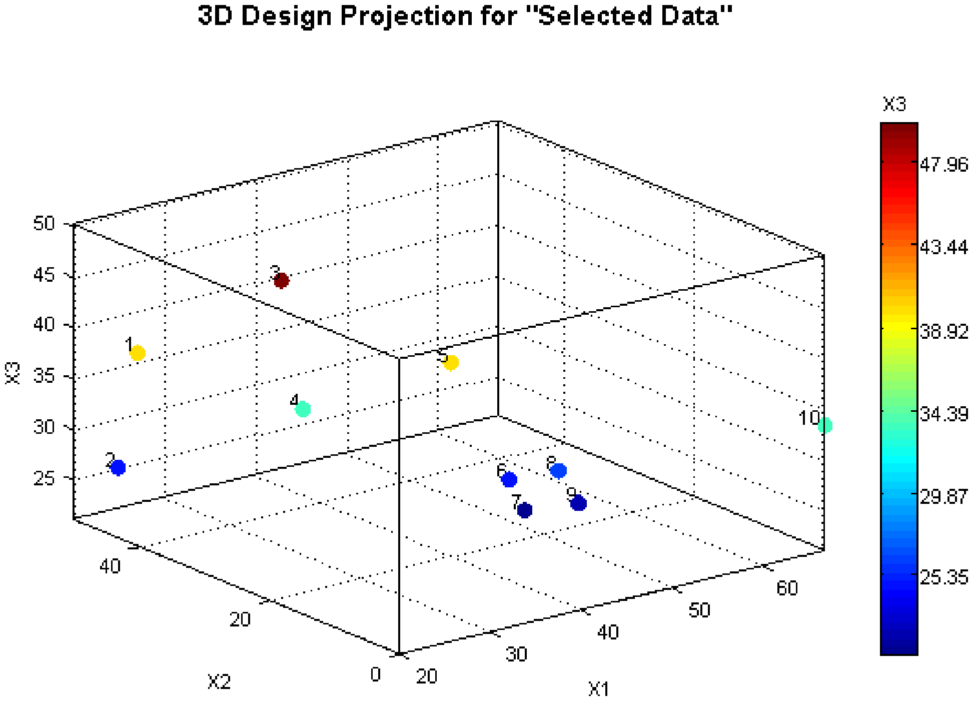

Figure 2. Optimisation Model Using Percentage Ratio Bagasse, Press Mud and Molasses Ratio

Using the Resulting Physicochemical Results to Determine the Best Formulation

Coding Model for y:
X1: [27.44, 36.08] → [-1, 1]
X2: [30.92, 40.2] → [-1, 1]
X3: [7, 11.12] → [-1, 1]
X4: [21.43, 28.25] → [-1, 1]

$$y = 1 + 2x_1 + 17x_2 + 27x_3 + 33x_4 + 3x_1^2 + 8x_1x_2 + 12x_1x_3 + 15x_1x_4 + 18x_2^2 + 22x_2x_3 + 25x_2x_4 + 31x_3x_4 + 34x_4^2 + 4x_1^3 + 5x_1^2x_2 + 6x_1^2x_3 + 7x_1^2x_4 + 9x_1x_2^2 + 10x_1x_2x_3 + 11x_1x_2x_4 + 13x_1x_3^2 + 14x_1x_3x_4 + 16x_1x_4^2 + 19x_2^3 + 20x_2^2x_3 + 21x_2^2x_4 + 23x_2x_3^2 + 24x_2x_3x_4 + 26x_2x_4^2 + 29x_3^3 + 30x_3^2x_4 + 32x_3x_4^2 + 35x_4^3 \quad (2)$$

X1 represent CC, X2 represent VM, X3 represent MC and X4 represent AC.

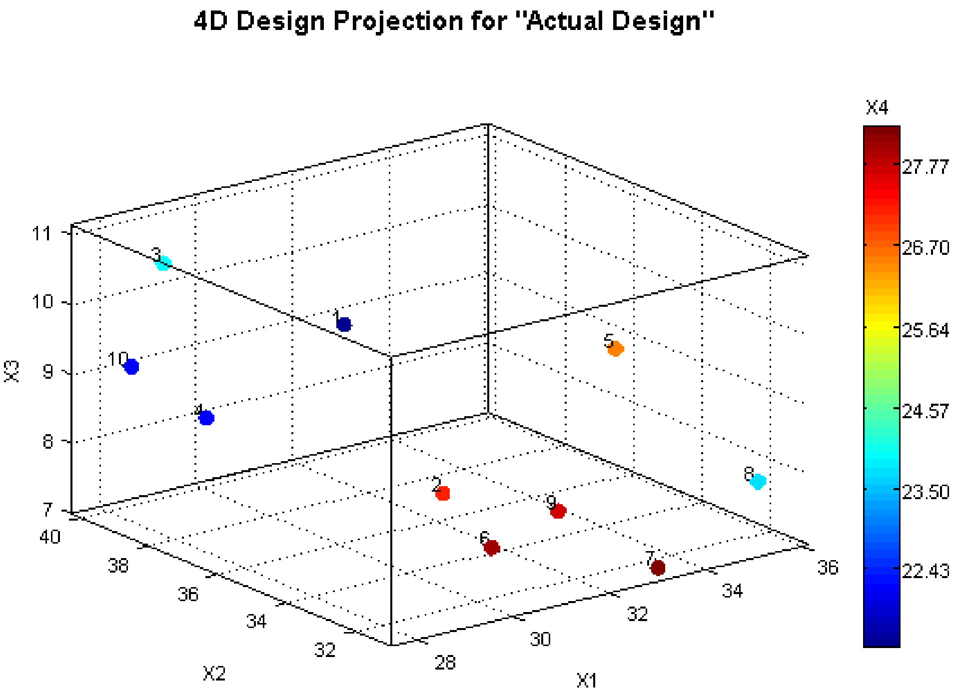

Figure 3. Model of Optimization of Physicochemical Results

From the above equations of physic-chemical properties and percentages formulation ratios, the ratio 2, 6, 7, and 9 maximizes our objective function and form a 3-D surface with minimum value of f(x) as compared to the rest. Then substituting the ratio values (of the 3-D surface formed) to the objective function, y, ratio 7 gives the minimum value, while it maximizes utilization of bagasse (which is the most abundant but hazardous of the sugarcane wastes) by minimizing on molasses (least abundant waste) and press-mud. Looking at both physicochemical and ratio models, we can conclude that ratio 7 gives us the best results as compared to the rest in optimization.

According to Schimding, *et al*. (2002), the resultant product is not just suitable for provision of energy to the rural households, but it reduces indoor air pollution thereby assuring health of the rural poor. The ash content is highest among the ratios due to abundance of a combined bagasse and press mud ratio. The resultant ash has been proven to contain nutrients that can be supplemented for crop major nutrients needs.

Conclusion

Based on the results it can be concluded that formulation ratio 7 of 52.6% bagasse, 26.3% press mud and 21.1% molasses can produce press mud briquettes that will adequately integrate better management of sugarcane wastes with a bearing of abundance and environmental toxicity. The ratio takes the highest amounts of bagasse, which accounts for 22-36% of cane crushed, fulfilling an integrated waste management strategy in sugarcane processing factories. Press mud bound briquettes can provide fuel energy for households and may significantly reduce the burden of deforestation, that has adverse environmental consequences. The surplus briquettes made can be sold and hence creating additional source of income for rural households. Recommendation is made for use of press mud as a binder, in production of briquettes from bagasse in place of clay from swamp that leads to destruction of habitat.

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