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Potential to Use Sorghum Brewers Spent Grains as a Boiler Fuel

Musaida Mercy Manyuchi,[a] Richard Frank,[b] Charles Mbohwa,[a] and Edison Muzenda [a]

The potential of using sorghum brewers spent grain (BSG) was examined for the production of bioelectricity. A local brewery company, with a production capacity of 24 tons per day of sorghum brewers spent grain as biomass waste, was used as a source of boiler fuel. After a full proximate analysis, the sorghum brewers spent grain had an average calorific value of 12.6 MJ/kg whilst coal had 19.9 MJ/kg. In addition, the BSG had a fixed carbon content of 41.6%. This indicated that it was feasible to generate electricity using sorghum brewers spent grain as a source of fuel just like coal; however the moisture content of the BSG must be controlled at minimum levels to attain high calorific values. An assumed feed rate of 1100 kg/h BSG being fed, operation at 86% efficiency, maximum pressure of 9 bars, and a steam output of 1689 kg/h were designed to supply a one megawatt (MW) turbine generator. An economic analysis was done with a total investment cost of USD$ 3.4 million, a payback period of 3.7 years, and a return on investment of 27.4%. Sorghum BSG can be provided as an alternative source of bioelectricity for the brewery industry.

Keywords: Bioelectricity; Brewers spent grains; Direct combustion; Economic analyses

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INTRODUCTION

Electricity is an important aspect of every nation's industrial growth and the economic development of any nation worldwide (Mbohwa, 2003; Mbohwa and and Fukuda, 2003). A study by Attigah and Mayer-Tasch (2013) indicated that there is a strong correlation between reliable access to electricity and the overall productivity of an industry. This means that erratic electricity supplies often result in poor productivity indices. Hence there is a strong need for a constant and reliable electricity supply in any industry worldwide and particularly in developing countries like Zimbabwe. Due to the increased interest in the increased use of biomass in bio energy, there is need to explore alternative route for electricity generation, and brewers spent grains presents such an opportunity (Olagire 2012).

Conversely, the brewery industry is generating brewers spent grain (BSG) that has the potential for conversion into energy (Mussato *et al.* 2006; Weger *et al.* 2014; Buffington 2014). Huge amounts of brewers' waste are generated on a daily basis, and they contribute to about 85% of the bio waste produced, and this can end up at the landfills causing waste management problems (Mussato *et al.* 2006; Aliyu and Bala 2011; Olajire 2012). BSG being a lignocelluloses material contains 17% cellulose, 28% lignin, and 2% non-cellulosic materials, which are mainly polysaccharides (Mussato *et al.* 2006; Buffington 2014). Figure 1 shows the BSG generation process in the brewing industry.

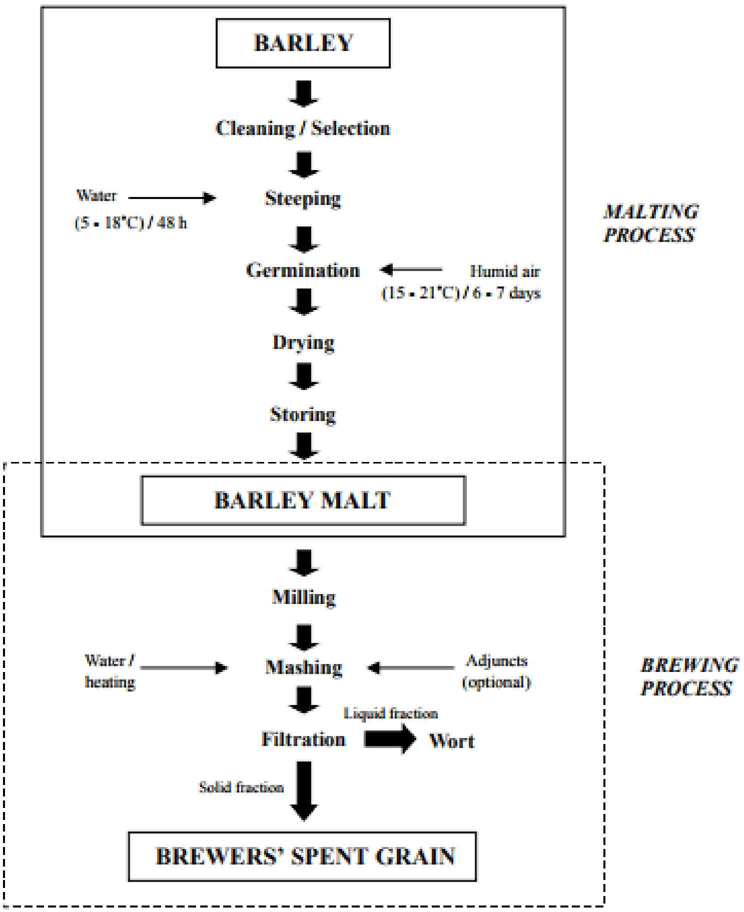

Fig. 1. BSG generation process from the brewery process (Mussato *et al.* 2006)

Energy can be harnessed from the BSG either through combustion, anaerobic digestion, or gasification (IRENA 2012). BSG can also be a source of various energy including bioethanol, biogas, syngas, and biomass briquettes (Mussato *et al.* 2006). Figure 2 shows a summary of the brewing process and potential uses of the BSG in bio energy generation.

In Zimbabwe, electricity is generated commercially through hydropower and thermal power. Zimbabwe has one hydropower station in Kariba, which has an installed capacity of 750 MW, but it is churning out only 694 MW. Four thermal power stations in Munyati, Bulawayo, Hwange, and Harare have a joint capacity of 1190 MW, but they are producing just 763 MW, giving a national total of 1457 MW against a nominal national capacity of 1940 MW. Electricity tariff comparative studies within the Southern African Development Community (SADC) region show that the Zimbabwe Electricity Supply Authority (ZESA) electricity tariffs (at around 9.86 US cents/KWh) are lower than those for Namibia (17.00 US cents /KWh) and Swaziland (10.30 US cents /KWh), while they are generally higher, as compared to information given by Briceño-Garmendia and Shkaratan (2011), for other SADC member states.

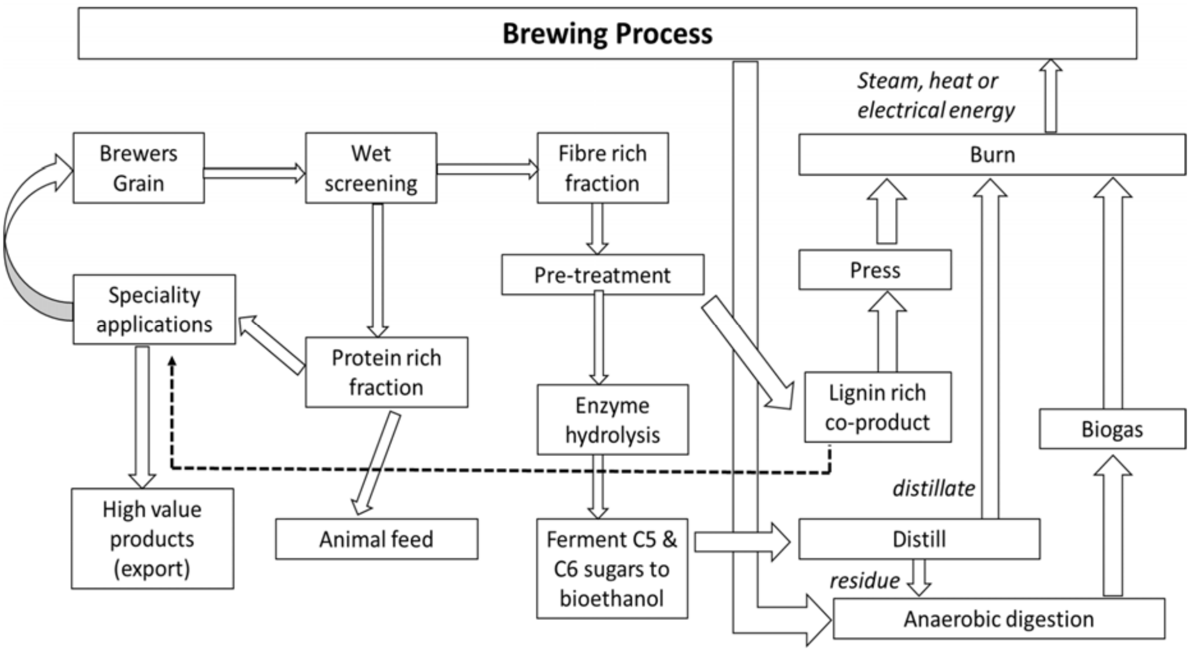

Fig. 2. Bio energy potential of brewers spent grains (Cook, 2011)

The cost of producing bio electricity from BSG is dependent on many factors, which include the cost of electricity, heat requirements in the brewing process, water usage, investment cost, maintenance, and labor costs (Martin and Parsapour 2012). To subsidise the high tariff rates at which the brewery company is obtaining electricity from ZESA, there is need to come up with a more economic but equally efficient power generation alternative. This study therefore assessed the potential to use the BSG from the malting process as an alternative source of electricity that can meet 30% of the brewery electricity demand, which is 3 MW. Furthermore, a cost benefit analysis was done to determine the feasibility of generating bio-electricity from BSG.

EXPERIMENTAL

Materials

Analysis of feedstock

A kilogram of sorghum brewers spent grains was measured from a sample obtained from a local brewery company in Kwekwe, Zimbabwe. The BSG were obtained from a heap out of the process that had accumulated and was ready for use as animal feed or land filling. The BSG was analyzed for their physicochemical properties, which included moisture content, volatile matter, fixed carbon content, ash content, and the calorific value. The physicochemical properties of the BSG were compared to those of coal that is used for firing the boiler at the brewery. According to Crofcheck (2010), the analysis of biomass feedstock is very important because it helps predict the ultimate yield of product gas. The analysis of the quality of the biomass feedstock is also of great importance because it helps minimize the cost associated with a pre-treatment of the feedstock before processing. The following analyses were performed on the biomass feedstock: moisture content, calorific value, fixed carbon, volatile matter content, and ash content

Methods

The physicochemical characteristics of the BSG and the coal (total moisture on a dry basis, ash content, volatile matter, fixed carbon and calorific value) were measured in triplicate, and the variation was compared using histograms. A sensitivity analysis on the impact of varying moisture content of the BSG was done based on the assumption that each of the parameters interacted linearly. During the sensitivity analysis, moisture content values of up to 60% were considered using correlations reported in literature on the relationship between moisture content and the calorific value.

Moisture content determination

A Memmert UF55 moisture oven (Mermmet, Germany) was used to determine the moisture content of the brewery spent grains. The classic oven method of moisture determination uses the principle of calculating the percentage of weight loss of a sample after drying and assuming it to have been the percentage moisture content (Sanni and Fakunle, 2016). For moisture determination, the Memmert UF55 oven was set at 105± 5 °C using a multifunctional digital PID- microprocessor controller with a color display. The system uses a quiet air turbine to force air circulation within the oven so that there is an even temperature distribution within the oven. Its safety features are the presence of an oven temperature monitor that switches off heating when temperatures rise approximately 200 °C above the nominal temperature

The moisture content was determined in accordance with Eq. 1,

$$\text{Moisture content (\%)} = (M_2\text{-}M_3)/\,(M_2\text{-}M_1) \times 100 \qquad (1)$$

where M_1 is the mass of the empty dish (g), M_2 is the mass of the dish + the wet spent grains sample (g), and M_3 is mass of the dish + the dried spent grains sample (g).

Calorific heat value determination

The calorific values of a fuel express the amount of energy released during the complete combustion of a mass unit of a given fuel (Celaya *et al.* 2015). A Nenus Instruments (India) bomb calorimeter was used for the experiments, which is a device that measures heat energy transferred (enthalpy change) between products and reactants at 25 °C. Briggs *et al.* (1996) stated that the bomb calorimeter uses the concept of igniting the sample in a constant volume container (jacket) in water until complete combustion is achieved. The sample is ignited and the difference between the maximum and minimum temperatures of the water was used to compute the gross calorific value.

The brewery spent grains sample was ground to powder, and 1.00 g was measured using an analytical balance. The sample was placed in a bomb calorimeter for firing and the results were displayed. The gross calorific value displayed was then used to calculate the net calorific value.

Volatile matter determination

Volatile matter is any portion of the biomass that is released as volatile gases when heated to temperatures around 400 °C. The volatile matter content represents the percentage of the biomass that volatilizes as a gas; normally high volatile matter content indicates a high amount of the biomass (Celaya *et al.* 2015).

The sample was first oven dried as part of the sample preparation. Approximately 2 g of the sample was weighed in a porcelain crucible and put in a muffle furnace at 550 °C for 10 min. Next, it was cooled in a desiccator, and then weighed, and the percentage volatile matter was calculated as shown in Eq. 2,

$$\text{Volatile matter (\%)} = 100 \times (A - B) / A \quad (2)$$

where A is the mass of the oven dried sample (g) and B is the mass of the sample after 10 min in the furnace (g).

Fixed carbon content determination

The amount of fixed carbon in a sample gives a rough estimate of the calorific value of a substance. This is because carbon generates most of the heat during burning, so there is a higher probability that a sample with high carbon content would have a high calorific value. The determination of the ash content is shown in Eq. 3,

$$\text{Fixed carbon content (\%)} = (M_3 - M_1) / (M_2 - M_1) \times 100 \quad (3)$$

where M_1 is mass of the empty crucible (g), M_2 is the mass of the crucible + brewery spent grain sample (g), and M_3 is the mass of the crucible + ash (g).

Ash content determination

Ash is an inorganic material bound in the physical structure of the biomass that is left as a residue after dry oxidation at 575 °C (Senthilkumar *et al.* 2010). Its accumulation on heat transfer surfaces in boilers, and internal surfaces in gasifiers, normally causes an acceleration in the corrosion rate of such equipment and also reduces its efficiency, hence the need for an ash analysis. The determination of the ash content is shown in Eq. 4,

$$\text{Ash content (\%)} = (M_3 - M_1) / (M_2 - M_1) \times 100 \quad (4)$$

where M_1 is the mass of the empty crucible (g), M_2 is the mass of the crucible + brewery spent grain sample (g), and M_3 is mass of the crucible + ash (g).

Economic assessment methodology

A local brewery company with a production capacity of 24 tons per day of sorghum BSG as waste was used as a source of boiler fuel for this study and considered for an economic assessment. The cash discounted methodology, which is based on the total costs from the process, was used determining the economic feasibility of generating bioelectricity from BSG.

RESULTS AND DISCUSSION

Potential to Use Brewers Spent Grains as a Combustion Fuel

Calorific value

The analysis of the BSG's physicochemical characteristics indicated that the BSG had an average calorific value of 12.6±0.7 MJ/kg, which was approximately 37% less than that of coal, which was 19.9 ± 1.9 MJ/kg (Fig. 3). Irrespective of the fact that the calorific value of BSG was lower, this indicated that the BSG could be thermally converted into electricity (Veringa 2014). The results were compared to coal to check the feasibility of using BSG in bioelectricity generation or its potential to be used as a combustion fuel.

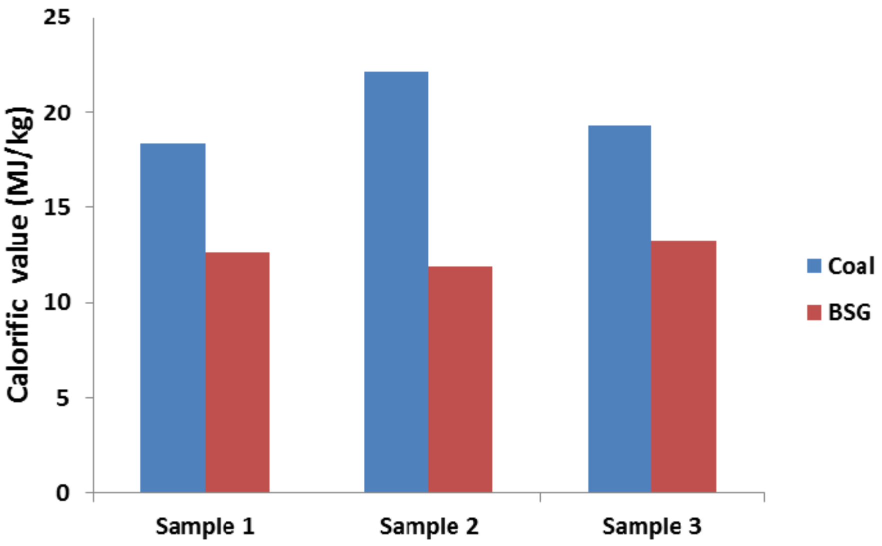

Fig. 3. Comparison of the BSG and coal calorific values

Moisture content

The average moisture content (5.8±1.0%) in the BSG was 84% as compared to the standard coal used for boiler combustion and electricity generation (0.9±0.6%), as indicated in Fig. 4. High moisture content values in the BSG are attributed to the fact that the brewing process is a wet process, and despite the BSG being sun dried for a while, the moisture content values were still very high. A high moisture content of the BSG has potential to lower the calorific value of the BSG, limiting its potential for being used in boiler combustion or bio electricity generation. The BSG must then be further dried using a rotary drier as proposed by Sani and Fakunle (2016) when they also observed moisture content values of 8.16 to 9.1% in spent brewers' grains.

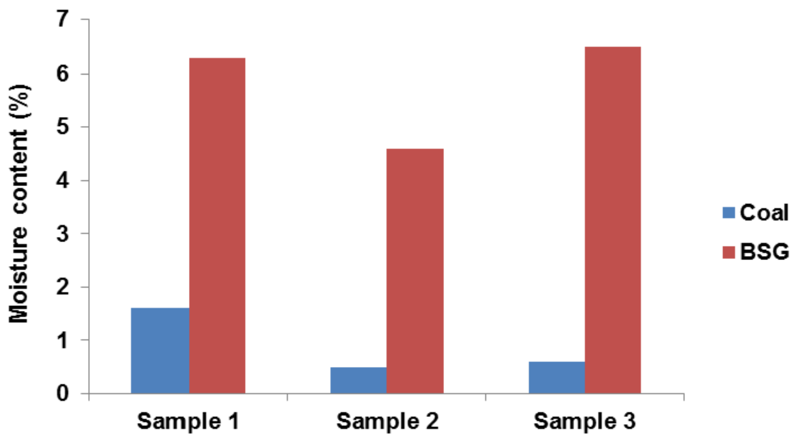

Fig. 4. Comparison of the BSG and coal moisture content

Ash content

The average ash content in the BSG (11.9±1.1%) was 40% as compared to the standard coal (7.1 ±1.5%) used to fire the boilers and generate electricity (Fig. 5). The ash content in this study was on the higher side compared to values in literature as earlier reported by other researchers with values between 3 and 5% (Dong and Ogle 2003; Senthilkumar *et al.* 2010). High ash content in the feedstock for combustion or electricity generation has a tendency to lower the energy efficiency as well as the calorific value.

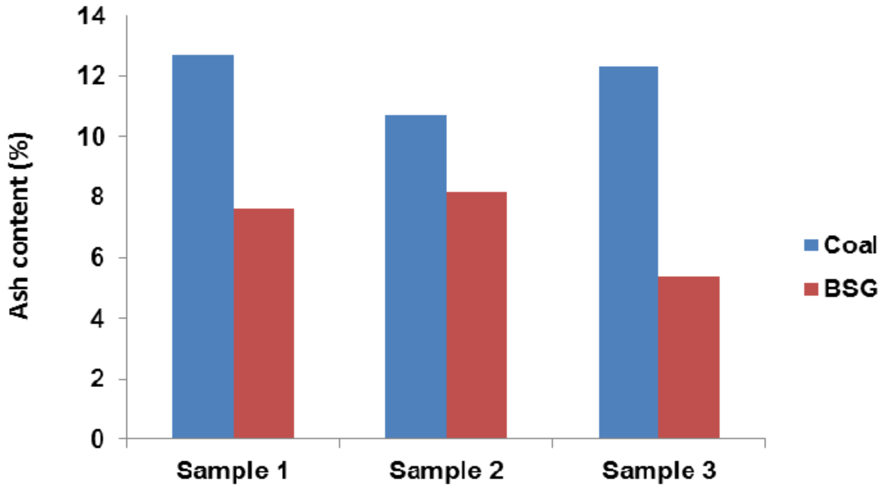

Fig. 5. Comparison of the BSG and coal ash content

Volatile matter content

The volatile matter in the BSG (47.0±0.3%) was almost 50% higher as compared to the standard coal (23.6±1.9%) used for boiler energy combustion and electricity generation (Fig. 6).

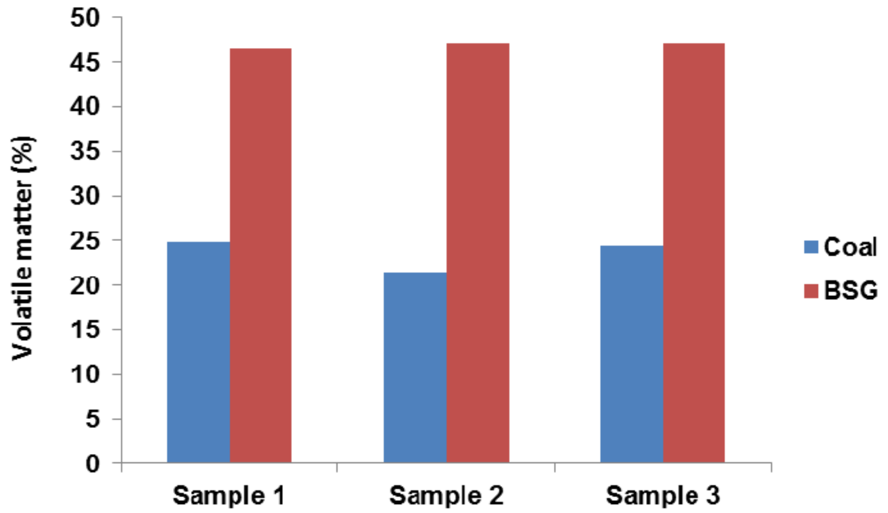

Fig. 6. Comparison of the BSG and coal volatile content

The higher volatile content in the BSG was attributed to the high volatiles that are available in the BSG, which results in lower calorific values as compared to coal (Celaya *et al.* 2015). The high volatiles can be reduced by carbonizing the BSG to bio char which can be pelletized to a coal like fuel effectively increasing the calorific value of the BSG (Celaya *et al.* 2015).

Fixed carbon content

The fixed carbon content in the BSG (41.5±0.9%) was 36% lower as compared to the fixed carbon content in the standard coal (64.5±3.0%), as indicated in Fig 7. The fixed value observed in this study was slightly higher in comparison to a value of 35.6% that was reported by Khidzir *et al.* (2010). The fixed carbon content is directly related to the calorific value of a material. The fixed carbon of the BSG can probably be increased through carbonization and then pelletizing to bio pellets (Celaya *et al*. 2015).

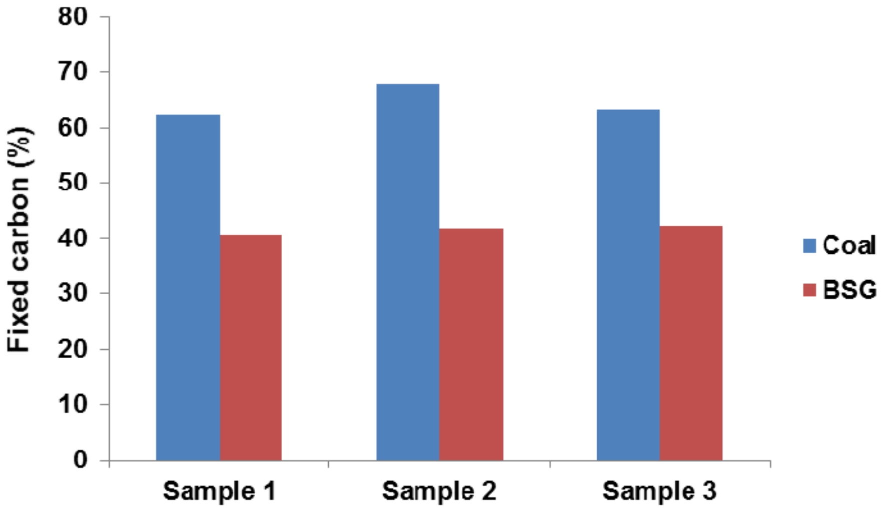

Fig. 7. Comparison of the BSG and coal fixed carbon content

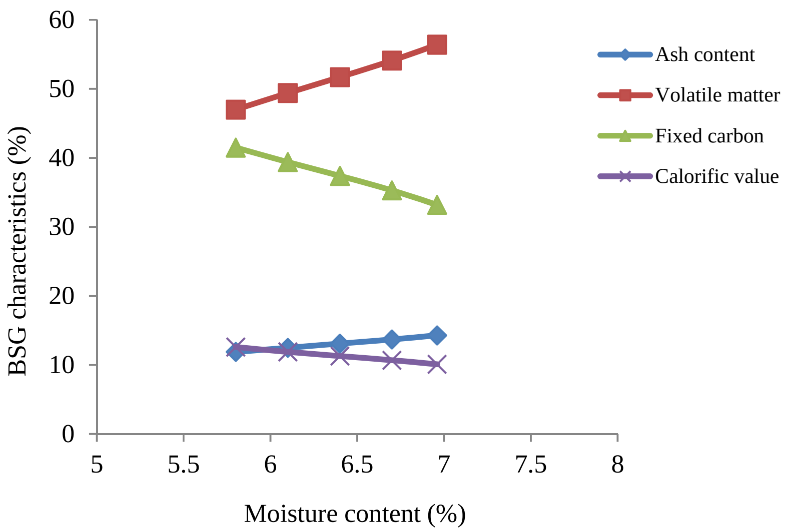

Fig. 8. Summary of the BSG physicochemical properties against moisture changes

A sensitivity analysis on the effect of the moisture content on the BSG physicochemical parameters indicated that moisture content is a critical parameter in the potential use of BSG as a boiler fuel or electricity generation. Decreasing the moisture content of the BSG to approximately 4.6% results in increased BSG calorific values up to 15.1 MJ/kg (Fig. 8). The increase in calorific value is attributed to an increase in the fixed carbon content (49.8%) and a decrease in both ash content and the volatile matter (Fig. 8). The converse is also true for an increase in the BSG moisture content, the calorific value and the fixed carbon will significantly decrease.

Effect of Higher Moisture Content Values in the BSG

From this study, it can be assumed that moisture content has the greatest effect on all the other BSG physicochemical properties and its potential to be used as a solid fuel. The increase in the moisture content results in increased ash content and volatile matter, which ultimately cause a decrease in the calorific value and fixed carbon content of the BSG. Most BSG is not dried post the process and can have moisture contents as high as 60%; this has negative effects on the potential of using BSG as a solid fuel. Dewatering and drying techniques must be employed to realise this potential. Several correlation on the effect of moisture content on the biomass calorific value were adopted from the literature, and the predicted effect of moisture content on the BSG calorific value quantified in according to correlations 1, 2 (Ebeling and Jenkins 1985) and correlation 3 (Sheng and Azevedo 2005).

Correlation 1: Calorific value = 20.067 - 0.234Ash content

Correlation 2: Calorific value = 26.601 - 0.304Ash content - 0.082Volatile matter

Correlation 3: Calorific value = 19.914 - 0.2324Ash content

All the three correlations indicated that as the moisture content increases up to 60%, the calorific value also will significantly decrease, as indicated in Fig 9.

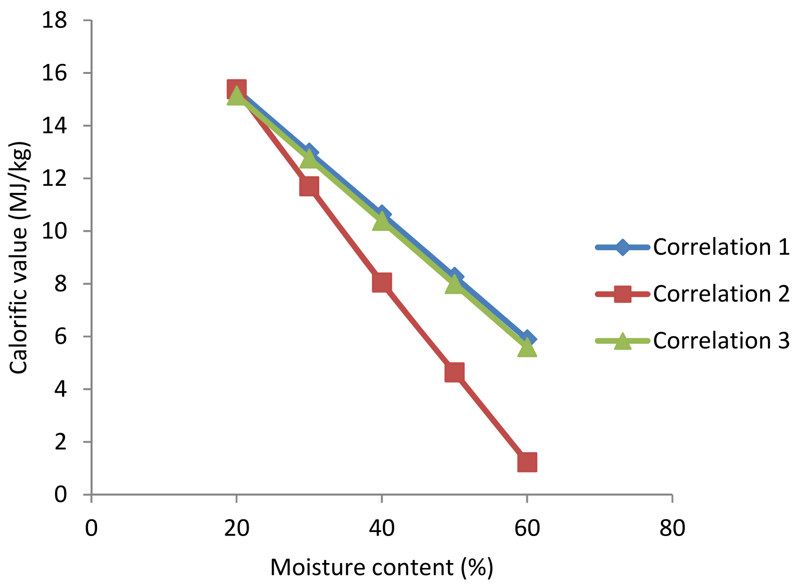

Fig. 9. Effect of moisture content increase on the BSG calorific value

Bioelectricity Production Process Design

An assumed feed rate of 1100 kg/h of sorghum BSG biomass feedstock, at 6% moisture and a calorific value of 12.6 MJ/kg, was fed into a 1623 m^3 water capacity biomass boiler unit producing a steam output of 1689 kg/h steam at a temperature of 573 °K and a pressure of 9 bars. As the superheated steam exited the boiler, it was directed to the turbine unit, where a turning effect was induced on the turbine blades by the pressure and velocity of the steam as mechanical shaft energy. The turbine blades, which were connected to a turbo alternator electricity generator unit, then induced a rotational motion on the series of coils in a magnetic field housed in the turbo alternator electricity generator unit. This resulted in the formation of a voltage, using Faraday's law of electromagnetic induction. The electricity generator unit has an output of 1 MW of electricity. The vaporized steam, now at 343 °K, was then pumped back into the boiler unit using a centrifugal pump. The electricity generated from the BSG can be utilized for refrigeration, packaging, compressed air generation as well as used in the brew house and boiler house

Pre-Economic Analysis

This section clearly evaluated the cost of the project by using a pre-economic feasibility study. Thus, the cost method that was used was the Lang factorial method. The Lang factorial method is attributed to Lang (1948), as cited in Peters and Timmerhaus (1993), and it expresses the fixed capital cost of the project as a function of the total purchase equipment cost. A summary of the economic factors considered is given in Table 1.

The assumed feed rate of 1100 kg/h of BSG being fed, operating at 86% efficiency, maximum pressure of 9 bars, and steam output of 1689 kg/h was designed to supply a one megawatt turbine generator. An economic analysis was done with a total investment cost of USD$ 3.4 million, a payback period of 3.7 years, and a return on investment of 27.4%, as shown in Table 1. The shorter payback period and return on investment are an indication that it is feasible to used BSG either as a boiler fuel or a raw material for bioelectricity generation. The economic indicators can also be greatly improved if the physicochemical characteristics of the BSG are improved mainly the calorific value and the fixed carbon content.

Table 1. Summary of Economic Analysis

Item	Cost (US$)
Total purchase cost of equipment	841,144.00
Physical plant cost	2,186,974.00
Fixed capital	3,061,764.00
Working capital	306,176.40
Total investment cost	3,367,941.00
Fixed costs	201,106.00
Variable costs	817,581.00
Annual operating costs	1,018,687.00
Rate of return on investment	27.4%
Payback period	3.7 years
Breakeven point	780 KW

CONCLUSIONS

1. Sorghum brewers spent grains' physicochemical characteristics, as obtained in dry form from the subject brewery, were almost similar to that of coal. However, the moisture content of the BSG can be further decreased by further dewatering and drying before using as a fuel for increasing the calorific value of the BSG.
2. Sorghum brewers spent grains can be used as a boiler combustion fuel and possibly for bio electricity generation due to their calorific value
3. There is economic potential to generate bioelectricity using sorghum brewers spent grain as a source of fuel.
4. The BSG's calorific value can be enhanced by carbonizing the BSG to bio pellets as a future study which allows removal of volatile matter and increase of the fixed carbon.

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