IARS' International Research Journal
p-ISSN 2202-2821 e-ISSN 1839-6518 (Australian ISSN Agency)

Vol. 12 No. 02 2022
828012022022005 © Author(s)

Agricultural Waste Management by Hydrothermal Carbonization

Waseem Raja
Department of civil engineering, Indian Institute of Technology Jammu, Jammu & Kashmir, INDIA

Ubhat Ali
Department of civil engineering, Indian Institute of Technology Jammu, Jammu & Kashmir, INDIA

Akhil Gupta
Department of civil engineering, Indian Institute of Technology Jammu, Jammu & Kashmir, INDIA

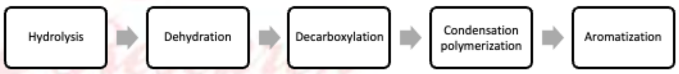
Pratik Kumar
Department of civil engineering, Indian Institute of Technology Jammu, Jammu & Kashmir, INDIA

ABSTRACT – *There has been a huge emphasis on converting waste into energy in developing countries like India since a couple of decades now. Agriculture is a huge industry in India and produces huge amount of agricultural waste which goes around 350 million tons every year. Out of this huge weight of waste more than 40 million tons is sugarcane bagasse. Only a small percentage of this waste is collected and out of that, less than 20% gets advanced treatments like incineration, pyrolysis etc. and the rest of it ends up in landfills. In this study Hydrothermal Carbonization of bagasse is carried out in order to raise its carbon content and achieve a higher calorific value. The waste after undergoing the HTC is called hydrochar and mostly resembles the properties of lignite coal. A number of tests are performed on the feedstock at 200 °C and 220 °C for three reaction periods viz. 2, 4 and 6 hours. The yield of the char is found to decreases with increase in temperature and retention time whereas the Carbon percentage shows a positive trend and goes as high as 69.1 % at 220 °C with Calorific value as 24.44 MJ/kg at 6 hours reaction period.*

Keywords: Waste management; waste to energy; hydrothermal carbonization.

I. Introduction

Hydrothermal Carbonization (HTC) is defined as coalification of biomass in laboratory/man-made conditions (Hans Günter Ramke, 2009) (Witchaya Pruksakit, 2016). It is an exothermic reaction which takes place in a closed system with water as a substrate and an elevated temperature > 180° C. Feedstock is mixed with water and its temperature is elevated to subcritical level i.e., above its boiling point and below the critical point which is 374° C (Funke, 2010). The feedstock is fed to the reactor in a pressure locked condition and its temperature is elevated preferably above 180° C in order to execute hydrolysis followed by combined dehydration and decarboxylation (S. Kent Hoekman, 2011) (Ekaterina Sermyagina, 2015). The pressure in the closed conditions rises autogenously with respect to change in the temperature and hence generation of the vapors. Unlike the coal formation in nature which takes several hundreds to thousands of years, HTC requires few hours ranging between 2-24 hours to convert the biomass into a potential solid fuel (Kawnish Kirtania, 2018). The main advantage of HTC over existing technologies like incineration and pyrolysis is that it does not require pretreatment such as drying and hence reduces the cost of pretreatment (Weiner, Breulmann, Wedwitschka, Führer, & Kopinke, 2018). HTC involves exothermic reactions, and the exact mechanism is largely unknown, but the literature review suggest that HTC process involves the following mechanism (A. Leena Pauline, 2020):



HTC has been experimented on a range of feedstocks ranging from sewage, municipal solid waste yard waste (Waseem, 2019), synthetic compounds, wood to cattle paunch etc. Keeping in view the availability of raw material and climatic conditions of India, we have selected sugarcane bagasse for our experimental study to record the changes in various characteristics of the raw material after undergoing the HTC.

According to a study by (Kalpana Bisht) India has about 4 million hectares of land growing sugarcane which gives a yield of 70 tons/ha. The main contributing province to the sugarcane production are Uttar Pradesh, Maharashtra, Haryana, Gujarat, Punjab, Andhra Pradesh. Bagasse can be directly used as a solid fuel but the main problems with that are its low calorific value, bulky volume and its natural degradation (Dubey, 2019). Therefore, HTC at different reaction conditions is performed to increase its Carbon content and calorific value, shelf life and storability. This work demonstrated the effect of HTC on sugarcane bagasse and explored it potential uses as solid fuel.

II. Material and Method

Sugarcane bagasse is used as the feedstock. It was, cut and ground to a coarse mix using a domestic grinder in order to ease and fasten the reaction in a lab scale HTC reactor. The initial characteristics of bagasse named as sample S are analyzed and can be found in the table below:

Table 1 Initial characterization of the feedstock

Sr. no	Waste Sample	Moisture Content %	C %	H %	N %	Calorific Value (MJ/kg)
01	S	37%	45.60	5.50	0.36	15.07

The basic chemical composition of sugarcane bagasse is 50% cellulose, 25% hemi- cellulose and 25% lignin (H. Hajiha). The hydrolysis of cellulose, hemicellulose and lignin starts at 180◦C, 180◦C and 200◦C respectively. The most basic example (Eloise Bevan) to understand this step in HTC can be:

$$C_6H_{12}O_6 \longrightarrow C_6H_2O + 5\ H_20 + \text{Energy}$$

To carry out the HTC experiments the reactor is filled with the feedstock and water. The reactor is partially filled to accommodate the volume changes due to decrease in density of water on subsequent temperature changes. For every reaction, 400 gm of feedstock is taken and fed to the reactor with 1 L of water. The purpose of filling water is only to provide a reaction medium, generally the feedstock should be covered and no fixed quantity is required. The samples of bagasse prepared for experiments at various temperatures and time periods are named as

Table 2: Nomenclature for various time and temperature

Sr.no	Temperature	Reaction Time (Hours)	Sample identification
01	200°C	2	A2
02	200°C	4	A4
03	200°C	6	A6
04	220°C	2	B2
05	220°C	4	B4
06	220°C	6	B6

The reaction time or reaction period means the minimum time period for which the mentioned temperature is maintained. After the completion of each reaction the reactor is set aside, undisturbed to come to room temperature and stabilization of the feedstock, this period is called residence time. A residence time of 24 hours is given to every set of experiments. After completion of the residence time, the reactor is emptied, and the slurry is filtered to collect the hydrochar. The hydrochar is further oven dried and the various changes in the pre-decided parameters are analyzed.

Figure 1: HTC Reactor

III. Results

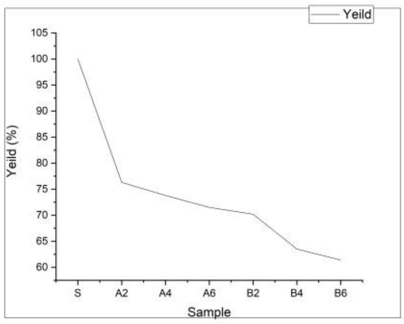


Figure 2: Yield percentage of char after HTC reaction

International Research Journal
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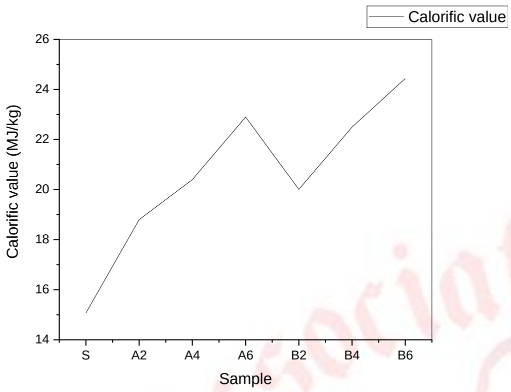

Figure 3: Change in calorific value of char after HTC reaction.

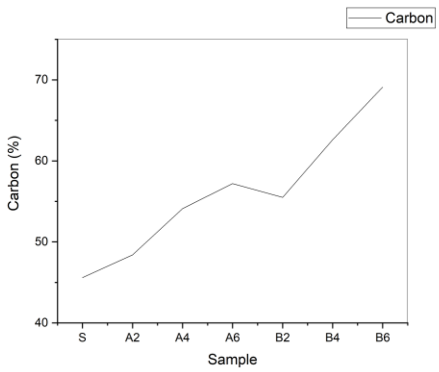

Figure 4: Carbon percentage of char after HTC reaction

CHN concentration is analyzed using a CHN/S/O Elemental Analyzer, model: 2400 Series II, PE, USA, calorific values are tested using a bomb calorimeter and the char yield is calculated on basic gravimetric analysis principle as:

Yield % = [Dry weight of char obtained / (Wet weight of feed stock – moisture content of feed stock)] × 100.

Table 3: Results of Various Parameters

S.no	Sample	Yield %	C %	H %	N %	Calorific Value (MJ/kg)
1	S	-	46	5.5	0.3	15.07
2	A2	76.3	48	5.1	0.3	18.8
3	A4	73.8	54	4.9	0.3	20.4
4	A6	71.5	57	4.7	0.3	22.9
5	B2	70.2	56	5	0.3	20.01
6	B4	63.5	63	4.6	0.4	22.5
7	B6	61.4	69	4.1	0.3	24.44

IV. Discussion

The general and most apparent observation has been that the hydrochar produced is light in weight and hence the yield is less. With sample A2 the yield obtained is 76.3% while the carbon concentration rose to 48.4% and calorific value reached 18.80 MJ/kg. The decrease in the yield is due to the mechanism of HTC in which various compounds are formed and get soluble in water. Similarly for sample A2 the similar trend can be observed, the yield decreased by another 2.5% whereas the carbon concentration rose by 18.64% as compared to sample S. As the reaction period is increased by another 2 hours for sample A6, the same trend of decrease in yield and increase in Carbon concentration and calorific values is followed. Similarly, when the temperature is increased to 200℃ for sample B2, B4 and B6, the yield went considerably down as 70.2, 63.5, 61.4 percent while the carbon concentration and calorific values reached to 55.5, 62.6, 69.1 percent and 20.01, 22.50, 24.44 MJ/kg. To make a comparison with different types of coals our HTC char is most comparable with lignite type of coal. If the temperature and pressure conditions are optimized, the sub-bituminous type of char can be achieved using HTC in less than 10 hours.

Table 4: Carbon content and calorific values of various types of coals (Sangchul Park, 2021)

Sr.no	Type of Coal	Carbon %	Calorific Value (MJ/kg)
1	Peat	>60	14.7
2	Lignite	65	23
3	Subbituminous	70	30

The morphological changes in the hydrochar as compared to its precursor sugarcane bagasse can be tracked with the help of SEM images of sample S and B6 as under:

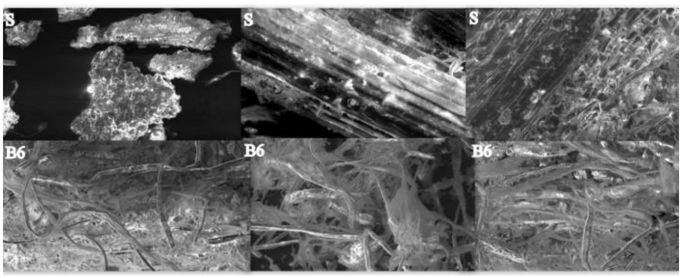

Figure 5: SEM images of S and B6

V. Conclusion

Waste to energy processes is being researched extensively to meet sustainable development goals and cater the growing energy demand. It provides safe and environment friendly disposal of municipal solid waste along with products which can be used as fuels. WtEs can produce electricity and heat along with solving the problem of solid waste management. The above results show a positive rise in the Carbon concentration and Calorific values during all the reaction conditions. Most of the hydrochar produced in different conditions is comparable to peat and lignite type of coal and the sample B6 nearly shows the properties of sub bituminous coal. These can be transformed into briquettes and can be used as fuel in domestic and hydrothermal projects. The biochar has an application in agriculture as well where it is used as soil adamant. The SEM images of the original bagasse consist of a mix of densely packed spherical and rod-shaped structures. The main morphological developments which can be tracked in the SEM images of B6 are that they have become smooth, less dense, which implies that the porosity has increased which is a result of the weakening of lignocellulosic components of biomass during HTC. The hydrochar produced can be turned into pellets or briquettes for better applicability as a solid fuel in boilers, incinerators or even for domestic purposes. The results obtained in this study show that the properties of bagasse as a solid fuel can be enhanced using HTC and the natural degradation of it can be curbed which will lead to less wastage and greater efficiency. Hence, keeping in view the above results and their impacts, we can conclude that HTC can serve as a simple and potential treatment to sugarcane bagasse in the field of waste to energy.

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