Bio- Fuel and Charcoal From Coconut Shell - A Renewable Energy Source

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Coconut shell is a source for renewable energy in various forms. Pyrolysis is an effective technique for converting coconut shell into bio-oil and charcoal. Coconut shell composition includes moisture, hemi-cellulose, cellulose and lignin. The decomposition of these components takes place at various higher levels of temperature. Therefore, a feasible process development becomes inevitable and the characterization of the bio-oil becomes imperative. As a first step, the percentage decomposition of each component with respect to temperature was studied using thermo gravimetric analyzer (TGA). Applying these TGA data, pyrolysis of coconut shell was carried out in a rotating type reactor initially and continuous type reactor subsequently in nitrogen atmosphere. The yield of both bio-oil and charcoal were found increased under these conditions and also by introducing a chilling plant for efficient cooling and effective condensation of the cracked gases. It was found that between 200 and 350°C the oil formation was highest, ie., 52% and with further increase of temperature to 450°C, though 10% more oil is formed, it affected the charcoal yield which decreased to 20 from 38%.Therefore, considering the viability of the project industrially, the optimum temperature for maximum yield of bio-oil and charcoal was set at 350°C. Interestingly, it was found that, a continuous type reactor, instead of rotating type, can increase the rate of production of fuel-oil and charcoal under similar conditions. The physical and chemical characteristics including fuel efficiency of these products were studied and the properties were found comparable with diesel.

Of the world's total energy requirement, among various sources of energy, biomasses also play a pivotal role which is considered as a sustainable source of renewable energy, especially in countries where there are more agricultural activities. The waste-to-energy (WTE) projects represent roughly 14% of U.S non-hydro renewable electricity generation. In India (2013), the contribution to power from renewable energy sources is 12.32%. Bio-oils are produced from agricultural wastes which are renewable and bio-degradable materials. Most importantly, it does not pollute the environment as there is no CO2 emission in application and hence no rise in greenhouse effect.

Coconut is abundant in the South Indian states which constitute around 90% of the total coconuts produced in the country. The Food and Agricultural Organization of the United Nations has reported that coconut palms are grown in more than eighty countries and that the total annual production of the coconut accounts to 61 million tonnes. Coconut shells are biomasses of coconut which are traditionally used for charcoal production and ultimately converted into activated charcoal. The heavy smoke produced at the time of charcoal formation by the destructive distillation of coconut shell is highly polluting. The pyrolysis technology has been used for generating liquid, solid and gaseous fuels from bio-masses and it has been used commercially for decades. Studies on forest and agricultural residues were also reported. Das *et al* has showed that pyrolysis of cashew nut shells in a fixed bed reactor under vacuum has produced bio-fuel. Khor *et al* has characterized bio-oil produced from oil palm empty fruit bunches (EFB) by slow pyrolysis. Works on bio-oil production from cotton stalk [10] and characterization of biomass-based flash pyrolysis oil [11] were reported. Paper on conversion of bio-resource (Oil palm EFB) into energy [12] and management of palm oil mills towards zero waste [13] were presented in journals and conferences. Research works on the recovery of fuels and chemicals from rice straw [14], sugarcane bagasse, rice husks, jute stick etc [15], olive bagasse, cotton stalk, corncob and tea waste [16] have been reported. However, there was no efficient process development known for coconut shell pyrolysis. Hence process development for effective coconut shell pyrolysis was an important objective of this work.

Bio-oil a high density oxygenated liquid unlike petroleum fuels which are hydrocarbons, can be used as a substitute for fossil fuels, in certain applications. It is a mixture of large number of major and minor organic compounds of alcohols, aldehydes, ketones, acids, ethers, esters, sugars, furan, nitrogen compounds and multifunctional compounds [17]. Bio-oil can be used as a fuel in diesel engine with slight modifications in fuel pump, linings, and the injection system.

It can be blended with standard diesel fuels to form a pollution free green bio-diesel fuel. The nonpolluting performance is a speciality of these oils. This green oil can also be used in oil burners for thermal applications and in combustion boilers to generate electricity. Bio-oil based small scale power generating plants in remote areas and villages is the need of the hour as such plants are viable due to low investment and that the biomasses needed for bio-oil production is cheaply available. As a first step emphasis has been given to bio-oil sources and its production. Hence study of the characteristics of the coconut shell oil (bio-oil) and charcoal was another objective of this research work.

Materials and methods

Coconut shells were identified as a source for renewable energy. Dry coconut shells procured from Northern Kerala was subjected to biomass pyrolysis in specially designed rotating type reactor. Pyrolysis is a technology extensively used for the thermal cracking of different materials like biomass, waste tires, waste plastics etc into high energy gases known as 'Syn Gases'. Pyrolysis is thermal decomposition which takes place at higher temperatures under inert atmospheres, in the absence of oxygen and with the support of catalysts in some cases like plastics.

It was essential to ensure the maximum yield temperature of bio-oil and good quality charcoal as well. Thermo gravimetric analysis (TGA) was carried out to study these properties and found that the maximum yield of bio-oil and charcoal could be achieved by setting the decomposition temperatures appropriately. The TGA results were convincing that for higher yield of Bio-oil, the cracking process need to be raised to 450°C and for maximum yield of charcoal, the cracking has to be controlled at 325°C.

A pyrolysis reactor (Fig.2) with 16 mm wall thickness and size, 2600 mm X 7600 mm with pyrolysis capacity of 10 tonnes per day (TPD) was used for the coconut shell pyrolysis trial aimed to suit for industrial production. The reactor used was rotating type and motor driven. It has a large front door with airlock safety valves and has provision to flush out Syn gase and flue gase through separate pipe lines. A nitrogen purging device also was used in the reactor for creating inert atmosphere inside the reactor which enables to prevent oxidation. The reactor heating was carried out with firewood and by consuming the non-condensable gases given out in the process. The dried coconut shell initially weighed is loaded in the reactor which follows the firing of the reactor.

Thermal decomposition of the coconut shell took place at various temperatures in nitrogen atmosphere and the Syn gases were cracked gases was liquefied in the condensers (Fig.3) and collected in the oil collectors (Fig.4). The non-liquefiable gases were sent for reactor firing.

Fig. 1 Coconut Shell

The process development was fine tuned by repeated trials with and without nitrogen purging (Fig.5) and with ordinary and chilled water simultaneously. The efficiency of cracking and the yield of bio-oil and charcoal were found increased when the cracking was done in nitrogen atmosphere and by cooling the condensers with chilled water. It was also noticed that the pressure and temperature control became easy when the diameter of the pipe lines for Syn and waste gases were increased from 3 to 6 inch.

The Bio-Oil characteristics to ensure the fuel efficiency were investigated as per ASTM standards. Calorific value (ASTM D240), Flash Point (ASTM D92), Viscosity (ASTM D445), Density (ASTM D189), Water content (ASTM D95), etc were studied. The oil efficiency can be further increased by refining the oil to the grade of bio-fuel. The charcoal characteristics were also studied as per ASTM standards.

Results and discussion

The thermo gravimetric analysis (TGA) of dry coconut shells revealed that the first decomposition, occurs between 100 and 200°C, which followed the release of moisture (>10%) and a small amount (>1%)

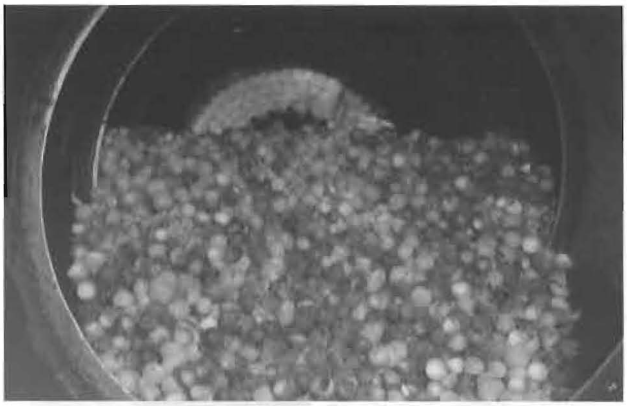

Fig.2 Coconut Shell inside the Rotating Reactor

of waste gases. The second and third decomposition takes place between 200 and 350°C which follows the cracking of hemicelluloses and cellulose [18] into the formation of volatile gases which on condensation is liquefied and in industry it is known as bio-oil (51.6%).

The fourth and final stage of decomposition takes place between 450 and 550°C resulting in the decomposition of lignin which contributes another 10% of condensable gases, which in turn is liquefied as bio-oil.

Fig. 3 Bio-oil Condensers and Oil Collectors

Another important highlight of the TGA results is the residue weight, which is the charcoal (Fig.6) part of the coconut shell at the above decomposition temperatures. Coconut shell when cracked at higher temperatures in the absence of oxygen is converted into charcoal besides volatile gases. The residue weight at each higher temperature give a clear indication of the charcoal yield. It is worthwhile to note

Fig. 4 Bio-oil from Coconut Shell

Fig. 5 Nitrogen Purging Machine

that good quality charcoal was formed at 325°C, the yield was found 51.98%.

But,for higher yield of bio-oil (51.16%), the decomposition temperature needs to be optimized at 350°C. The yield of bio-oil and charcoal at various temperatures above 200°C is clear from Fig 7 and table 1.

The burning efficiency of bio-oil was found comparable with petroleum diesel and importantly no smoky emissions were noticed while burning the oil. Obviously, unlike petroleum diesel, there is no carbon dioxide emission noticed in Bio-oil burning.

Fig 7 and Table 1 show that between 200 and 350°C, at each temperature, specific amount of weight losses were recorded which corresponds to the total amount of volatile matter and moisture. The weight % of volatile matter which corresponds to bio-

Table-I TGA of coconut shell: Residue wt%, (Charcoal), Weight loss Wt% and Volatile matter Wt% excluding Moisture, (Bio-oil)

Temp.,°C	Residue,Wt %	Moisture* + Volatile Matter Wt %	Volatile Matter, excluding Moisture, Wt%
28.9	99.99	0.001*	0
100	89.89	10.11	0
105	89.73	10.27	0
200	88.98	11.02	0
210	88.79	11.21	0.19
220	88.39	11.64	0.62
230	87.81	12.19	1.17
240	86.91	13.09	2.07
250	85.26	14.74	3.72
260	82.29	17.71	6.69
270	77.78	22.22	11.2
280	72.27	27.73	16.71
290	66.97	33.03	22.01
300	62.31	37.69	26.67
310	58.12	41.88	30.86
320	54.09	45.91	34.89
330	49.62	50.38	39.36
340	43.97	56.03	45.01
350	37.82	62.18	51.16
450	26.99	73.01	61.99
550	20.77	79.23	68.21
650	16.09	83.91	72.89
696	15.85	85.15	74.13

Fig. 6 Coconut Shell Charcoal

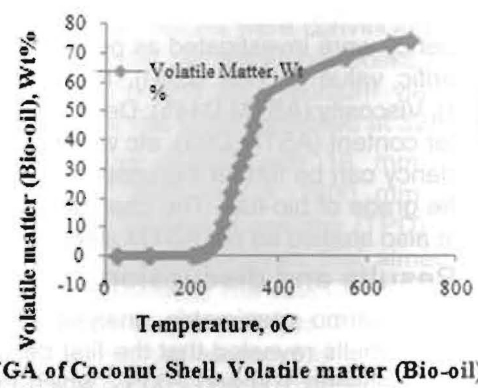

Fig 7 TGA of Coconut Shell, Volatile matter (Bio-oil) Vs Temperature

Table 2 Coconut Shell Oil (Bio-oil) Characteristics			
Parameters	Coconut shell oil (Bio-oil)	Plastic pyrolysis oil	Petroleum diesel
Calorific Value, K.Cals/ Kg	6300	10298	10038
Flash Point, oC	>100	58	98
Density, gm/cm3	1.0955	0.9940	0.98
Viscosity at 30oC, cSt	1.99	2.023	3.05
Water content, %	8	0.50	__

oil is obtained by subtracting moisture weight from the weight loss at each temperature. In the same way, the residue weight corresponds to the respective charcoal weight at each temperature. For example, weight loss at 105°C is 10.3% and, weight losses at 200, 250, 270, 290, 300, 325 and 350°Cs are 11.02, 14.74, 22.22, 33.03, 37.69, 48.02 and 62.18% respectively.Similarly, the residue weights (Fig 8) at these temperatures are found as 89.7, 88.98, 85.26, 77.78, 66.97, 62.31, 54.09 and 37.82% respectively.

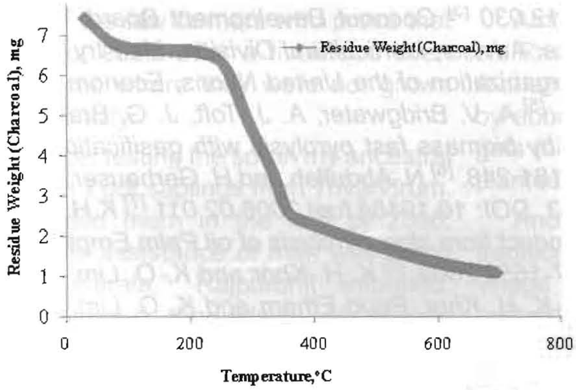

Figure 8 TGA of Coconut Shell: Residue Weight (Charcoal), mg Vs Temperature

Likewise the weight losses and residue weights from 350 and 450 are found as 62.18% and 37.82% and 73.01% and 26.99% respectively.

The results of industrial trial on coconut shell pyrolysis by both rotating and continuous type reactors were matching the results of TGA analysis. The rate of pyrolysis in continuous type reactor was higher than rotating type, as the reactor settings in continuous type reactor is so suited for non-stop operation whereas in rotating type the settings are suitable for separate batches only and it requires longer time for cooling the reactor before the next load is fed in. However, the quality of coconut shell oil (bio-oil) and charcoal were found same in both methods and the characteristics were found good in both cases. The quality parameters of the coconut shell oil are comparable with that of plastic pyrolysis oil and petroleum diesel and are given in Table 2.

The higher yield of bio-oil and charcoal are the interest of industry. Therefore, the yields of both bio-oil and charcoal were studied and the decomposition temperature were optimized for better yields. The coconut shell pyrolysis trials showed that the optimum yield of coconut shell oil and charcoal were 51.16 and 37.82% respectively at 350°C.The bio-oil yield was found increased around 10%, between 350 and 450°C, but above 450°C the oil yield was noted decreased as the oil part above this temperature gets decomposed to permanent gases.Solid charcoal consists of small amounts of volatile hydrocarbons, solid hydrocarbons and inorganic compounds. Above 450°C due to char loss, the charcoal yield also decreases.It will be interesting for the industrialists that the yield of pyrolysis products from five tonnes of coconut shells by rotating type reactor, comprises 550 litres (11 %) of moisture,1750 litres of bio-oil (35%),2000 Kg (40%) Charcoal and450 litres of other waste gases/permanent gases (9%). The bio-oil yield was found increased (45- 50%) when the decomposition temperature was kept low at 350°C and by condensing the hot vapours by chilled water. The quality parameters of coconut charcoal are presented in Table 3.

The present study on coconut shell pyrolysis showed that a pyrolysis plant with rotating or continuous type reactors can produce maximum quantity of coconut shell oil (bio-oil, 51.16%) and charcoal (37.82%) at 350°C in nitrogen atmosphere and chilled water coolingunder efficient reactor heating. The characterization of both bio-oil and charcoal has revealed that the calorific value, flash point, viscosity, density etc are comparable

Table 3 Coconut Shell Charcoal Characteristics	
Quality Parameter	Test Results
Moisture Content (%)	7.9
Volatile Matter (%)	12
Ash Content (%)	0.5
Fixed Carbon (%)	80
Dust Content (%)	0.2
Water content, %	8

with other oils like petroleum diesel and plastic pyrolysis oil and that the charcoal has shown excellent properties in comparison with charcoal produced by other conventional methods. It was further showed that temperature above 450°C will convert a portion of bio-oil into permanent gases and that the yield of oil found decreased above this temperature. Undoubtedly, charcoal yield was also found decreased above 350°C, due to char loss. The bio-oils are extensively used in boilers, furnaces and burners as fuel and in generators it is used in combination with diesel. The power crisis in remote and village areas could be addressed effectively by setting up small power generating plants where bio-oil can be easily supplied. The scope of exploiting bio-oil produced from abundantly available coconut shell for the rotation of turbines and generating electricity will be explored in future studies.

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