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Jute Stick- A Suitable and Economical Source as Charcoal and Activated Carbon Preparation

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Abstract: Charcoal is a light-weight black carbon residue produced by strongly heating wood with minimal oxygen to remove all water and volatile constituents. Jute sticks were used as a cheap precursor for the preparation of charcoal and activated carbon. Chemical activation with $CaCl_2$ caused the physicochemical changes in charcoal. Jute sticks were carbonized at a range of 250°C to 750°C temperatures by an electric muffle furnace where 40–45% higher yields were observed at 250°C temperature and yields declined (8–10%) with an increase in temperature up to 500°C. In the case of charcoal, the average moisture was 9.88%. The IR results of charcoal analysis were indicated 3,450 cm^{-1} for the moisture and 1689.34 cm^{-1} for carboxyl groups. Ash was obtained at a temperature of 550°C in thermogravimetric analysis. At the first phase (50–340°C) of activated carbon, moisture was released (24% weight loss) because of the activation of activated carbon, which consumes more water than charcoal. The oxidation of carbon occurred in the range of 340–550°C and the remaining 1% of inorganic materials became ash. Food and beverage processing, snow avalanche control, municipal drinking water, industrial pollution control, radio wave capture, methane solvent recovery, odor remover, metal purification, and sewage treatment will all benefit from this activated carbon. The properties of the final materials obtained after pyrolyzing at 700°C can be a suitable approach.

Keywords: Jute Stick, Carbonization, Charcoal, Chemical Activation, Activated Carbon

1. Introduction

Woods is the hard tissue of stems, branches, shrubs located beneath the bark of a plant consisting of xylem cells that strengthened with lignin deposition. Wood can be divided into softwood (xylem is porous) and hardwood (contains more fibrous materials). Jute belongs to the softwood category. Jute and jute stick products have more advantage than other soft or hardwoods in respect of the production of biomass. The most important product by the natural ordinary distillation of woods are mainly carbon or charcoal, besides that many other organic materials can be obtained such as hydrocarbons, a mixture of terpenes, ethanoic acid, carbon dioxide, carbon monoxide, methane, various organic alcohol, petroleum, tar, acetone, and water, respectively. The open pyrolysis method, which is an old and crude technique, for the production of charcoal from jute sticks, that destroys the green ambiance along with producing various pollutant gases. This technique is responsible for environmental pollution, in addition, many important by-products i.e., tar, and gasses, which are wasted every day, another more important generated energy cannot be reused. The destructive distillation technique has been utilized in many developed countries for the production of charcoal and activated carbon as a result, generating various greenhouse gases that are polluting the environment along with wasting a variety of by-products and energy (Chakraborty et al 2020). By using destructive distillation, methods for the preparation of charcoal and activated carbon from jute sticks and other worthless agriculture wastes are called green technology. On the other hand, by this process, various important by-products are produce which can be used as exported materials for earning foreign currency. Moreover, we can reuse the energy, which reduces the burning production cost and became less environmental pollution. Various derivatives

are derived from different parts of jute plants like bioadsorbent which are effective for dye removals (Banerjee and Dastidar 2005), jute stick powder used for Congo Red and Rhodamine B dye removal (Panda et. al. 2009) and jute stick activated carbon used for Brilliant Green dye removal (Asadullah et al 2010). The purity and lightness of jute stick charcoal are exceedingly vital properties than other sources of charcoal. Presently, a sustainable development strategy is adopted for inclusive development for which indigenous and renewable sources of raw materials are of pivotal interest for potential development. Activated carbon is a multi-tasking, reusable, and cheap material, due to its eco-friend properties; it is used for restoring or revitalizing water. Again, activated carbon has several types of uses such as industrial, chemical, pharmaceutical, agricultural, environmental adsorption of unwanted chemicals, neutralizing toxic materials, and so on. It is used for the purposes of the treatment to a number of poisonings for example acids, alkali, alkaline metals, hazardous chemicals, heavy metals, organic carcinogens, alcohol, spirit, etc overdoses patients by the oral medication of tablets or capsules. It is used as an over-the-counter drug to treat diarrhea, indigestion, and flatulence too. Moreover, activated carbon is used for the purpose of analysis in chemistry for example carbohydrates separation by the chromatographic methods. Ecological applications of activated carbon are water filtration, gracious organic and inorganic compounds capture, dry wash, operations of gasoline dispensing, oxygen and other gases purification, measurement of radon concentration in air, snow avalanche control, teeth-whitening products, skin blackheads removal cream various types of sound wave capture, nuclear biological chemical suits, toxin-clearing properties, antiviral, antibacterial and antifungal, deodorants, metallurgical fuel, respectively. Agriculturists are used for liquor making, livestock production for example animal feed additives and pesticides antiseptic.

The diversified uses of charcoal and activated charcoal are increasing dramatically. Therefore, the present study was undertaken for the preparation of activated carbon where physical and chemical activation was used. We have applied a chemical activation process, where the raw material is first saturated by strongly reacting chemicals as $CaCl_2$ followed by thermal activation in an inert condition (Figure 1).

Figure 1. *Flow diagram for the preparation of activated carbon from jute sticks.*

2. Materials and Methods

Tossa jute (*C. olitorious*) sticks were used as precursor material in this study which was obtained from the Head Office of Bangladesh Jute Research Institute (BJRI), Dhaka Bangladesh. All the chemicals (such as $CaCl_2$, Merck) used in the present experiment were reagent grade.

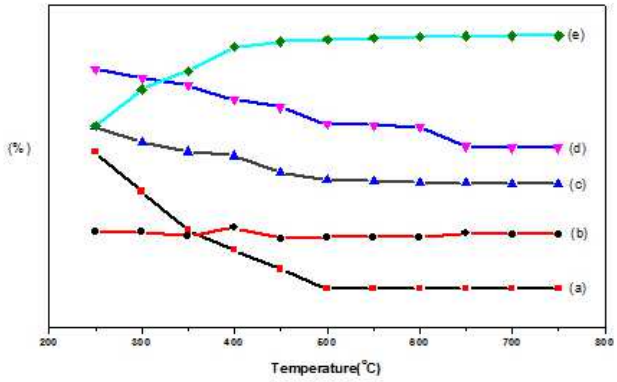

Figure 2. *Charcoal preparation at various temperatures with the composition (percentage) of- (a) Yield (b) Moisture (c) Volatile matter (d) Ash and (e) Fixed Carbon (FC).*

2.1. Physical Measurements, Analysis of Charcoal and Product Yield

Fourier transform infrared (FT-IR) spectra of samples were recorded on an FT-IR spectrophotometer in the region of 400 cm^{-1} - 4000 cm^{-1}. The thermal stability of the charcoal samples was tested by a thermogravimetric analysis (TGA) analyzer. For proximate analysis, the American Society for Testing and Materials (ASTM standard D1762-84) had been followed to determine moisture, volatile, ash, and fixed carbon (FC) [7]. The weight of the product after carbonization denoted the yield value of charcoal which was calculated using the following formula:

Yield (%)=(Weight after carbonization/ Weight before carbonization) x 100

2.2. Determination of Moisture, Volatile, Ash and Fixed Carbon (FC) Content

The charcoal sample was taken into a pot and covered with aluminum foil paper, heated for 4h at 110°C in the oven. The moisture reduction weight was calculated using the following formula:

Moisture (%)=(Weight reduction/ Weight before heating at oven) x 100

The charcoal was heated at 600°C in a closed crucible for 30min. The weight drop is for volatile materials which were calculated using the following formula:

Volatile (%)=(Weight lose/ Weight of oven-dried sample) x 100

Charcoal was heated at 900°C in an open crucible for 2h. During this time, all the samples converted into ash. Ash content was calculated using the following formula:

Ash (%)=(Weight of ash/ Weight of oven-dried sample) x 100

Moisture, volatile matter and ash percentages were subtracted from 100% charcoal and thus the fixed carbon was calculated using the following formula:

FC=100 – (Moisture + Volatile +Ash) %

2.3. Preparation of Charcoal

Jute sticks were cut into chips (5-7x1cm^2) and 50-55g of loose chips was taken for carbonization in a porcelain basin where the jute sticks were covered with perforated aluminum foil in order to promote the escape of volatile substances. The carbonization was carried out in an electric muffle furnace having internal dimensions of 35x20x12.5cm^3 (8750cm^3) with a thermocouple heating and temperature control. After the end of carbonization, the pot was taken out and was immediately covered tightly with a stainless steel plate. After the pot had cooled, the cover was opened allowing absorbing moisture which was then weighed after 24h. The yield of charcoal was calculated on an oven-dry basis after the determination of moisture.

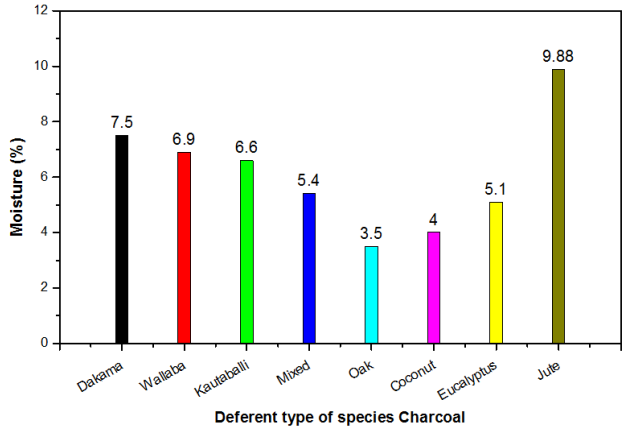

Figure 3. *Comparison of moisture percentage deferent type of species charcoal.*

2.4. Preparation of Activated Carbon

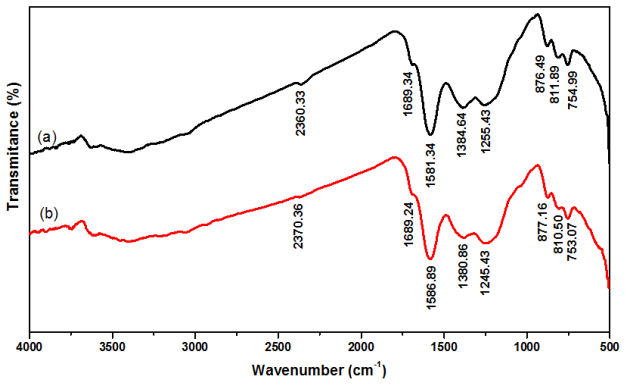

Figure 4. *FTIR spectra- (a) charcoal, (b) activated carbon.*

In order to make activated carbon, the raw material charcoal (10g) was mixed with 100g of $CaCl_2$ and the mixture was milled in a mortar. 100 mL water was added to the grained mixture and put overnight in a 500 mL beaker. A solid mixture was collected from the beaker by filtration and was put in a porcelain crucible covered with aluminum foil paper in the muffle furnace where the activation temperature was reached @ 10°C / min at 700°C temperature and maintained for 1h. The resulting carbons were washed with water to neutral pH and dried at 110°C overnight.

3. Result and Discussion

Jute-sticks were found to have a tendency to inflame or glow at temperatures above 270°C resulting in the collapse of the chip, deposition of ash, and a very low yield of charcoal. However, if the temperature was raised slowly between 150 and 250°C, at the rate of 5°C min^{-1}, then flaming and the collapse of the chip could be prevented, but the yield still decreased at temperatures above 300°C (Table 1). At 250°C and 300°C temperatures, charcoal yields are 40-45% and 33-40%. Below 300°C grayish color charcoal was obtained. At higher temperatures, the carbon percentage might be increased therefore, the total yield was decreased. We have observed that after 500°C charcoal yield nearly the same. Figure 1a and Table 1 demonstrate that when the temperature is increased then the yield of charcoal is decreased. Above 500°C temperature, ash and volatile matter decreases but the purity of carbon (FC) increases (Table 1) [8-11].

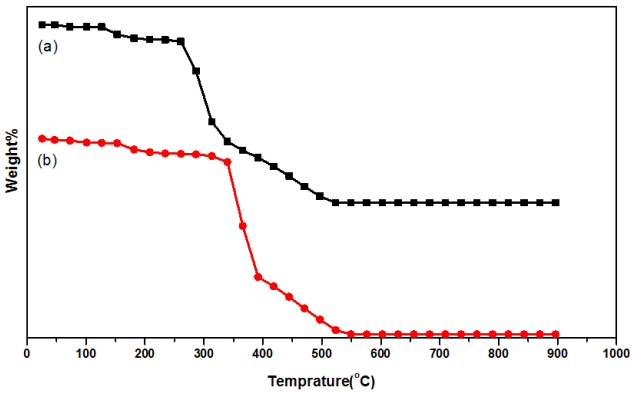

Figure 5. *Thermogravimetric graph- (a) charcoal (b) activated carbon.*

Fresh charcoal contains very little moisture and it is usually less than 1%. But charcoal absorbs moisture from the humidity of the air with time, and it is about 5 to 12%. If the charcoal is not properly carbonized, pyroligneous acids and soluble tars could be back on to the charcoal by rain or humidity of the air, the hygroscopicity of the charcoal is increased and the natural or equilibrium moisture content of the charcoal can rise to 15% or even more. Moisture is an adulterant that lowers the calorific or heating value of charcoal. Therefore, the moisture content is an important parameter in charcoal, and hence, it is needed for determining the calorific value of charcoal. The analytical results of charcoal moisture are summarized in Table 1, the proximate analysis can

determine the moisture percentage which is measured as mass loss from a sample under specified conditions after heating in a moisture oven upto 110°C. Eleven samples of charcoal were measured (in deferent sample weight) and determining moisture is 10.54, 10.70, 9.44, 11.82, 8.78, 9.07, 9.13, 9.21, 10.16, 9.99, and 9.89 percent (Table 1). The average percentage was 9.88% which has a similarity reported by other researcher [12].

Table 1. *Carbonized summary of jute stick.*

Temperature (°C)	Duration (Hour)	Yield (%)	Moisture (%)	Volatile (%)	Ash (%)	FC (%)
250	3.5-4	40-45	10.54	32.50	3.95	55.00
300	3.5-4	30-35	10.7	25.06	3.66	65.66
350	3.5-4	20-25	9.44	20.65	3.40	70.88
400	3.5-4	15-20	11.82	18.66	2.89	78.02
450	3.5-4	10-15	8.78	10.95	2.62	79.52
500	3.5-4	8-10	9.07	7.02	2.02	80.10
550	3.5-4	8-10	9.13	6.54	2.01	80.44
600	3.5-4	8-10	9.21	5.74	1.92	81.05
650	3.5-4	8-10	10.16	5.60	1.26	81.10
700	3.5-4	8-10	9.99	5.30	1.21	81.20
750	3.5-4	8-10	9.89	5.24	1.20	81.15

The weak broad peaks of both charcoal and activated carbon which are of O-H stretching vibrations at around 3,450 cm^{-1} reveal the presence of moisture. The peaks at 2360.33 cm^{-1} and 2370.36 cm^{-1} correspond to the C=O groups [13]. The peak at 1689.34 cm^{-1} and 1689.24 cm^{-1} are attributed to the stretching vibration of carboxyl groups-COO^{-}. The peak observed at1, 581.34 cm^{-1} - 1383.64 cm^{-1} and 1586.89 cm^{-1} - 1380.86 cm^{-1} is due to the C=C stretching that can be attributed to the aromatic C-C bond in both cases. The wave number with an absorption band peak of 1255.43 cm^{-1} -876.49 cm^{-1} and 1245.43 cm^{-1} - 877.16 cm^{-1} indicate the vibration of the C-O group of C-OH which is an impurity. The wave number with an absorption band peak of 811.89 cm^{-1} - 754.99 cm^{-1} and 810.50 cm^{-1} - 753.07 cm^{-1} (Figure 4) indicates the presence of aromatic C-H group vibrations which indicate the presence of hydrocarbon compounds [14-16].

Thermogravimetric analysis (Figure 5a) revealed that thermal decomposition of the analyzed charcoal occurred in three main phases. The first phase (50−260°C) is associated with moisture release (9.6% weight loss). The most intensive decomposition of an organic matter occurred in the range of 260−520°C (additional 88.4% weight loss). In this range of temperature, all carbon materials are oxidized to form carbon monoxide or carbon dioxide, and the rest inorganic materials become ash. On the other hand, thermal decomposition of the activated carbon (Figure 5b) occurred in the same three main phases like charcoal but was a little bit different. The first phase (50-340°C) is associated with moisture release (24% weight loss) because after activation activated charcoals consume more water than charcoal. The oxidation of carbon occurred in the range of 340−550°C (additional 75% weight loss) and the rest 1% of inorganic materials become ash [17, 18].

Carbonization temperature fixing is an important task to prepare charcoal from jute sticks. To find out the suitable temperature to make charcoal had used various temperatures (200-750°C). Carbon purity depends on the removal of ash in the charcoal it will be observed next year. The charcoal was activated by the activation chemical $CaCl_2$ and the final activated carbon was obtained after pyrolysis at 700ºC in an electric muffle furnace.

Jute stick is the core portion of the jute plant left after the extraction of the jute fiber. Whereas the fiber portion has great commercial value, the stick portion is considered to be agricultural waste. The actual amount of jute sticks, which is an annually renewable product, is huge every year. Due to its abundance, ready availability and cheapness, it will be a more economical source for making charcoal for fuel and chemical carbon than the hardwood resources. Therefore, further development work is in progress in our laboratory for preparing this charcoal under pilot-plant conditions, and for study of its performance in the various applications indicated above.

4. Conclusion

The present study revealed that high yield of charcoal (about 45%) was obtained 250°C and 300°C temperatures but yield declined (about 8%) at 500°C temperature which remain constant above 500°C temperature as well as activate carbon was achieved by after pyrolysis at 700°C with $CaCl_2$.

Declaration

The authors declare that they have no conflict of interest.

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