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BPA was established by the Act of Parliament, BPA Act 740, 2007 with a mandate to plan, execute and manage the Bui Hydroelectric Project which includes:

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TECHNO-ECONOMIC FEASIBILITY OF USING SORGHUM BREWERS SPENT GRAIN TO GENERATE ONE MEGAWATT OF ELECTRICITY USING DIRECT COMBUSTION TECHNOLOGY

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ABSTRACT

The paper presents a study that was conducted to assess the techno-economic feasibility of a sorghum brewers spent grain (BSG) fired boiler unit to generate 1 megawatt of electricity for a certain brewery company. The brewery company is currently generating 24 tons per day of sorghum brewers spent grain biomass waste which was used as a source of boiler fuel for this work. After a full proximate analysis the sorghum brewers spent grain had an average heating value of 12.6 MJ/kg whilst coal had 19.9 MJ/kg indicating that it is feasible to generate electricity using sorghum brewers spent grain as a source of fuel, and that sorghum brewers spent grains can be used as an alternative to coal. A process for conversion of the BSG to electricity was proposed for a biomass boiler unit consuming 1100 kg/hr BSG, operating at 86% efficiency, maximum pressure of 9 bar and steam output of 1689kg/hr was designed to supply a one megawatt turbine generator. Pressure, temperature and flow control mechanisms were assessed as a safety consideration. 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%. BSG provide an alternative source of electricity for the brewery industry.

Keywords: TECHNO-ECONOMIC, BSQ, RETURN ON INVESTMENT, SORGHUM BREWERS

INTRODUCTION

Electricity is an important aspect of the every nation's industrial growth, and also the economic development of any nation worldwide. A study by Attigah and Mayer-Tasch (2013) concluded that there is a strong correlation between a reliable access to electricity and the overall productivity of an industry. This means that that erratic electricity supplies, often results in poor productivity indices, hence the strong need for a constant and reliable electricity supply in any industry worldwide. On the other hand, the brewery industry is generating brewers spent grain (BSG) which has the potential to be converted into energy (Weger et al., 2014; Buffington, 2014). Energy can be harnesses from the BSG either through combustion, anaerobic digestion or gasification (IRENA, 2012). In Zimbabwe, the two ways in which electricity is generated commercially are through hydro power and thermal power. Zimbabwe has one hydro power station in Kariba which has an installed capacity of 750 MW, but is churning out 694 MW .Four thermal power stations in Munyati, Bulawayo, Hwange and Harare have a joint capacity of 1190 MW but are churning out 763MW giving a national total of 1457 MW against a national capacity of 1940 MW. Electricity tariffs comparative studies within the SADC region show that even though ZESA electricity tariffs, at around (9.86 US cents/ KWh) are lower than those for Namibia, around (17.00 US cents /KWh) and Swaziland, around (10.30 US cents /KWh), they are generally higher as compared to information given by (Briceño-Garmendia and Shkaratan, 2011) for other SADC member states (Figure 1).

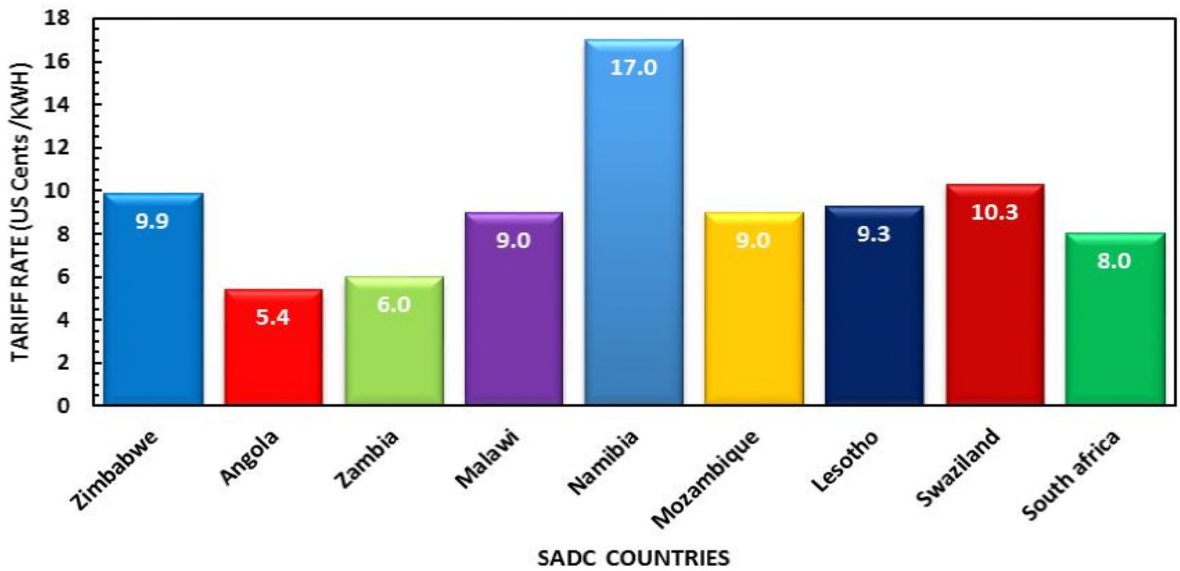

Figure 1. Comparison of electricity tariff rates in SADC region, adapted from information from (Briceño-Garmendia and Shkaratan, 2011)

In order 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. The BSG from the malting process then offer an alternative source of electricity which can meet 30% of brewery electricity demand which is 3 MW.

EXPERIMENTAL

Analysis of feedstock

Spent grain was obtained from a local brewery company. According to (Crofcheck, 2010), analysis of biomass feedstock is very important because it helps predict the ultimate yield of product gas. Analysis of the quality of the biomass feedstock is also of great importance because it helps minimize cost associated with pre-treatment of the feedstock before processing. The following analyses were carried out on the biomass feedstock: moisture content, heating value, fixed carbon and volatile matter content and ash content

Analysis of product gas

This involves the analysis of quality and composition of the product gas. (Crofcheck, 2010) also further stated that the product gas yield and its elemental composition go a long way in determining the condition of the final output, which in this particular research was electricity generation. Flue gas analysis was also of great importance because it helped determine the extent to which the research process operations would do damage to the environment. The following method(s) were employed in the analysis of the product steam: flue gas analysis and steam efficiency.

Moisture content determination

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

An empty sample dish was weighed and its mass (M_1) recorded. A 5g sample of the wet (before drying) spent grains was placed into the sample dish and the mass of the empty sample dish + spent grains sample (M_2) recorded. The sample dish now containing the wet spent grains sample was placed into the drying oven at 105 – 110 ºC for 3 hours. After 3 hours the sample dish with the spent grains sample was removed from the oven and cooled in a desiccator, and after cooling, weighed and mass (M_3) recorded. The moisture content was determined in accordance to the equation below:

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

Where

M_1 = Mass of empty dish,

M_2 = Mass of dish + wet spent grains sample and

M_3 = Mass of dish + dried spent grains sample.

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 fuel. A 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 used to compute the gross calorific value.

The brewery spent grains sample was ground to powder and 1.00g was measured using an analytical balance. The sample was put 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 using the

$$Q = \frac{(C_{water} + C_{cal})(T_2 - T_1)}{W_f} \qquad (2)$$

following equation:

Where

Q = Calorific value of species (KJ/kg),

W_f = Weight of the biomass material sample (kg),

C_{cal} = Heat capacity of the bomb calorimeter,

$T_2 - T_1$ = Increase in temperature and

C_{water} = Heat capacity of the water

Percentage volatile matter determination

Volatile matter is any portion of the biomass that is released as volatile gases when heated to temperatures around 400 °C. Volatile matter content represents the percentage of the biomass that will simply volatilizes as a gas and normally a high volatile matter content means a high amount of the biomass will also volatilizes as a gas.

The sample was first oven dried as part of sample preparation. A sample of 2 grams of the sample was the weighed in a porcelain crucible and put in a muffle furnace at 550 °C for 10 minutes. After that it was cooled in a desiccator then weighed and percentage volatile matter calculated as follows:

$$\% \text{ Volatile matter} = 100 \times (A-B)/A \quad (3)$$

Where

A = Mass of the oven dried sample,

B = Mass of after 10 minutes in the furnace

Fixed carbon content determination

The amount of fixed carbon in a sample gives a rough estimate of the heating value. This is because carbon generates most of the heat during burning and so there is a higher probability that a sample with high carbon content would have a high heating value. A crucible was weighed and mass noted (M_1). A sample of 10g of the brewery spent grains was weighed and put into a crucible and the mass (M2) was noted. The crucible containing the sample was put into the furnace at 575 ± 25 ºC for I hour and cooled in a desiccator. The crucible + sample was weighed and mass noted (M_3) as shown below.

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

Where

M_1 = Mass of empty crucible,

M_2 = Mass of crucible + brewery spent grain sample and

M_3 = Mass of crucible + ash.

Ash content determination

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

A crucible was weighed and mass noted (M_1). A sample of 10g of the brewery spent grains was weighed and put into a crucible and the mass (M_2) was noted. The crucible containing the sample was put into the furnace at 575 ± 25 ºC for I hour and cooled in a desiccator. The crucible + sample was weighed and mass noted (M_3) as shown below:

$$\% \text{ Ash content} = (M_3 - M_1)/(M_2 - M_1) \times 100 \quad (5)$$

Where

M_1 = Mass of empty crucible,

M_2 = Mass of crucible + brewery spent grain sample and
M_3 = Mass of crucible + ash.

EXPERIMENTAL RESULTS AND ANALYSIS

The BSG's physicochemical characteristics analysis indicated that the BSG had an average calorific value of 12.6 MJ/kg which was about 37% less than that of coal (Table 1). Although low, this indicates the BSG can be thermally converted to electricity (Veringa, 2014).

Process design

A feed rate of 1100 kg/hr of sorghum brewers spent grain biomass feedstock, at 6 % moisture and calorific value of 12.6 MJ/kg, is fed into a 1623 m· water capacity biomass boiler unit producing a steam output of 1689 kg/hr steam at a temperature of 573 °K and a pressure of 9 bars. As the superheated steam exits the boiler it is directed to the turbine unit where a turning effect is induced on the turbine blades by the pressure and velocity of the steam as mechanical shaft energy. The turbine blades, which are

Table 1. Summary of results for proximate analysis of BSG in comparison to coal

Parameter	Analysis 1		Analysis 2		Analysis 3		Average	
	Coal	BSG	Coal	BSG	Coal	BSG	Coal	BSG
% Total moisture	1.6	6.3	0.5	4.6	0.6	6.5	0.9	5.8
% Ash content	12.7	7.6	10.7	8.2	12.3	5.4	11.9	7.1
% Volatile matter	24.9	46.7	21.5	47.2	24.5	47.2	23.6	47.0
% Fixed carbon	62.4	40.5	67.9	41.9	63.2	42.2	64.5	41.5
Calorific value (MJ/kg)	18.4	12.6	22.1	11.9	19.3	13.3	19.9	12.6

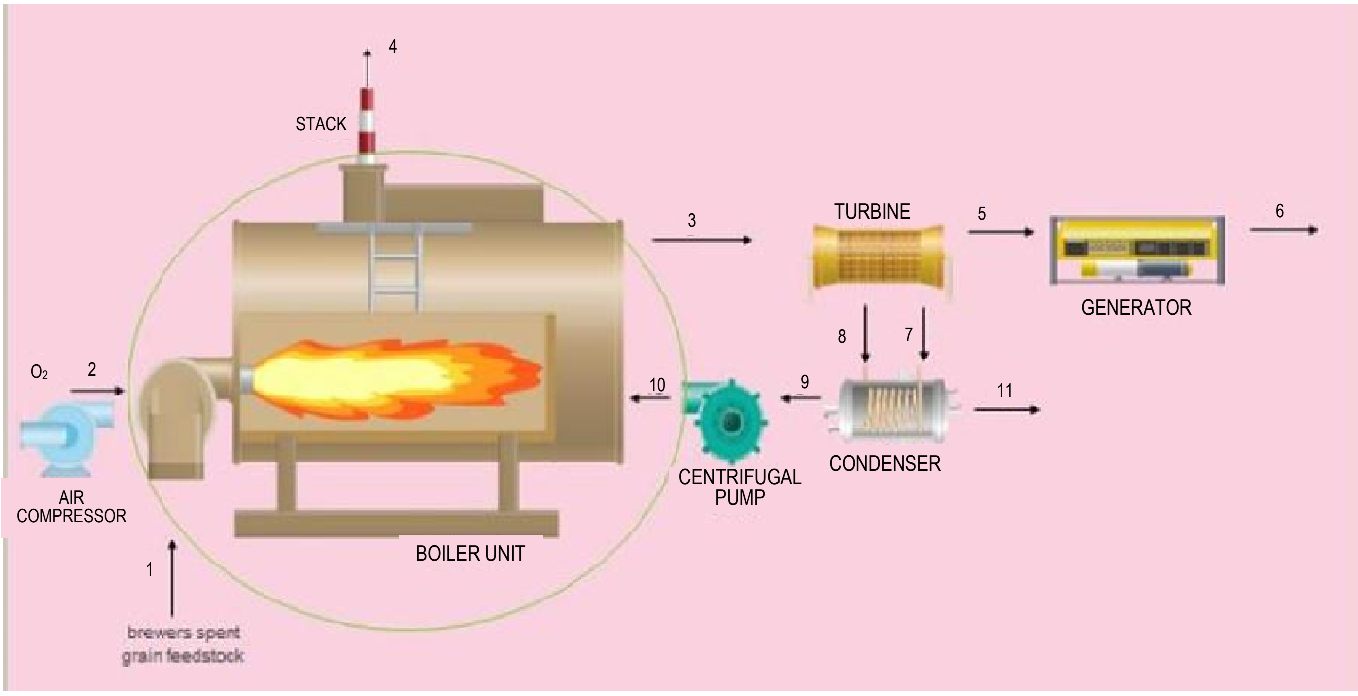

Figure 2. Process flow diagram

Rate of return on investment analysis

ROI = (cumulative net cash flow at project end)/ (life of project x original investment) x 100%

= (Electricity bill monthly saving x 12 months)/(Total Investment Cost+ Annual Operating Cost) x 100%

= Monthly ZESA bill is ($185 000) and cost per month of producing electricity is ($84980) so savings realized is ($100 000)

= (100 000 X 12)/(1 018687+3 367941) x 100% = 27.4 % (6)

Payback period analysis

Payback period is the inverse of the ROI. = (100)/27.4 = 3.7 years (7)

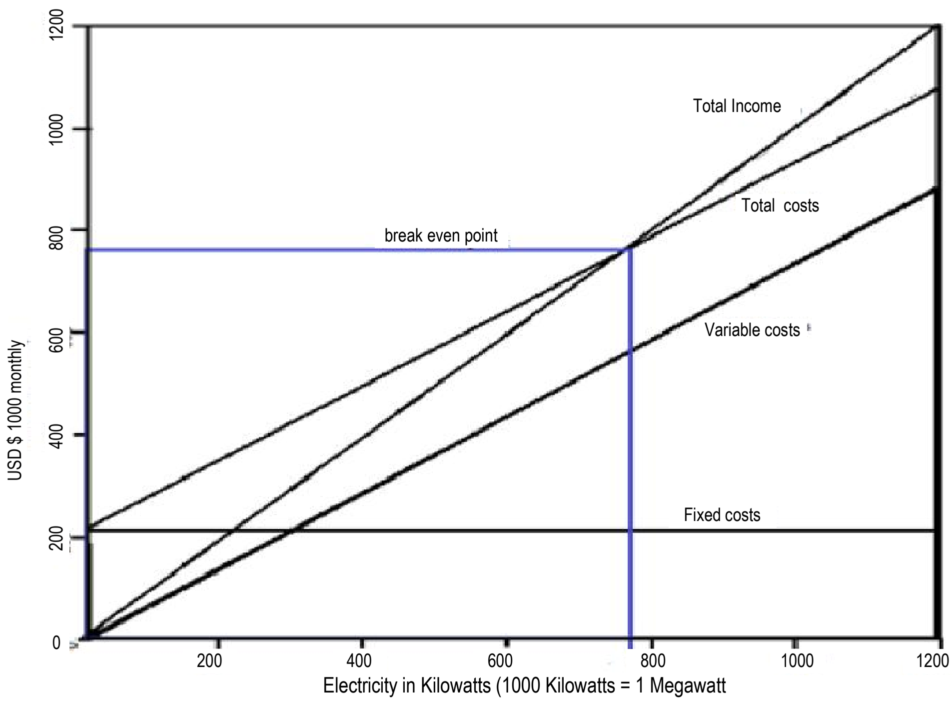

Figure 3. Break Even Analysis Chart

Economic analysis

This section seeks to clearly evaluate the costing of the project and so the costing method that was used was the Lang factorial method. The Lang factorial method is attributed to Lang (1948) cited in Peterhaus and Timmerhaus (1993) and it expresses 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 2.

CONCLUSION

As a conclusive remark, the results of the study show that it is feasible to generate electricity using sorghum brewers spent grain as a source of fuel, and that sorghum brewers spent grains can be used as an alternative to coal.

Acknowledgements

Harare Institute of Technology is acknowledged for funding this work.

Table 2. Summary of Economic Analysis

Item	Cost ($)
Total purchase cost of equipment	841 144.00
Physical plant cost	2 186 974.00
Fixed capital	3 061764.00
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

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