International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 08 | Aug 2021 www.irjet.net p-ISSN: 2395-0072

Development and Evaluation of Carbonization Cum Steam Activation Unit for Coconut Shell

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Abstract - *Coconut shell (Cocos Nusifera), an agricultural waste converted into activated carbon in integrated carbonization cum activation unit at steam flow rate of 0.75 kg/h and temperature of around 550ºC. The steam activation was conducted for 1 h residence time. The waste heat of carbonization process was utilized for steam generation and activation process. The mass conversion efficiency of carbonization was found to be 16.49% and the yield of steam activation process was 88%. Adsorption properties showed that for 1 h steam activation process, the iodine number was 485 mg/g and methylene number was 288 mg/g.*

Key Words: Coconut shell, Carbonization, Activated carbon, Iodine number, Methylene blue number

1. INTRODUCTION

Coconut is cultivated in over 95 countries around the world, in the tropical belt of world over an area of about 12,196 million hectare with production of 69,836.36 million nuts and productivity is 49968 nuts/hectare (FAO, 2019). About 73% of the world production comes from the three major producing countries: Indonesia (27.7%), Philippines (23.6%) and India (21.5%). The annual coconut production of India is 624.5 lakh tonnes coconuts with the yield of 5.29 tonnes/hectare. The crop is cultivated on area of about 118.1 lakh hectare (FAO, 2021). The crop contribute ₹ 15000 crore to GDP of country annually [1]. The coconut production of Maharashtra is about 187.44 million nuts along the productivity of 6670 nuts/hectare. Nearly 95% of area under coconut cultivation of Maharashtra is concentrated in Konkan region and most of the orchards are situated near the seashore. At national level, Maharashtra contributes about 1.42% share in area and 0.92% in annual production.

The shell of the mature coconut is a uniformly dense material like hardwood that consists mainly of lignin and cellulose. Coconut shell (CS) is one of the main polluter that contributes to the world's pollution trouble as it is a solid waste with approximately 3.18 million tonnes annually, which represent over 60 % of national waste volume [2]. Coconut shell, has cause profusely obtainable agricultural waste from local coconut industries. Their disposal is costly and may cause environmental problems. These shells can be used as a charcoal and activated charcoal. Coconut shell has calorific value of 20.8 MJ/kg [3]. In Konkan region, the average production potential of coconut shell as a biomass is 17,737.65 tonnes annually [4].

Activated carbon is a very useful adsorbent which is a microcrystalline, non-graphite form of carbon produced from any carbonaceous material. The carbon is activated to achieve a very large internal surface which makes it ideal for adsorption. It can be used for purification applications in different industrial processes such as wastewater treatment, gas cleaning, metal removal from waste, anti-pollutant for air, for removal of taste, colour, and odours from vegetable and animal oils. Activated carbon can be produced by first carbonization of biomass and then activation of bio-char produced with physical or chemical activation processes. Compared to chemical activation a physical activation is a simple, less expensive and eco-friendly process. Activation agents involve (CO_2, water or air) are also easily available [5]. During the preparation of activated carbon from coconut shell or other biomass, large amount of heat energy (about 600 ºC to 900 ºC) is required to maintain the temperature for carbonization process and further to activate the carbon (250 ºC to 600 ºC) [6]. For getting this energy large amount of biomass is needed to burn out. Some of energy produced is losses to the atmosphere as heat. Hence, this work is subject to utilizing this waste heat and thus increasing the efficiency of process.

2. MATERIALS AND METHODOLOGY

2.1 Raw material

The raw coconut shells were collected from local market and sources like temples, hotels etc. and cleaned for removal of coir, coir pith, dust and remaining of coconut kernel. The coconut shells were dried in solar tunnel dryer after washing with water. The dried samples were used for further carbonization and activation process.

2.2 Development of carbonization cum steam activation unit

The existing open top gasifier developed at Department of EOES, CAET, Dr. BSKKV, Dapoli was used as heat source for steam activation of coconut shell charcoal. The combustion chamber of open top gasifier was used for production of charcoal. The steam activation unit has facility to be placed on the top of gasifier. The heat available from open top gasifier during the charcoal production was used for steam generation as well as for heating the activation unit. The steam activation unit consist the components; activation reactor, steam jacket / steam production unit, steam injection pipe as shown in Fig.1. The technical specifications of activation unit are described in table 1.

Table -1: Technical specifications of carbonization cum activation unit

Particulars	Specification
Gasifier reactor inner diameter, m	0.26
Gasifier reactor outer diameter, m	0.30
Gasifier reactor height, m	0.60
Diameter of burner, m	0.26
Height of burner, m	0.16
No. of secondary air vents, no.	14
Height of ash chamber, m	0.15
Diameter of ash chamber, m	0.30
Area of grate, m^2	0.053
Height of grate from bottom, m	0.225
Adjustable primary air vent, m^2	0.0053
Height of activation reactor, m	0.20
Diameter of activation reactor, m	0.09
Capacity of activation reactor, kg	0.500
Height of steaming jacket, m	0.10
Diameter of steaming jacket, m	0.26
Capacity of steaming jacket, lit	4.0
Length of steam injection pipe, m	0.50

The reactor height and inner diameter of open top gasifier were 0.60 m and 0.26 m. The length of activation reactor was taken as 1/3rd of gasifier reactor height and the diameter of activation reactor was taken as 1/3rd of inner diameter of open top gasifier. Therefore,
Height of activation reactor = $1/3 \times$ Gasifier reactor height = $1/3 \times 0.60 = 0.20$ m
Diameter of activation reactor = $1/3 \times$ Inner diameter of gasifier = $1/3 \times 0.26 = 0.09$ m

The steam flow rate essential for activation of coconut shell charcoal was 0.03 kg/h [7], hence the volume of steaming chamber was considered to hold the water of minimum 3×10^{-5} m^3. The radius of steaming chamber selected as 0.13 m.
Volume of steaming chamber = $\pi \times (0.13)^2 \times h$.
Therefore, h = 0.06 m (Approx.)

Considering the losses, the height of steaming chamber was taken as 1.5 times the calculated value and selected as 0.10 m.

2.3 Preparation of activated carbon

The known quantity of raw coconut shell was inserted into the carbonization chamber and ignited. In steaming unit 3 L of water was taken. The coconut shell charcoal obtained from open top gasifier was powdered to less than 2 mm particle size and 0.250 kg of sample was steam activated in activation reactor. The activation reactor was screwed to the steaming unit with closing the top of gasifier. The constant steam flow rate of 0.75 kg/h was maintained for the steaming of charcoal. The gases evolved during carbonization was come out through secondary air vents of gasifier and by burning of these gases flame was obtained which helped to maintain a temperature required for activation process and steam generation.

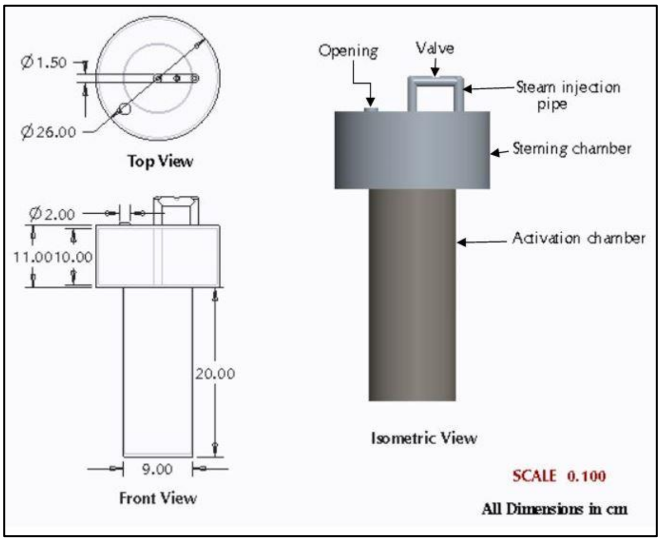

Fig -1: Schematic view of steam activation unit

Fig -2: Pictorial view of existing open top gasifier and developed steam activation unit

2.4 Characterization of activated carbon

Proximate analysis of coconut shell activated carbon (CSAC) was carried out to find out percentage moisture (ASTM D-3173), volatile matter (ASTM D-3175), ash (ASTM D-3174) and fixed carbon content (by differences method). In elemental analysis C, H, N and O percent was calculated theoretically by imperial formulae based on proximate analysis [8]. Bulk density determined as per the standard procedure ASTM D6683 and heating value measured using of bomb calorimeter (ASTME- 711). Adsorption capacity of activated carbon was analyzed in terms of methylene blue number and iodine number as per ASTMD 4607–94. Methylene blue number was calculated by using formula [9],

$$q\ eq.\ (mg/g) = \frac{(Co - Ce) \times V}{M} \times 100$$

Where, qeq = Amount of methylene blue adsorbed (mg/l), V = Volume of solution treated (l), Co = Initial concentration of methylene blue (mg/l), M = Mass of carbon taken (g), Ce = Equilibrium concentration of methylene blue (mg/l).

3. RESULTS AND DISCUSSION

3.1 Performance of open top gasifier for heat generation and charcoal production

The performance evaluation of developed unit was carried out by using coconut shell for 1 h residence time for simultaneous carbonization and activation process. The results were obtained for series of test run for carbonization unit and average values are shown in table 2. The quantity of coconut shell used for the carbonization was taken as 6.1 kg depending on volume of carbonization reactor. The start-up time required was 6 min with use of averagely 20 ml of auxiliary fuel (burned engine oil). The total operating time including start-up time, boiling start time and the steam activation residence time was 1.38 h for 1h activation.

Table -2: Operating parameters of open top gasifier as heat source

Sr. No.	Parameter		Value
1.	Mass of sample, kg		6.1
2.	Auxiliary fuel used, ml		20
3.	Start – up time, min		6
4.	Time, min	0	26.8
		20	540.33
		40	528.00
		60	503.33
		80	457.67
		100	-
		120	-
		140	-
	Average temperature of carbonization reactor, ºC		507.33
5.	Time, min	0	-
		20	636
		40	569.33
		60	511.33
		80	422.33
		100	-
		120	-
		140	-
	Average flame temperature, ºC		534.75
6.	Total operating time, h		1.38
7.	Boiling start time, min		22.33
8.	Output quantity, kg	I. Charcoal	0.770
		II. Unburnt	0.00
		III. Fins	0.140
		IV. Ash	0.100
		V. Losses	5.090

During the process of carbonization, the variation of temperature inside the carbonization reactor and flame temperature with respect to operating time of the reactor was measured at an interval of 20 minute from the starting of gasifier until the end of the process. The maximum flame temperature and carbonization reactor temperature reached during 1 h residence activation process were recorded as 636 ºC and 540.33 ºC, respectively at 20 minutes after starting the gasifier. This revealed that, acceptable temperature was reached and maintained for steam activation process of charcoal in open top gasifier. Similar results for flame temperature was reported by [10]. Around 83.4% of input was lost during steam activation of charcoal.

3.2 Performance of steam activation unit

It was observed that, depending upon the environmental conditions and the temperature reached in carbonization reactor, time required to steam generation in steamer was averagely 0.38 h (23 min). The steam activation process of coconut shell charcoal with steam flow rate of 0.75 kg/h resulted in output quantity of 0.220 kg activated carbon i.e the yield of activated carbon for 1 h residence time was 88%.

Table -3: Operating parameters of developed activation unit

Sr. No.	Parameter	Value
1.	Quantity of coconut shell charcoal, kg	0.250
2.	Form of charcoal	Powder
3.	Size of charcoal particles	2 mm
4.	Initial quantity of water in steamer, lit	3.0
5.	Initial temperature of water in steamer, ºC	28.90
6.	Start of steam injection, h	0.38
7.	End of steam injection, h	1.38
8.	Average temperature of steam, ºC	105.33
9.	Total steam injected, kg	0.750
10.	Steam injection flow rate, kg/h	0.750
11.	Output of activation process, kg	0.220

3.3 Characterization of coconut shell charcoal and activated carbon

Fig. 4.5 showed the variation in composition of coconut shell in terms of moisture content, volatile matter, ash content and fixed carbon according to carbonization and activation treatments.

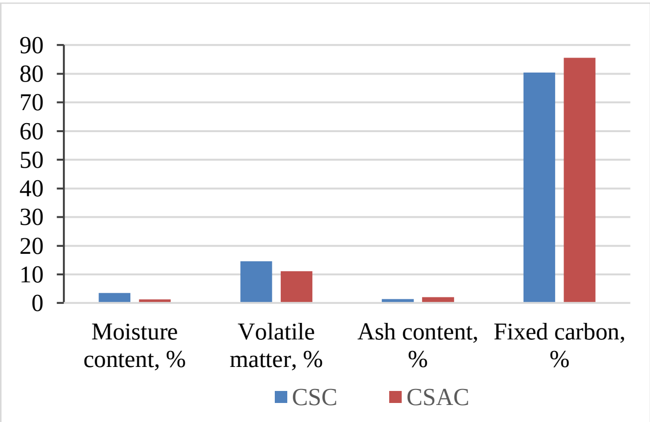

Chart -1: Effect of carbonization and activation on chemical composition of coconut shell

The moisture content and volatiles in the coconut shell decreased gradually from carbonization to activation process. The ash content and fixed carbon of coconut shell increased after carbonization.

It was observed that the carbonization and activation process parameters have a significant effects on the elemental composition of coconut shell.

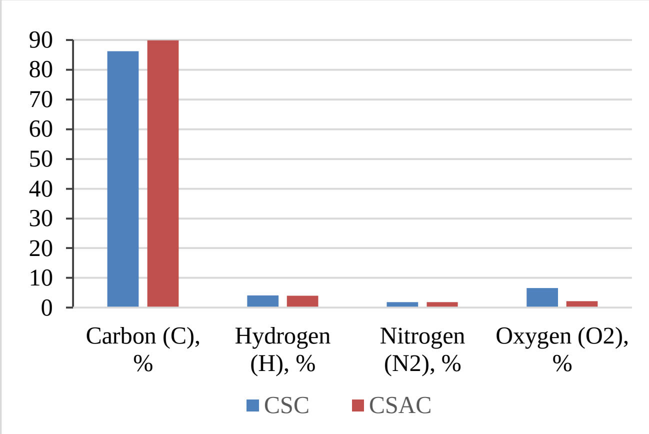

Chart -2: Effect of carbonization and activation on elemental composition of coconut shell

The carbon content of coconut shell charcoal increased after activation process releasing off the gases such as hydrogen, nitrogen and oxygen.

The results of chemical analysis of coconut shell activated carbon showed that the iodine number as 485 mg/g and methylene blue number as 288 mg/g. Similar results were reported by [11].

4. CONCLUSION

The developed carbonization cum activation unit was found to be suitable for production of activated carbon by simultaneous carbonization and activation process with utilization of heat produced during carbonization for steam generation. The temperature attained at activation reactor during process was around 550ºC. The resulted coconut shell activated carbon showed that increased carbon content than coconut shell charcoal. The iodine number and methylene blue number were found to be 485 mg/g and 288 mg/g.

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