Value addition of brewers spent grains to bio coal using hydrothermal carbonization

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Abstract

The production of alternative energy sources from waste residues is increasingly becoming popular. This paper focuses on the value addition of brewery spent grains waste by converting it to bio coal using hydrothermal carbonization. Brewery spent grains (BSG) from a local brewery company were used to determine the potential of making bio coal that can be used as a replacement to the conventional fossil fuel. Hydrothermal carbonization was conducted at 200 °C at a pressure of 25 bars for a residence time of 2 hours. The BSG were mixed with wastewater in the ratio 5:1. The bio coal that was produced had a calorific value of 26.1 MJ/kg and a fixed carbon content of 53.1%. The calorific values and fixed carbon were slightly higher than the conventional fossil coal which is an indication than BSG provides an alternative source of raw material for bio coal production, a source of renewable energy.

Keywords: Brewery spent grains, bio coal, calorific value, fixed carbon, hydrothermal carbonisation

1. Introduction

The brewing of clear beer generates a lot of solid waste called brewery spent grains (BSG) and wastewater which have little value and have potential to degenerate the environment if not properly managed. The solid waste of beverage companies comprises of 85% spent grains, which are a major disposal problem (Smith and Ross, 2016). An average of 65 000kg of spent grains are produced for 5 brews (Fiori et al., 2014). The amount of brewers spent grains generated varies from brand of beer, time of the year depending on the demand of beer, usually during winter time the beer production volumes are cut, The brewing of beer requires a lot of energy, and a local brewery company uses an average of 100 KW electricity and 19 tonnes per day of fossil coal at a cost of US$0.12 per kilowatt hour and costs $210 per metric ton respectively (Wang et al., 2014). Currently the BSG waste is sold to farmers as stock feed, used for compositing or is sent for land filling. With the increase in environmental awareness, there is a need to come up with a suitable method to dispose of the brewery waste through thermal conversion processes like hydrothermal carbonization. The hydrothermal conversion process involves the thermo chemical conversion of biomass to bio coal under hot compressed water (Stelte, 2011; Neves et al., 2011). This procedure involves removal of unwanted elements such as sulfur,chlorine,nitrogen,pottasium and mechanical impurities such as sand and stones. After removal of unwanted elements, the biomass is crushed, homogenised and soaked to allow an efficient biomass conversion process.

2. Materials and methods

The brewery spent grains was obtained from a local brewery. The raw brewery spent grain was tested for moisture content, total solids, volatile solids, ash content, fixed carbon, nitrogen, hydrogen and carbon to nitrogen (C/N) ratio and the calorific value using standard methods. During hydrothermal carbonization, biomass was first soaked in a 2L HTC reactor and pressurized at 25 bars through the use of steam at a temperature of 220 °C at a residence time of 2 hours in the reactor. The bio coal produced was dried and its physicochemical properties were also measured in comparison to coal.

3. Results and Discussion

3.1 Brewery spent grains characterization

The raw BSG was characterized by high volatile solids of around 83.1% and total solids of 94.2%. These high volatiles have potential to pollute the environment if the BSG is burned directly like that as a solid fuel hence the need for the thermo conversion to bio mass (Baxter, 2005). The summary of the raw brewery spent grains characterization results is indicated in Table 1. There is little value in the solid waste as it can be thrown away which is however an environmental burden. This hence gives rise to the need off adding value to it through carbonization.

Table 1. Raw brewery spent grains characterization

Parameter	Raw brewery spent grains
Moisture content	5.8%
Total solids	94.2%
Volatile solids	83.1%
Ash content	11.1%
Carbon	45.8%
Nitrogen	0.42%
Hydrogen	6.0%
C/N ratio	109.0

3.2 Hydrothermal carbonization of brewery spent grains

3.2.1 The hydrothermal carbonization process description

A controlled process must be follwed during the conversion of the BSG to bio coal. During the thermo conversion process, unwanted elements and mechanical impurities are removed from the brewery spent grains (Funke and Ziegler, 2009). After removal of unwanted elements, the bio mass is crushed to ensure homogeinization then soaked in water. The soaked biomass is pumped into the HTC reactor, functionong at a pressure of 25 bars with heated steam at 220 ◦C being used as the pressurized media. At this stage, the BSG decomposition, dehydration and carbonisation occurs to form the bio coal paste. The conversion process is slightly exothemic .

The bio coal paste then undergoes mechanical compression to remove 50 % of the water from the cooled-down bio coal paste and a bio coal cake is formed. The bio coal cake is dried using waste heat from the process to a moisture of 5-25%. Drying process produces pulverised bio coal which is pelletized and stored for further use as an energy use.

3.2.2 Comparison of fossil coal and BSG bio coal

The BSG Bio coal and fossil coal's physicochemical properties were characterised and the results are shown in Table 3. The fixed carbon of bio coal (53.1%) was higher than that of fossil coal (47.3%). The fixed carbon gives an estimation of the heating value and the results obtained showed that the BSG bio coal was superior. This can be further alluded by the higher calorific value of 26.1 MJ/kg obtained from the BSD bio coal in comparison to the fossil coal of 24.7 MJ/kg (Table 3). This behaviour in fixed carbon and calorific value can be attributed to the fact that the volatile matter of bio coal was less than that of fossil coal by 27% (Table 3). The moisture content in the BSG bio coal and the fossil coal was almost the same. The ash content of fossil coal was higher than that of bio coal by 2.3% (Table 3). Higher ash content values affect burning capacity of solid fuels and combustion efficiency. The characteristics of the BSG bio coal are an indication that BSG bio coal can be used in place of fossil coal (Erlach and Tsatsaronis, 2010).

Table 2 1. Fossil coal and bio coal characterization

Type of coal	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Calorific value (MJ/kg)
BSG bio coal	3.6	21.6	21.5	53.1	26.1
Fossil coal	3.3	22.1	27.3	47.3	24.7

3.3 Effect of process parameters on product yield and quality

3.3.1 Effect of temperature and residence time on hydrothermal carbonization

The hydrothermal carbonization temperature and residence time had an effect on the BSG bio coal percentage yield. From Figure 1 it was observed that as the carbonization temperature increased the yield decreased with highest yields of 70% being obtained at 200 °C and lower yields of 40% being obtained at 300 °C for residence times of 1-2 hours. However, as the residence time increased, the yield almost became constant irrespective of the temperature used and this was attributed to the fact that with increase in time, all the BSG will be converted to bio coal and there will be no biomass left for conversion.

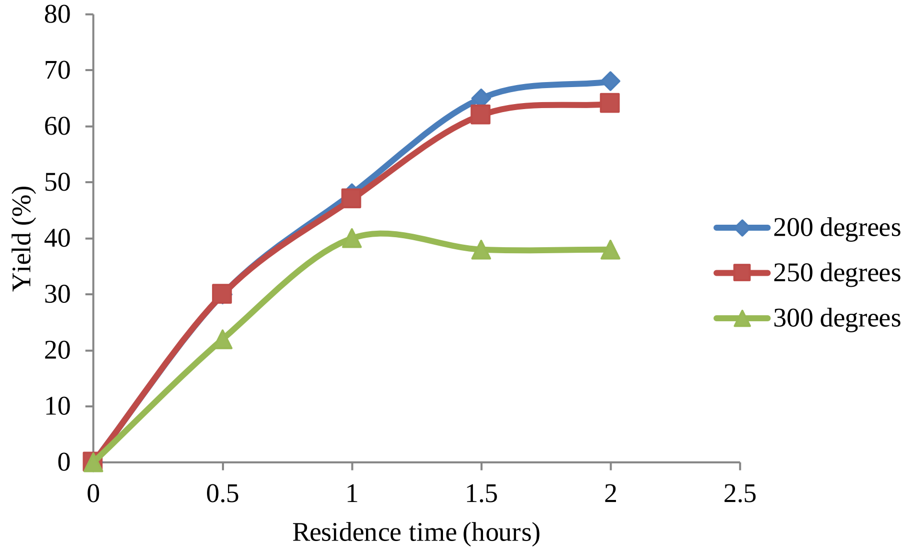

Figure 1. Effect of temperature and residence time on the BSG hydrothermal carbonization

3.3.2 Drying of BSG bio coal at different temperatures

It is essential to dry the bio coal so that its burning efficiency is increased as well as to increase the ignition efficiency (Gerhardt et al., 2010). As the drying time increases up to 2 hours, the moisture content in the bio coal also decreased irrespective of the temperature applied. Figure 2 shows that after drying for 2 hours at 100 °C the moisture content of bio coal were constant at 0.2%. When dried at 75 °C the moisture content was 0.6% after 2 hours. From literature the accepted moisture content for bio coal must be within a range of 0.1% – 2% (Yan et al., 2009).

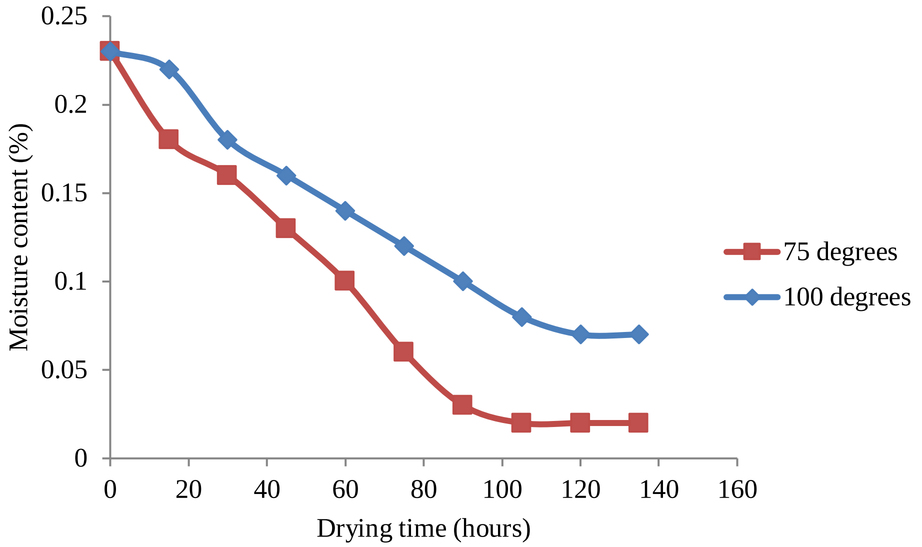

Figure 2. Drying of bio-coal at different temperatures

Figure 3 shows the bio coal obtained from this study. The bio coal was in spherical form with diameter ranging from 2.0 cm -2.72 cm.

Figure 3. BSG bio coal pellets

4. Conclusion

Brewers spent grains can be converted to bio coal using the hydrothermal carbonization process. The percentage conversion of brewery spent grains to bio coal at 200 °C and 25 bars was 70%. The BSG bio coal had a calorific value and fixed carbon that is higher than that of fossil coal making it a good alternative energy for larger domestic use. The conversion of BSG to bio pellets is also a good waste management initiative.

References

Baxter, L., Biomass-coal co-combustion: Opportunity for affordable renewable energy, *Fuel*, vol. 84, pp. 1295-1302, 2005.

Fiori, L., Basso, D., Castello, D., and Baratieri, M., Hydrothermal carbonization of biomass: design of a batch reactor and preliminary experimental results, *Chemical Engineering Transactions*, vol. 37, pp. 55-60, DOI: 10.3303/CET1437010, 2014.

Funke, A., and Ziegler, F., *Hydrothermal carbonization of biomass: A literature survey focusing on its technical application and prospects*. Proceedings of the 17th European Biomass Conference and Exhibition, Florence, Italy, and Munich, Germany, pp. 1037−1050, 2009.

Erlach, B., and Tsatsaronis, G., *Upgrading of biomass by hydrothermal carbonization: Analysis of an industrial-scale plant design*. Proceedings of the ECOS – 23rd International Conference. June 14-17, Lausanne, Switzerland, 2010.

Gerhardt, M., Berg, M., and Kamm, B., *Hydrothermal carbonization of lignocellulosic biomass and its precursors*. Proceedings of the International Conference on Polygeneration Strategies with special focus on Integrated Bio refineries, September 07-09, Leipzig, Germany, 2010.

Neves, D., Thunman, H., Matos, A., Tarelho, L., and Gomez-Barea, A. (2011). Characterization and prediction of biomass pyrolysis products, *Progress in Energy and Combustion Science*, vol. 37, no. 5, pp. 611-630, 2011.

Smith, A. M., and Ross, A. B., Production of bio-coal, bio-methane and fertilizer from seaweed via hydrothermal carbonisation. Algal Research, vol. 16, pp. 1–11, 2016.

Stelte, W., Pelletizing properties of torrefied spruce, *Biomass and Bioenergy*, vol. 35, no. 11, pp. 4690-4698, 2011.

Wang, L., Lurina, M., Hyytiäinen, J., and Mikkonen, E., Bio coal market study: Macro and micro environmental factors in the bio coal sector in Finland, *Biomass and BioEnergy*, vol. 63, pp. 198-209, 2014.

Yan, W., Acharjee, T. C., Coronella, C. J., and Vasquez, V. R., Thermal pretreatment of lignocellullosic biomass, *Environmental Progress and Sustainable Energy*, vol. 28, no. 3, pp. 435−440, 2009.