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Characterization of coir pith for fluidized bed gasification

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Abstract
Biomass characteristics are necessary for the proper selection of the gasification system and to design and evaluate the performance of biomass gasifiers. The coir pith is analyzed for its physical properties, chemical composition and kinetic parameters. The mean particle size of coir pith was found to be 0.551 mm. The relative size range of the coir pith was found to be 0.817. The bulk density, porosity and particle density of coir pith were found to be 87.0 kg m^{-3}, 71.4% and 305.0 kg m^{-3} respectively. Coir pith was found to have more volatiles (62.0%) than fixed carbon (26.0%) and ash (12.0%). The elemental carbon and oxygen were found to be 47.1 and 48.3 per cent respectively. The calorific value of coir pith was found to be 18.24 MJ kg^{-1}. Thermograms obtained for raw coir pith revealed distinct stages of thermal degradation. The ignition temperature was found to be 550°C.

Keywords: Coir pith, gasification, physical and chemical properties, thermogram

Introduction
Many technologies are available for the conversion of biomass into energy. Thermo chemical conversion has attracted particular attention for converting biomass into more useful and valuable energy product. Gasification is a process through which biomass materials can be subjected to a series of chemical changes to yield clean and combustible gas at high thermal efficiencies. Gasification is one of the promising thermo-chemical technologies that can produce a variety of fuels like syngas or fuel gas depending upon the feedstock and gasifying atmosphere (Gómez-Barea *et al*. (2009) [1] and Matsumoto *et al*. (2009)) [4]. Fluidized bed gasification technology is a typical gasification technology that has been widely applied for production of industrial fuel gas, city gas and chemical syngas. The first fluidized bed gasifier was developed in 1920s and after continuous improvement it has shown great advantages were studied by Ju *et al*. (2010). Large quantities of various biomass wastes are generated in developing countries like India. It was estimated that around 7.5 million tonnes of coir pith is available annually in India which can produce about 129 PJ of heat and 8.7 million tonnes of CO_2 was reported by Sheeba *et al*. (2009) [6]. For gasification of coir pith fluidized bed gasification offers significant advantages such as isothermal operation, simple scaling up procedures, high capacities and a good turn down ratio, over other types of gasifier configuration. Biomass characteristics are necessary to properly select the gasification system and to design and to evaluate the performance of biomass gasifiers. Biomass can be characterized in terms of physical properties of raw coir pith, proximate analysis and Ultimate analysis, Calorific value – Higher Heating Value, ash deformation and Fusion temperature and Rate of devolatilization – Thermograms. In this paper, the physical, chemical and kinetic properties of coir pith were analyzed and the results of this study will be useful for proper selection of the gasification system and to design and evaluate the performance of biomass gasifiers.

Materials and Methods
The coir pith is analyzed for its physical properties, chemical composition and kinetic parameters.

Physical properties of coir pith
Particle mean size
Sieve analysis is the most common method used for the analysis of particles and is suitable for the size ranging from 0.075 to 3 mm approximately (Henderson and Perry, 1966) Coir pith [12% (w.b) moisture content] was used for sieve analysis.

Particle mean size is calculated by using set of Indian standard sieves and following the procedures of Warren and Smith (1976). The cumulative fractions of coir pith retained on various sieves were calculated to find the relative particle size range of coir pith.

$$Mean\ Particle\ size,\ d_{mc} = \frac{1}{\Sigma(x_i / d_i)}$$

Where
d_{mc} = Mean particle size of coir pith
x_i = Mass fractions retained, g.
d_i = Average aperture size, mm.

$$Relative\ Particle\ size\ range = \frac{\frac{1}{2}(d_{0.84} - d_{0.16})}{d_{mc}}$$

Where
$d_{0.84}$ = Particle size below which 84% of the mass of the sample lies, mm.
$d_{0.16}$ = Particle size below which 16% of the mass of sample lies, mm.

Bulk density
It is determined by filling a vessel of known volume with coir pith.

$$Bulk\ density, \rho_{bc} = \frac{Mass\ of\ Coir\ pith, kg}{Volume\ of\ vessel, m^3}$$

Particle density
To find particle density, porosity of coir pith is determined by using pressure bottle method.

$$Porosity,\ P_c = \frac{H_1 - H_2}{H_1} \times 100$$

Where
H_1 = initial manometer level, cm H_2O
H_2 = final manometer level, cm H_2O

$$Particle\ density, \rho_{Pc} = \frac{\rho_{bc}}{1 - P_c}$$

Terminal velocity of coir pith
Terminal velocity of coir pith is calculated to keep the fluidizing air velocity between U_{mf} and U_t to avoid carry over of solids.
Terminal velocity of coir pith,

$$U_t = \left[\frac{4(\rho_{pc} - \rho_f)^2 g^2}{225 \mu_f \rho_f}\right]^{1/3} \times d_{mc}$$

Where
U_t = Terminal velocity ms^{-1},
ρ_p = Particle density of coir pith kg m^{-3}
ρ_f = Fluidizing air density, kg m^{-3} :
g = Acceleration due to gravity ms^{-2}
μ_f = Viscosity of fluidizing air kg $m^{-1}s^{-1}$:
d_{mc} = Particle mean size

Angle of repose
It is determined by dumping coir pith through a circular opening on a leveled horizontal surface and the product takes a shape of inverted cone.

$$Angle\ of\ Repose, \theta_c = \tan^{-1}(h/r)$$

Where
h = height of the cone, cm.
r = radius of the horizontal plate, cm.

Chemical composition of coir pith
Proximate analysis
ASTM standards D3172-73 through D3173-75, modified procedures recommended for volatile were used to determine the moisture content, ash content, volatile matter and fixed carbon of coir pith. Moisture content was determined by drying the known quantity of sample in an open crucible kept at 110°C in oven for one hour.

$$Moisture\ content\ of\ coirpith\ (w.b) = \frac{W_1 - W_d}{W_1} x100$$

Where,
W_d = Oven dried sample, g,
W_1 = Initial weight of coir pith, g.

The ash content of coir pith was determined by gradually heating the oven dried sample to 750° C in a muffle furnace. The difference in weight was taken as the ash content.

$$Ash\ Content = \frac{W_3}{W_1} x100$$

Where
W_3 = Final weight of the sample taken out from the furnace, g. Volatile matter was determined by keeping the oven dried sample in a closed crucible at 600°C for six minutes and then at 750°C for another six minutes.
The difference in weight (W_d – W_4) was taken as the total volatile matter.

Where
W_4 = final weight of the sample in a closed crucible, g.
Fixed carbon was found out by applying mass balance.

$$\text{Fixed carbon} = W_d - \text{Ash Content} - \text{Volatile matter}$$

The calorific value of the oven dried coir pith was determined in a standard bomb calorimeter (Toshniwall isothermal bomb calorimeter) by the ASTM D2075-77.

$$\text{Calorific Value}, CV_c = \frac{WT}{M}, \text{cal g}^{-1}$$

Where
CV_c = Calorific value of the coir pith, cal /g
W = Water equivalent of the calorimeter assembly in Cal °C^{-1}.
T = Rise in temperature, °C.,
M = Mass of the sample burnt, g.

Ultimate Analysis

The ultimate analysis was carried out to know the carbon, hydrogen, oxygen, nitrogen, using an elemental analyser EA1108 with auto sampler AS – 200 and Data processor DP 200 – PRC. The analytical methods employed in chemical composition analysis of coir pith are shown in table below.

Table 1: Analytical methods employed in analyzing ultimate composition

Parameter	Methods	Reference
Total N	Kjeldahl digestion	Jones and Case (1990)
Total P	Vanadomolybdo phosphoric yellow colour methods	Piper (1966)
Total K and Na	Flame photometry	Piper (1966)
Total Ca and Mg	Complexometric titration method	Lanyan and Heald (1982)
Fe, Mn, Zn, Cu	Atomic absorption spectrometry	Jackson (1973)
Lignin	H_2SO_4 treatment method	Sadasivam and Manikam (1996)
Cellulose	Anthrone reagent method	Sadasivam and Manikan (1996)
Organic carbon	Wet chromic acid digestion	Walkely and Black (1934)

TGA studies

TGA studies of coir pith was carried out CECRI, Karaikudi, to study the kinetics of reactions including pyrolysis as a function of temperature. The sample was heated in an inert atmosphere (alpha - alumina) at the rate of 50°C per minute. The thermogram obtained by plotting percent weight loss per C° as a function of temperature was analysed to know the temperature at which pyrolysis gets initiated, reached maximum and when it is completed. The activation energy (E) and frequency factor (A) were calculated by using the following modified Arhenius equation (Bining and Jenkins, 1992) and drawing reciprocal plots [1/T x 1000, K^{-1} Vs. ln[-ln (1-x) / T^2] and least square fits were made. The slope of the linear equation was taken as the value of E/R where E is the apparent activation energy and R is the gas constant.

$$C_1 = \ln\left[\frac{AR}{qE}\left(\frac{1-\frac{2RT}{E}}{1-5\left(\frac{RT}{E}\right)^2}\right)\right]-\frac{E}{RT}$$

Where

C_1 = Y intercept in the reciprocal plot = ln (-ln (1-x) / T^2)

X = extent of reaction in terms of mass fraction

E = activation energy,

R = gas constant, 8.314 J $^0K^{-1}$ mol^{-1}

E/R = C_2,

C_2 = slope in the reciprocal plot

q = heating rate ^oK min^{-1},

A = frequency factor, s^{-1}

T = temperature ^oK

Results and Discussion

Physical properties of Coir Pith

The mean particle size of coir pith was found to be 0.551mm (Fig. 1.).

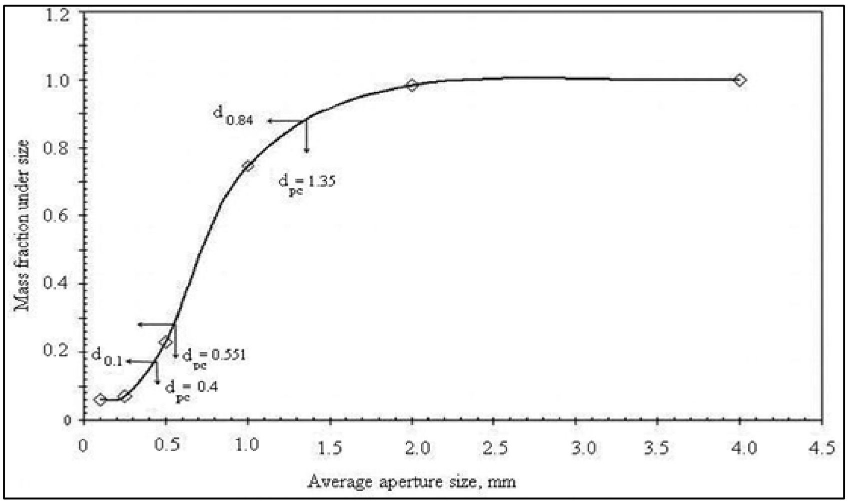

Fig 1: Cumulative Fraction curve of Coir pith

The mass fractions under sizes of 0.84 and 0.16 were 1.3 and 0.4 respectively. The relative size range of the coir pith was found to be 0.817. The other physical properties of coir pith are tabulated as follows.

Table 2: Physical properties of coir pith

S. No.	Properties	Values
1	Bulk density	87 kg/m^3
2	Porosity	71.4%
3	Particle density	305 kg/m^3
4	Angle o f repose	36.7°
5	Terminal velocity	1.043m/s

Chemical composition of coir pith

The lignin content of coir pith was 40.6 %, cellulose and organic carbon content were 26.8 and 30.23 % respectively. The elements which indicated manural value such as N,P and K were less than 1% and other elements such as Fe, Mn, Cu, were less than 0.1%. Coir pith had more volatiles 62.0% than fixed carbon 26.0% and ash 12.0%. The elemental carbon and oxygen were found to be 47.1 and 48.3 % respectively. The calorific value of coir pith was found to be 18.25MJ/kg

Kinetic parameters of Coir pith

The kinetics of the devoltilisation of coir pith was determined in TGA (Fig. 2.).

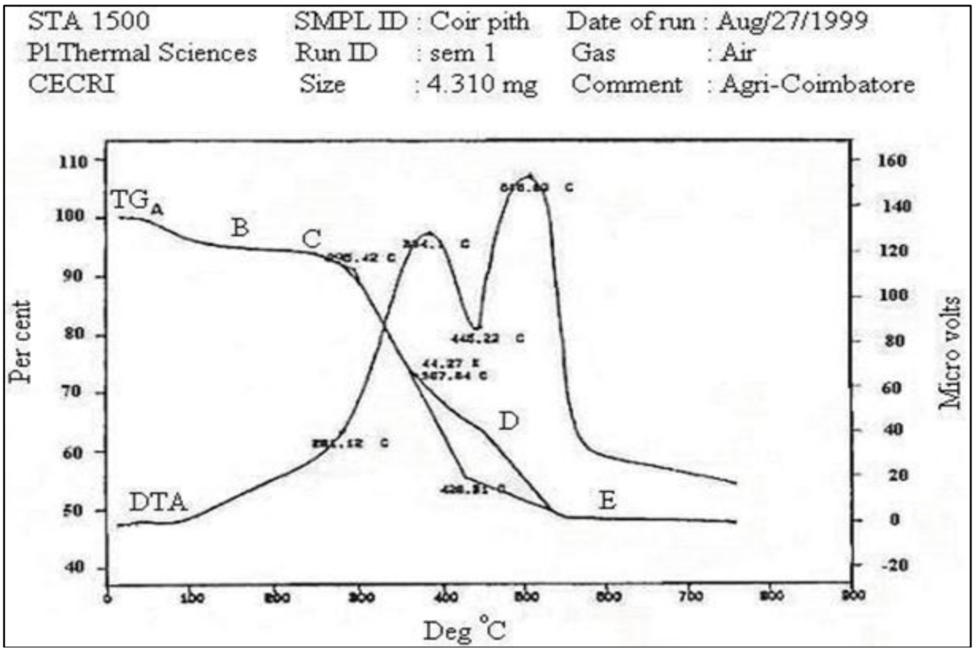

Fig 2: Thermogram of Coir pith

The thermograms can be divided into four distinct stages (A to E) the percentage and rate of mass loss is shown in the table.

Table 3: Stage wise percentage and rate of mass loss

Stage	%	Rate mg/min
A – B	4.4	0.095
B – C	1.600	0.034
C – D	30.40	0.327
D – E	15.2	0.218

The percentage of mass loss in the stage A to B was due to the removal of moisture from the material. The sleep fall in the third stage C-D, contributed maximum mass loss due to removal of volatile matter from the materials. The volatiles removal commence at 300^{0}C and reached completion at 550^{0}C.

The mass reduction in the fourth stage may be considered as the start of ignition of fixed carbon. The ignition temp of coir pith was found to be 550^{0}C. The activation energy was found to be 32-35 KJ mol^{-1} which is lower than the value reported for wood. Pyle and Zaror (1984) [5] reported a value of 66-69 KJ mol^{-1} for the activation energy of pinewood and a frequency factor of 2000 to 3000 s^{-1}. Kasaoka *et al*. (1985) [3] reported an activation energy of 47 to 58 KJ mol^{-1} for coal char during gasification. Lesser activation energy value of coir pith obtained was due to the assumption of single step kinetics and lower heating rate employed as against multiple reaction kinetics assumed in the above reports.

Air requirement for gasification of coir pith

The Stochiometric air requirement for burning 1 kg of coir pith was found to be 3.29 m^3 per kilo gram of coir pith. For gasification 25 to 40.0% of stochiometric air requirement is to be supplied.

Conclusion

The physical, chemical and kinetic properties of coir pith were analyzed. A major mass fraction (51.9%) was in the size range of +0.5 to 1.0 mm with particle mean size of 0.5111 mm. The bulk density, porosity and particle density of coir pith were found to be 87.0 kg m^{-3}, 71.4% and 305.0 kg m^{-3} respectively. Coir pith was found to have more volatiles (62.0%) than fixed carbon (26.0%) and ash (12.0%). The elemental carbon and oxygen were found to be 47.1 and 48.3 per cent respectively. The calorific value of coir pith was found to be 18.24 MJ kg^{-1}. Thermograms obtained for raw coir pith revealed distinct stages of thermal degradation. The ignition temperature was found to be 550ºC. The apparent activation energy (E) and frequency factor (A) were 32-35 KJ mol^{-1} and 874-1951 s^{-1} respectively.

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