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Three Stage Carbonisation: Biochar Production from Jute Stick

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ABSTRACT

Carbonisation is a gradual pyrolysis process that converts biomass to a highly carbonaceous, charcoal-like substance. The residue after peeling off the jute fiber is known as jute stick which has a very similar composition to hardwoods. Through a single stage carbonisation process, the jute stick pretreated with metallic salts or using pre-hydrolysis approach generates superior quality charcoal with a high yield. The issue with single stage carbonisation for both pretreated and untreated charcoal is that it cannot be generated at high temperatures (over 400°C) efficiently; the yield percentage declines dramatically beyond 350°C, making large-scale production uneconomical. If the carbonisation procedure can be broken down into several stages with varying heating rates and durations based on the decomposition temperature of functional groups present on the jute stick (primarily hemicellulose, α-cellulose, and lignin), the yield percentage may be preserved to a greater extent. The overall goal of this study was to produce high-quality charcoal at high temperatures using a three-stage carbonisation process and compare the results to single-stage carbonisation for both pre-treated and untreated jute sticks. The experiment was conducted in three stages with distinctive heating rates and temperature zone for all pre-treated samples. According to the results obtained by proximate analysis, salt impregnated with pre-hydrolysed jute stick charcoal produced the best results, with a yield of roughly 51% and 93% fixed carbon, followed by salt impregnated charcoal with a yield of 39% and 95% fixed carbon. These are both substantially greater than generated charcoal from a single step carbonisation process. Overall, charcoal made in three stages with any of the three forms of pretreatment is far more efficient than charcoal made from raw jute sticks, i.e. without any pretreatment.

Keywords: Jute stick, Biochar, Carbonisation, Pre-hydrolysis, Salt-impregnation

1. Introduction

Charcoal is a light-black carbon residue created by incomplete heating of cellulose structures such as wood or other livestock and botanical resources in a low-oxygen environment [1]. Soot and smoke are typically formed by wood fires due to incomplete combustion of certain volatiles. Charcoal burns at a higher temperature than wood, creates almost little visible flame, and produces just heat and CO_2. Wood charcoal has been produced in regions where wood is abundant since prehistoric times [2].

Jute, often known as the 'Golden Fiber,' was one of Bangladesh's most important cash crops, with a stranglehold on the export market for a long time. Unfortunately, jute has lost much of its former splendor, thus substantial research has been conducted over the last few decades to promote the use of jute fiber. Bangladesh generates 5.5–6.0 million bales of raw jute annually [3]. Surprisingly, while having a similar composition to hardwoods [4], jute sticks have received less attention simply because they are lighter in weight and less dense. Aside from strength, wood has a variety of additional uses, one of which is high-grade charcoal, which may be applied to jute sticks as well. Some businesses have recently started making charcoal powder from jute on a modest scale and exporting it [5], but the yield of their process is low . Because jute has hitherto been considered a type of agricultural waste, this finding might open up new avenues for jute's usage beyond fiber.

Kilns and retorts are widely used to convert wood into charcoal. A kiln is a thermally insulated chamber that produces temperatures sufficient to convert wood into charcoal. Both products and by-products are recovered in retort whereas in kilns only product is recovered. Earth Pit and Earth Mound Kilns are widely used to produce charcoal and they have a conversion rate around 8% to 12 % [6].

In the case of other biomass conversion into charcoal, various studies have been conducted in three stages. Zandersons et al. [7] performed pyrolysis on sugar baggase. On an oven dry (OD) bagasse basis, the potential charcoal output was significant, about 35 percent. However, the charcoal production did not surpass 23-28% due to the fine distributed and fibrous nature of the bagasse bulk, which attributed to the quick pyrolysis stage. They suggested a two-stage approach with varying heating rates. Moreno et al. [8] performed carbonisation of resorcinolformaldehyde organic xerogels and they studied the effect of temperature, particle size, and heating rate on the porosity of carbon xerogels. The carbon xerogels production technology became significantly more competitive as a result of the time savings. However, they advised a quick or flash pyrolysis procedure must be created in order to utilize it on an industrial scale. Wilk et al. [9] performed carbonisation of wood residue in low temperature. In an electrical furnace, the torrefaction process of wood residue was examined at temperatures of 230°C, 260°C, and 290°C for 0.5, 1.0, and 1.5 hours. The method run at 260°C with a heating period of 1.0 hour was determined to be the most efficient carbonising technique among the examined samples. In comparison to raw biomass, the results revealed the significant benefits of torrefied material (charcoal). At higher torrefaction temperatures, the difference in energy yields has shown smaller values. Srrezov et al. [10] conducted a study where the major goal

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of this study was to thermally analyze three distinct biomass samples, wood sawdust, bagasse, and macadamia nut shell, in order to generate key quantitative data for mass and energy evaluations of their carbonisation potential and behavior. In the biomass conversion process, a number of multiple and linked reaction stages had been found. The moisture content and firmly bound hydrated components dissolved in an endothermic heat event during the early stages of biomass decomposition. Thermal decomposition was shown to be largely exothermic at temperatures over 230 °C, with the evolution of carbon oxides (CO and CO_2), hydrocarbons, and bio-oils, whereas the evolution of hydrogen began at temperatures above 600°C. The gathered bio-oils had a highly complex structure, with components ranging in molecular weight from 400 to 600 a.m.u..

Nabil et al. [5] discovered that yield percentage had a linear constant drop slope from 250°C to 350°C temperature range in single stage carbonisation using untreated jute stick. The slope of the graph was less steep at temperatures between 350°C and 400°C. With increasing temperature, the yield percentage decreased; the highest yield was recorded at 250°C about 44.5 percent, and the lowest yield was found at 400°C around 16 percent. At high temperatures, the amount of fixed carbon was shown to rise. At 400°C, the value hits its maximum, which was around 80 percent. At 250°C, the lowest fixed carbon value of roughly 57 percent was discovered.

Banarjee et al. [11] carbonized untreated jute sticks in single and three stages, finding that three stage carbonisation provided much greater yields and fixed carbon percentages than single stage carbonisation. The highest yield in single stage carbonisation was 35-40% at 240-260°C with 70% fixed carbon, whereas the maximum yield in three stage carbonisation was 34 percent at 250-440°C with 88-90 percent fixed carbon. At 320-350°C, single stage carbonisation yielded 10-15% with 75-80% fixed carbon, indicating that three stage carbonisation was clearly superior to single stage carbonisation.

When carbonising jute sticks, it was seen that at the transition temperature of components, the reaction turns out to be exothermic in which case the charcoal yield decreases as the formation of volatile materials when the constituents undergo thermal decomposition rapidly if the temperature was left uncontrolled [12]. As a result, hemicellulose was excessively decomposed during single-stage carbonisation. So, regulating the temperature at each components' individual transition phase may facilitate to achieve maximum yield.

The goal of this study was to examine the influence of three stage carbonisation for pre-treated and untreated jute sticks, as well as compare the results of proximate analysis and calorific value with charcoal obtained from single stage carbonisation.

2. Material and Method

2.1 Material

Jute sticks were collected from local village market of Khulna, Bangladesh. They were picked in such a way that they reflect the whole section of a standard stack. The sticks were crushed into pieces of 1.5 to 2 mm in length, properly cleaned to eliminate any foreign matter (i.e. dirt, dust, muck), and dried in the sun until the water-soaked state was gone. They were then oven-dried for 2 hours at 105°C to eliminate any remaining moisture and water particles from the sun-dry.

2.2 Specimen Preparation

For Pre-hydrolysis process, 45 grams of the oven-dried sample was added to 500 mL water for each batch and boiled for 2 hours in a stainless-steel chamber at 135°C-140°C at gauge pressure 4-4.2 bar. The samples were then sun-dried and oven-dried again, as before, and weighted, yielding an average weight decrease of 10%.

Salt $ZnSO_4$ had been chosen as the catalyst of choice for testing. 50gm oven-dried jute sticks had been dipped into 1L of 10% (W/V) salt solution in a plastic zipper bag, sealed, and stored for 24 hours. The salt solution was then emptied out, and the chopped jute sticks were air-dried in the sunlight before being oven dried at 105°C and reweighted. The amount of salt impregnated had been estimated based on the increased weight percentage, and 8% weight gain was found.

The sample was first pre-hydrolysed and then dipped into salt solution as described earlier in order to test the mutual effect of pre-hydrolysis and salt analysis,

2.3 Method

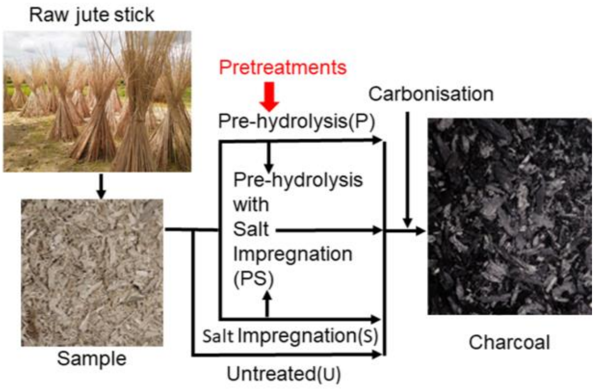

Fig.1 Schematic diagram of biochar production from jute stick

Fig.1 illustrates the schematic diagram of biochar production from jute stick. For carbonisation process, a steel jar was wrapped in aluminum foil, few holes were punched in the foil to allow the volatile to escape the jar. The jars were then covered with a lid that had holes in it to let the volatiles escape, then placed in the muffle furnace to carbonise. The experiment was conducted in three stages, with distinct temperature zones heating at varying rates and for varied lengths of time. The samples of pre-hydrolysed and salt impregnated with pre-hydrolysed jute stick were introduced to furnace at 240°C and heated for 30 minutes, then elevated to 380°C at 2°C/minute, after that raised to 450°C at 5°C/minute and held there for 30 minutes more. The samples that were salt impregnated, were introduced to furnace at 250°C and heated for 30 minutes, then elevated to 500°C at a rate of 5°C/minute and held there for 15 minutes.

Fig.2 Raw Jute Stick Powder (at left) and Produced Charcoal after Carbonisation (at right)

Fig.2 shows the visual condition of raw jute stick (or pretreated jute stick powder) and produced charcoal after carbonisation. First, the total yield of charcoal had been determined after the weight reduction from the observed jute stick sample after heating at a certain temperature range. After that Proximate Analysis was done from the charcoal sample by taking around 0.5 gm. Proximate Analysis provides biomass composition in terms of gross components [13]. Here, the analysis was performed on a dry basis by following the ASTM standard (D1762-84) [14].

A digital bomb calorimeter (GDY-1C Oxygen Bomb Calorimeter) had been used to determine calorific value.

3. Results and Discussion

3.1 Physical Characteristics

Table 1 Yield and Proximate Analysis of Charcoal

Type	Obs. no.	Yield (%)	Volatile (%)	Ash (%)	Fixed Carbon (%)
Pre-hydrolysed with Salt Impregnated	1	51.67	3.37	3.65	92.98
	2	50.72	3.64	3.05	93.31
	3	51.51	3.17	3.45	93.38
	4	51.59	3.17	3.07	93.76
	5	51.49	3.18	3.57	93.25
Pre-hydrolysed	1	35.74	4.63	4.26	91.11
	2	35.07	4.00	4.00	92.00
	3	35.31	3.78	4.16	92.06
	4	35.25	3.23	3.80	92.98
	5	35.50	3.36	4.29	92.35
Salt Impregnated	1	40.53	3.67	2.01	94.32
	2	39.21	4.06	1.98	93.97
	3	38.88	2.14	2.18	95.68
	4	39.59	2.79	2.11	95.10
	5	39.53	2.16	2.52	95.32

Table 1 represents the yield and proximate analysis results for each type of pretreated jute stick charcoal and Table 2 demonstrates the average values of each analysis including respective calorific values.

Table 2 Average Yield, Proximate Analysis, and Calorific value of produced Charcoal

Type	Average				
	Yield (%)	Volatile (%)	Ash (%)	Fixed Carbon (%)	Calorific Value (MJ/kg)
Pre-hydrolysis with Salt ($ZnCl_2$) Impregnated	51.39	3.3	3.36	93.33	30
Pre-hydrolysis	35.37	3.80	4.1	92.10	28
Salt Impregnated	39.54	2.96	2.15	94.87	24

The average yield for pre-hydrolysed with salt impregnated jute sticks had been 51.4% with standard deviation of 0.38 and for only pre-hydrolysed jute sticks the average yield had been 35.37% with standard deviation of 0.25; where average yield had been 39.55% with standard deviation of 0.62 for salt impregnated jute sticks. The average volatile and ash percentage for pre-hydrolysed with salt impregnated jute sticks had been 3.31% and 3.36% respectively where for salt impregnated jute sticks, the average volatile and ash percentage had been 2.96% and 2.18% respectively; for only pre-hydrolysed jute sticks the average volatile and ash percentage had been 4.1% and 3.8% respectively. The average fixed carbon for pre-hydrolysed with salt impregnated jute sticks had been 93.33% with standard deviation of 0.28 and for only pre-hydrolysed jute sticks the average fixed carbon had been 92.1% with standard deviation of 0.68; where average fixed carbon had been 94.88% with standard deviation of 0.71 for salt impregnated jute sticks. Fig.3 represents the yield and fixed carbon comparison among the three types of pretreated jute stick charcoal.

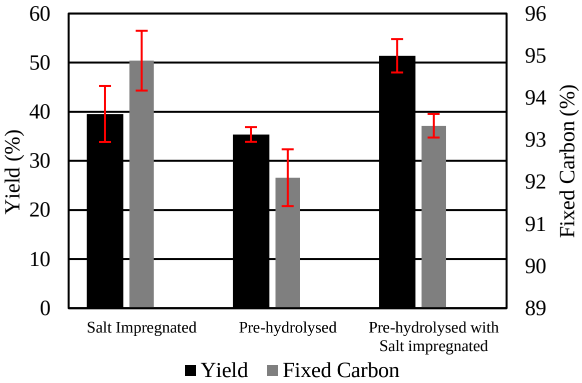

Fig.3 Yield and Fixed Carbon Comparison among Pretreated Jute Stick Charcoals

The lower calorific value for pre-hydrolysed with salt impregnated jute sticks was 30 MJ/kg and for only pre-hydrolysed jute sticks, the calorific value had been 28 MJ/kg; where the calorific value had been 24 MJ/kg for salt impregnated jute sticks.

3.2 Biochar Characterization

The yield and fixed carbon were significantly higher in pretreated jute sticks than untreated jute sticks. In untreated jute stick, the yield and fixed carbon percentage were 34% and 88-90%, respectively [11]. Due to the production of less volatile components, the charcoal yield increased in the presence of salt. Jute sticks typically burn up rapidly, but in the presence of salts, they carbonize slowly and at temperatures as high as 500°C, which eliminates more volatiles and results in charcoal with a very low volatile content and a greater fixed carbon content. However, compared to untreated jute stick charcoal, such charcoal had an ash level that was 2-3% greater. In pre-hydrolysed jute stick, the partial removal of hemicellulose content reduces the amount of volatile material formation. Moreover, the faster heating rate at the disintegration stage of α-cellulose and lignin attributed to the better yield retention than the single stage carbonisation. In case of pre-hydrolysed with salt impregnated jute stick, the process combines the merit of both process which produces the maximum yield in charcoal production.

4. Conclusion

In this project, Jute stick was pretreated with three different procedures: Pre-hydrolysis, Catalyst ($ZnSO_4$), Pre-hydrolysed with Catalyst ($ZnSO_4$). In all conditions, the yield, moisture, volatile, ash and fixed carbon content had been determined and calorific value of produced charcoal was determined for each variety. From the overall point of view, charcoal produced with salt impregnated with pre-hydrolysed was the most useful among all pretreatments. It can be concluded that:

- The average yield for pre-hydrolysed with salt impregnated jute sticks had been 51.4% and for only pre-hydrolysed jute sticks, the average yield had been 35.37%; where average yield had been 39.55% for salt impregnated jute sticks.
- The average fixed carbon for pre-hydrolysed with salt impregnated jute sticks had been 93.33% and for only pre-hydrolysed jute sticks, the average fixed carbon had been 92.1%; where average fixed carbon had been 94.88% for salt impregnated jute sticks.
- The volatile and ash percentage was lowest in salt impregnated jute stick charcoal.

All three process had a significant higher value of yield and fixed carbon content with less ash and volatile matter than the charcoal produced without any pretreatment. The production of industrial compounds like carbon disulfide, chloroform, and carbon tetrachloride can utilize high fixed carbon contained charcoal. By treating high-grade charcoal from jute sticks with certain salts, cabonising in high temperature could lead to be into an active form. Such activated charcoal can be utilized as a filler in polymers and rubber, in the pharmaceutical sector and for refining sugar. Also conceivable is the graphitization of premium materials charred jute stick material. a fixed-carbon medium-grade charcoal content.

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