

Original Research Article

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Energy Balance Study of Combined Carbonization and Liquefaction of Coconut Shell

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ABSTRACT

The work was carried out to study the combine carbonization and liquefaction of coconut shell (*Cocos nucifera*) biomass in order to produce the charcoal and bio crude oil. The characterization was carried out before and after carbonization process in terms of proximate analysis, higher calorific value and bulk density. The carbonization cum liquefaction was evaluated in terms of mass conversion efficiency, volumetric energy ratio, energy density ratio and properties of charcoal and bio-oil. The results obtained from the characterization of selected coconut shell (*Cocos nucifera*) biomass revealed that coconut shell showed its higher suitability for carbonization cum liquefaction with higher fixed carbon (21.796 %), lower ash (1.84 %), higher calorific value (5041 kcal/kg) and high bulk density (486.33 kg/m³). Total amount of charcoal produced by carbonization cum liquefaction process from 32.948 kg coconut shell was 10.83 kg, with 3140 ml bio-oil, the fixed carbon content of coconut shell charcoal was 76.497 %. The higher calorific value of coconut shell charcoal and bio-oil was 6795 kcal/kg and 5320 kcal/kg, respectively. The mass conversion efficiency, volumetric energy ratio and energy density ratio of charcoal and bio-oil production using coconut shell (*Cocos nucifera*) was found to be 42.4 per cent, 4.04 per cent and 2.51 per cent respectively. Coconut shell fuel showed its higher suitability for combine charcoal and bio-oil production in terms of mass conversion efficiency, volumetric energy ratio and energy density ratio.

Keywords

Energy, Balance, Carbonization, Liquefaction, Coconut shell

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Introduction

Coconut (*Cocos nucifera*) is a popular plantation and is grown in 92 countries worldwide. India accounts for 23.34% of the world's coconut production, producing 10,894,000 tonnes annually (FAO, 2009). The Konkan region of Maharashtra is a major coconut producing region in the Maharashtra. The average production of coconuts in the

Konkan region is about 1,313.9 lakh nuts annually (Anonymous, 2010).

An individual coconut fruit is made of an outer exocarp, a thick fibrous fruit coat known as husk, the hard protective endocarp or shell called "eyes" are at one end of the nut. The coconut shell is the strongest part covered in coconut fruit. Inside the shell there is a thin, white, fleshy layer, about 12.25 mm thick at

maturity, known as the “coconut meat”. The interior of the nut is hollow and is partially filled with watery liquid called “coconut milk”. The coconut shell accounts about 135 g/nut and is used as biomass for heat generation. The average production potential of coconut shell as a biomass in Konkan region is 17,737.65 tonnes annually (Anonymous 2010). Conventionally, the coconut shell is subjected to open burning or burnt in boilers, which contribute significantly to CO₂ and methane emission.

Carbonization is more convenient process to produce charcoal which is the energy dense, smoke free fuel and consist of the fixed carbon content about 70 % or more. In carbonization process, large amount of heat is liberated in atmosphere in the form of flue gases and efficiency of carbonization as separate process is reduced. Solid biomass properties can be improved by carbonization, but converting them to liquid may further expand their utilization. Liquid bio fuels are easier to store, transport and handle than solid biomass. Pyrolysis is promising process to produce liquid fuels from biomass. The bio-oil is immiscible in fossil fuels and it has a heating value of about half of what a conventional fuel oil has.

If the flue gases from carbonization process are allowed to condense, then along with charcoal, bio-oil is also produced which may increase total efficiency of process and also flue gases escapes at low temperature after liquefaction in atmosphere reduces the hazard to environment. The combine effect of carbonization and liquefaction of the biomass was studied with following specific objectives

Objectives

To evaluate the performance of carbonization and liquefaction unit using coconut shell as a feed stock.

To study energy balance of the carbonization and liquefaction process of coconut shell.

Materials and Methods

The carbonization and liquefaction of the coconut shell was carried out to produce the charcoal and bio-oil simultaneously using the slow pyrolysis process. The coconut shell was carbonized in the charcoal kiln and the exit gases were condensed using cold water as a heat exchanging medium. The carbonization cum liquefaction unit was evaluated at 17° 45' N latitude and 73° 26' E longitude and at an altitude of 256m above mean sea level. The stepwise methodology to accomplish the objectives is summarized under the following sub headings.

Characterization of coconut shell before and after carbonization.

Performance evaluation of biomass carbonization cum liquefaction unit.

Characterization of bio-oil

Study the mass and energy balance of carbonization and liquefaction process.

Carbonization cum liquefaction unit

The technical specification of carbonization cum liquefaction unit is shown in Table 1. The schematic view of liquefaction unit is depicted in Figure 1. The carbonization cum liquefaction unit consist of carbonization kiln, double jacketed condensing unit, inlet and outlet for cooling water, inlet and outlet for flue gases, collecting port for bio-oil.

Double jacketed condensing unit

The size of double jacketed condensing unit was determined by considering the amount of flue gases generated during the carbonization

process. The condensing unit was developed for condensation of hot flue gases into bio-oil. The inner and outer jacket has been 30mm apart each other to hold the water outside and flue gases inside.

Inlet and outlet for cooling water

The inlet and outlet pipe for cooling water and hot water was provided on the outer side of jacket. It helped to supply the heat exchanging medium for transferring the heat from hot flue gases to water.

Inlet and outlet for flue gases

The inlet and outlet pipes were provided on the inner jacket to transfer hot flue gases generated from carbonization process to the atmosphere.

Collecting port for bio-oil

The bio-oil collecting port of the unit was connected to the inner jacket with tapered shape. The tapered shape provided the free flow facility to the oil into collecting jar.

Characterization of coconut shell and its output after carbonization and liquefaction

The coconut shell (*Cocos nucifera*) was used as feedstock for evaluation of carbonization cum liquefaction unit. The material was characterized before and after carbonization in terms of proximate analysis, calorific value and bulk density.

The moisture content of coconut shell and its charcoal was determined by oven dry method as per ASTM D-3713. The volatile matter of coconut shell and its charcoal was determined by using muffle furnace as per ASTM D-3175. The ash content of coconut shell and its charcoal was determined by using muffle furnace as per ASTM D-3174. The fixed

carbon content was calculated by using the weight difference method as Fixed carbon (%) = 100 - % (moisture content + volatile matter + ash content).

The higher heating value of material was determined by using bomb calorimeter. The higher calorific value of solid fuel using bomb calorimeter experiment was determined as;

$$\text{Calorific value (kcal/kg)} = \frac{(W+w) \times (T_2 - T_1)}{X}$$

Where,

W = Mass of water placed in calorimeter, g

W = Water equivalent of apparatus, g

T₁ = Initial temperature of water in calorimeter, °C

T₂ = Final temperature of water in calorimeter, °C

X = Mass of fuel sample taken in the crucible, g

The bulk density of selected material was measured using a known volume cylindrical shaped container of 200 lit. (0.2m³). The pH of bio oil was measured using pH meter to determine the nature of crude oil. The higher heating value of bio oil was determined by using bomb calorimeter. The viscosity of bio-oil was measured by using redwood viscometer and reported in terms of centi stocks.

Performance evaluation of carbonization cum liquefaction unit

The performance evaluation of biomass carbonization cum liquefaction unit was carried out to study mass conversion of fuel, energy density ratio and volumetric energy

ratio of process by conducting three test of coconut shell as a biomass. The following parameters were measured during the performance evaluation of carbonization cum liquefaction unit and average values were reported as result.

Weight of sample (kg): The quantity of selected biomass material for carbonization cum liquefaction unit process was measured by using weighing balance.

Size and density (kg/m³): The size and density of material was measured before and after carbonization cum liquefaction process.

Average wind speed (m/s): Wind speed was measured with the help of digital anemometer during experimentation.

Starting and operating time (minute): The time after pre-ignition of carbonization chamber known is as starting period. Time span after pre-ignition of carbonization chamber to completion of carbonization process known is as operating period was measured with help of stop watch.

Quantity of supplementary fuel (ml): The supplementary fuel was needed for pre-ignition of biomass in carbonization chamber. The quantity of supplementary fuel used for every test was measured and recorded.

Temperature of flue gases at exit of carbonization kiln and liquefaction unit: The temperature of flue gases which liberated are from exit of carbonization kiln as well as exit of liquefaction unit was measured by using K-type thermometer at an interval of 30 minutes.

Temperature of inlet and outlet of cooling water: The temperature of inlet cooling and outlet hot water from condensing unit was measured by using glass thermometer at an interval of 30 minutes.

Output of carbonization (kg): The output material obtained after carbonization process included charcoal, ash and unburnt materials. After every test run, the output material weighed and noted down (Plate 2).

Output of liquefaction (kg): The output obtained after liquefaction process bio-oil, after every test run, was measured and noted down (Plate 3).

The mass and energy balance of carbonization process based on the average results were studied. The performance evaluation of carbonization and liquefaction process was determined in terms of mass conversion efficiency, volumetric density ratio and energy density ratio.

The mass conversion efficiency is the ratio in terms of mass output after carbonization and liquefaction process to mass input before carbonization in kiln.

$$\text{Mass conversion efficiency (\%)} = \frac{\text{Output after carbonization} + \text{Output after liquefaction}}{\text{Mass of input}} \times 100$$

The volumetric energy ratio is the ratio of volumetric energy of charcoal and bio-oil produced after carbonization and liquefaction to volumetric energy of biomass before carbonization.

$$\text{Volumetric energy ratio} = \frac{\text{Volumetric energy of coal} + \text{Volumetric energy of bio-oil}}{\text{Volumetric energy of biomass}}$$

The energy density is the ratio of energy of carbonization and liquefaction and hot water to energy of biomass.

$$\text{Energy density ratio} = \frac{\text{Carbonization output energy} + \text{Liquefaction energy} + \text{Energy in Hot water}}{\text{Energy in biomass}}$$

Results and Discussion

Characterization of selected biomass and its output before and after carbonization and liquefaction

The characterizations of coconut shell (*Cocus nucifera*) and its output were carried out as per standard test procedures. The results obtained are summarized in Table 2. It was observed that, the moisture content of coconut shell was decreased from 12.38 per cent to 6.50 per cent during carbonization process. The volatile matter of coconut shell after carbonization was decreased from 64 per cent to 13 per cent. The fixed carbon content of coconut shell was increased from 22 per cent to 77 per cent and calorific value was increased from 5041 kcal/kg to 6795 kcal/kg after carbonization. The calorific value of bio-oil was found to be 5320 kcal/kg. The pH of bio-oil was found to be 5.25 which shows acidic nature due to presence of pyrogalic acid.

Performance evaluation of carbonization cum liquefaction unit

The results obtained from the evaluation of carbonization cum liquefaction unit are summarized in Table 3.

It was observed that, total operating time required for carbonization of coconut shell (*Cocus nucifera*) biomass was 7.16 hr. About 30-40 kg of biomass was carbonized within 7.16 hrs. in carbonization and liquefaction unit. The carbonization and liquefaction of coconut shell (*Cocus nucifera*) biomass revealed that, the final output was 10.83 kg charcoal(32.86%), 1.64 kg unburnt (4.977%), 0.283 kg of ash (0.86%) and bio-oil 3140 ml.

Thermal profile of carbonization and liquefaction

The variation in temperature of exit flue gases from carbonization kiln, liquefaction unit with corresponding ambient temperature is depicted in Figure 2.

It was observed that, the temperature of flue gases at exit of carbonization varied in the range of 220 to 250⁰C which is hazardous for environment, while the temperature of flue gases at the exit of liquefaction varied in the range of 40 to 55 ⁰C which is safe for the environment.

This shows that condensing flue gases at exit of carbonization reduces temperature of flue gases which is beneficial for environment (Fig. 3 and 4).

Fig.1 Schematic view of carbonization cum liquefaction unit

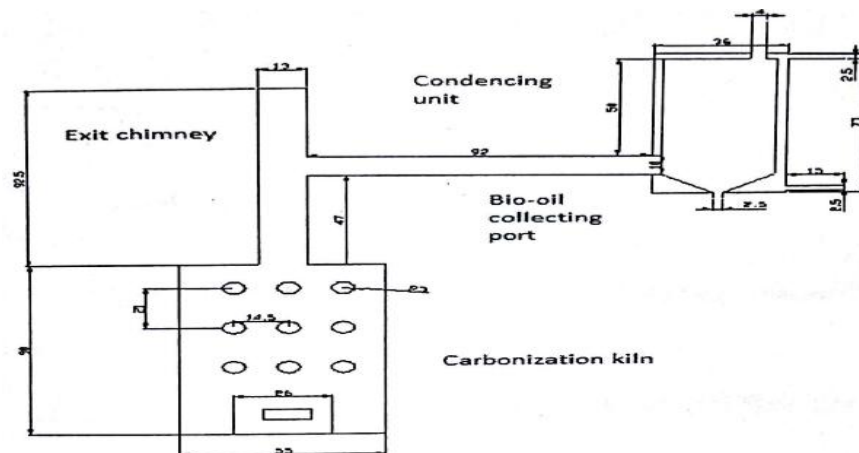


Fig.2 Thermal profile of exit flue gases from carbonization cum liquefaction unit

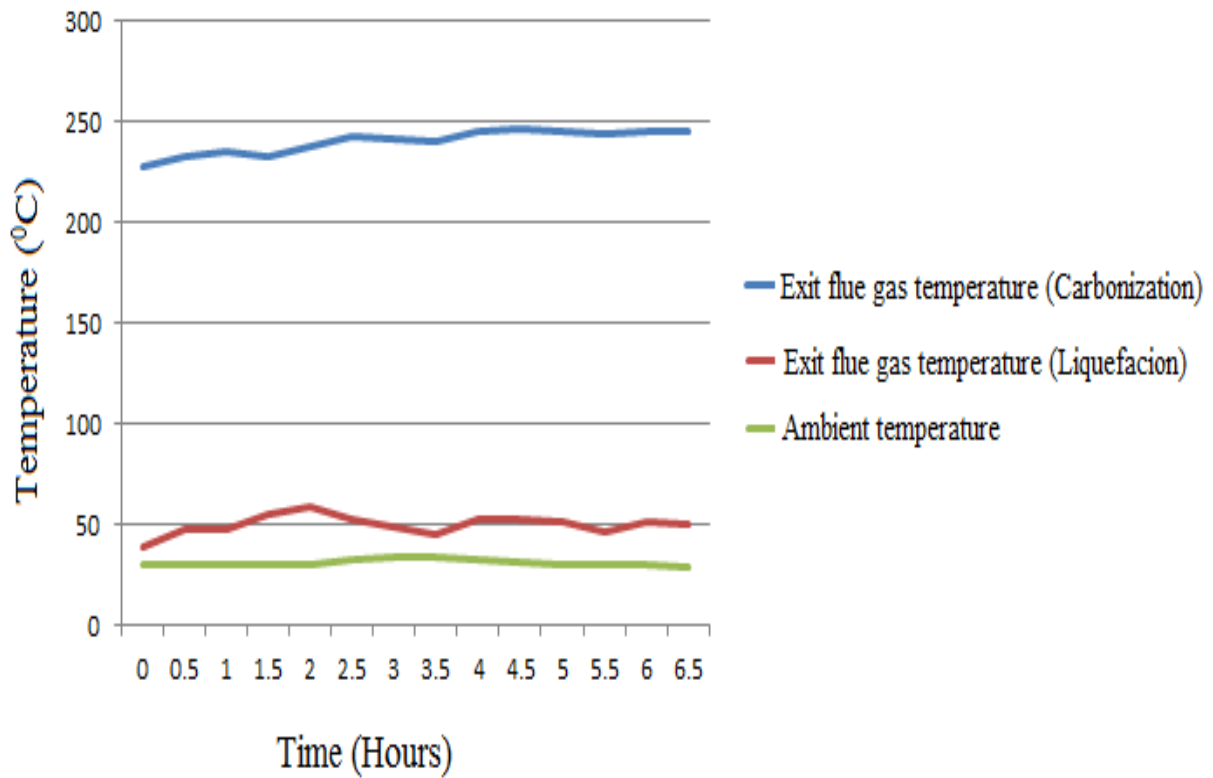


Fig.3 Pictorial view of output after Carbonization from coconut shell



Fig.4 Pictorial view of output after Liquefaction from coconut shell



Plate.1 Pictorial view of carbonization cum liquefaction unit



Table.1 Technical specifications of carbonization cum liquefaction unit

Sr. No.	Particulars	Specifications, mm	Material
I. Carbonization unit			
1.	Exit chimney	950 x 130 x 2	GI sheet
2.	Top cover	61 mm ϕ	MS 18 SWG
3.	Carbonization chamber	900 x 550 x 2	MS 18 SWG
4.	Inlet air vent	330 x 300 x 2	GI Pipe
5.	Exit door	233 x 240 x 2	MS 18 SWG
II. Liquefaction unit			
6.	Inner jacket, mm	600Lx 300W x 300H	GI 18 SWG
7.	Outer jacket, mm	660L x 360W x 360H	GI 18 SWG
8.	Inlet water pipe, mm	150L x 25 ϕ	GI pipe
9.	Outlet water pipe, mm	200L x 25 ϕ	GI pipe
10.	Inlet flue gas pipe, mm	300L x 100 ϕ	GI pipe
11.	Outlet flue gas pipe, mm	200L x 40 ϕ	GI pipe
12.	Outlet of bio-oil pipe, mm	30L x 25 ϕ	GI pipe

Table.2 Characterization of coconut shell and its output

Sr. No.	Parameters	Coconut shell (<i>Cocos nucifera</i>)	Charcoal	Bio-oil
1.	Moisture content, %	12.38	6.50	-
2.	Volatile matter, %	63.98	12.5	-
3.	Ash content, %	1.84	4.5	-
4.s	Fixed carbon, %	21.80	76.50	-
5.	Higher calorific value, kcal/kg	5041	6795	5320
6.	Bulk density, kg/m ³	486.33	618.87	1095
7.	pH	-	-	5.25
8.	Viscosity at 28.6 ⁰ C, Cs	-	-	4.02

Table.3 Operating parameters of carbonization cum liquefaction unit

Sr. No.	Parameters	Coconut shell (<i>Cocos nucifera</i>)
1.	Weight of biomass, kg	32.95
2.	Size of biomass, m	$\phi=0.05-0.07$ $h=0.05-0.08$
3.	Average wind speed, m/s	2.17
4.	Quantity of supplementary fuel, ml	160
5.	Operating time, hr.	7.17
6.	Output	1. Charcoal, kg
		2. Unburnt, kg
		3. Ash, kg
7.	Ambient temperature, °C	32.63
8.	Temperature of flue gas at exit of carbonization, °C	225.66
9.	Temperature of flue gas at exit carbonization cum liquefaction unit, °C	51.08
10.	Temperature of inlet cold water, °C	33.84
11.	Temperature of outlet hot water, °C	38.27
12.	Output of liquefaction, ml	3140

Table.4 Efficiency of carbonization using coconut shell as biomass

Sr. No.	Conversion efficiency	Coconut shell (<i>Cocos nucifera</i>)
1.	Mass conversion efficiency, %	42.4
2.	Volumetric energy ratio	4.0164
3.	Energy density ratio	2.40

Table.5 Energy input and output of carbonization cum liquefaction process

Sr. No	Process	Input			Output		
		Mass, kg	Heat value, kcal/kg	Energy, kcal	Mass, kg	Heat value, kcal/kg	Energy, kcal
1.	Coconut shell	32.95	5041	166101	-	-	-
2.	Charcoal	-	-	-	10.83	6795	73589.9
3.	Unburnt	-	-	-	1.64	5041	8267.24
4.	Bio-oil	-	-	-	3.14	5320	16704.8
5.	Hot water	-	-	-	273.43	1	1211.30
6.	Total			166101			99773.2

Mass and energy balance of carbonization and liquefaction process

The different efficiencies of carbonization and liquefaction i.e. conversion efficiency, volumetric energy ratio and energy density ratio were determined. The efficiency of carbonization with liquefaction using coconut shell (*Cocos nucifera*) biomass are summarized in Table 4.

The results revealed that mass conversion efficiency of combined process was 42.4 percent. The volumetric energy ratio was found to be 4.02. The energy density ratio was found to be 2.40 for coconut shell (*Cocos nucifera*). It gives both products charcoal as well as bio-oil which have higher calorific value than its raw material. Also the integrated unit releases the flue gases at low temperature (55⁰C) as compared to carbonization only (225⁰C) in the atmosphere which reduced the effects on environmental condition as well as produces hot water which can be used for domestic purpose.

Energy balance of carbonization cum liquefaction process

The energy input and output of carbonization cum liquefaction process of selected biomass are shown in following Table 5.

The energy value of the original 32.95 kg of coconut shell biomass was 166101 kcal which is converted in to various products in the combine unit and produced 10.83 kg coconut shell charcoal (73589.9 kcal), 3.14 litre bio-oil (16704.8 kcal) 273 ltr. Of hot water (1211.3 kcal).

The total output energy of process using coconut shell in carbonization cum liquefaction process was 99773.2 kcal which is 60% of the original value as compared to 25% in traditional charcoal kiln alone.

The combine carbonization cum liquefaction study of locally available biomass i.e. coconut shell (*Cocos nucifera*) fuel showed its higher suitability for charcoal and bio-oil production in terms of mass conversion efficiency, volumetric energy ratio, energy density ratio, storage and handling properties. The combine process of carbonization and simultaneous liquefaction recovered the higher energy than single process of carbonization.

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