Assessment of Power Generation Potentials by Some Agricultural Wastes

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***Abstract* - India is developing country. If country will be increases, then demand of increase will be increase. But at the same time, we as a nation have to economize on our energy costs to focus on human developmental needs. In such context, the idea of biomass energy becomes very important and relevant. With its inherent advantages of carbon neutrality and sustainability, biomass energy is the way forward for the nation and the world at large scale. Though many forms of bioenergy are in focus of many research and development organizations, harnessing the biomass energy through combustion is the simplest method. In this project, we attempt to analyze and discuss the feasibility and sustainability of this method. But in practice, technical variables such as calorific value, ash content, presence of Sulphur, greenhouse gas emissions play a significant role in the actual adoption of biomass as a major source of energy. To study these, we have chosen wastes of six different agriculture-based biomass species such as banana (Musa acuminate), coconut (Cocos nucifera), areca-nut (Areca catechu), rice (Oryza sativa), Gram (Cicer arietinum) and palm (Borassus flabellifer). The samples were analyzed by proximate and ultimate analyses and further correlation was established through regression analysis. Proximate analysis showed that the coconut has the highest volatile matter content (i.e., 73 wt.%) and banana has the highest fixed carbon content (i.e., 20 wt.%) which indicated higher calorific values. The determination of calorific values validated the former results. Palm exhibited lowest ash content suggesting no ash related problems during combustion. Ultimate analysis performed on some of the selected species showed high carbon and hydrogen contents in the leaves of coconut and areca-nut. Out of some selected biomass ashes tested for their fusion temperatures, rice has the lowest initial deformation temperature (i.e., 938 0C) which is substantially above the boiling temperature, suggesting that all the selected biomass samples can be used safely for combustion in boilers up to a temperature of 800 0C. The bulk density of rice husk has been found out to be the highest (i.e., 336.257 kg/m3), suggesting facilitation of higher amount of rice husk in the boiler and economical transportation and handling. The land requirements for energy plantation with selected biomass species were computed and found that approximately 4931, 524, 1757, 814, 3043 and 1146 hectares of land for harvesting banana, coconut, areca-nut, palm, wheat, and rice biomass species for assuring a perpetual supply of electricity at the rate of 5475 MWh per year for a group of 10-12 villages consisting of about 2000 households. Further from the calculations of fuel requirement it was observed that coal requirement can decrease from 4968.0 to 4289.1 t/year and 4968 to 4008.6 t/year with the increase in biomass content from 0 to 15 % in the briquettes of coal with rice husk and coal with palm leaf respectively which suggests that agricultural biomass wastes can be used in co-firing mode for generation of electricity by substituting a portion of coal.**

***Index Terms* - Biomass, Ash fusion temperature, Bulk density, Calorific value, Proximate analysis, Regression analysis, Ultimate analysis**

INTRODUCTION

Fossil fuels are the primary source of generation of electricity. The fast depletion of fossil fuels, economic issues, and environmental concerns over emission from conventional power plants has compelled researchers to strategize the fuel mix. Therefore, the quest for the alternative sources of electricity generation which should be eco-friendly and renewable is crucial in order to decrease our reliance on conventional sources of energy.

In India, about 500 MT of agricultural residues are generated every year from agricultural lands [2]. Biomass has become indispensable and enthralling way of power generation in India due its accessibility, lower investments, and high energy potentials. Sustainable production and proper utilization of biomass can solve the problems in context to energy crisis, climatic concerns, power transmission losses, waste land development and rural unemployment [5]. In order to recognize true potential of bioenergy in generation of electricity, it is essential to have complete knowledge of their fundamental properties like energy values, chemical composition including proximate and ultimate analyses, bulk density, ash fusion temperatures, etc. [6]. Studies and the findings of proximate analysis, ultimate analysis, calorific values, bulk densities, ash fusion temperatures and regression analysis to calculate heating values from proximate and ultimate analyses data of different components of six biomass species namely banana, coconut, arecanut, rice, wheat, and palm, and their impact on power generation has been outlined and discussed in this project.

Biomass

It is the biodegradable organic material derived from plants, microorganisms, and animals which includes by-products and residues from agricultural industries, forestry, and biodegradable organic waste from industrial and municipal operation.

Applications of biomass energy

Given the diverse quality of biomass, biomass energy can be applied to various applications such as:

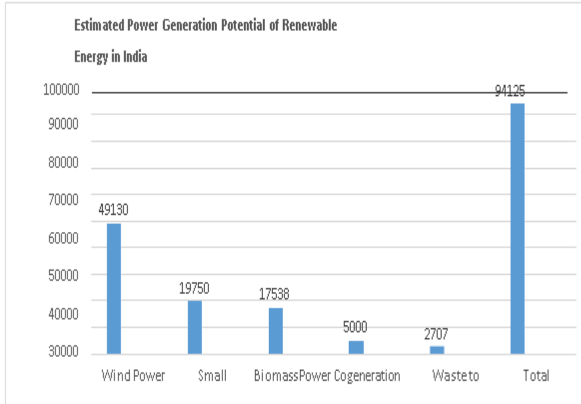
a. It can be used as solid fuel for combustion to produce heat or it can be also used in combined heat and power (CHP) plants.
b. It can be blended with fossil fuels (co-firing) to improve efficiency and reduce the residues of combustion in the boiler.
c. It can potentially replace petroleum as a source of fuel for transportation.
d. In conjunction with fossil fuels biomass can be utilized to generate electricity.

Why Biomass Energy?

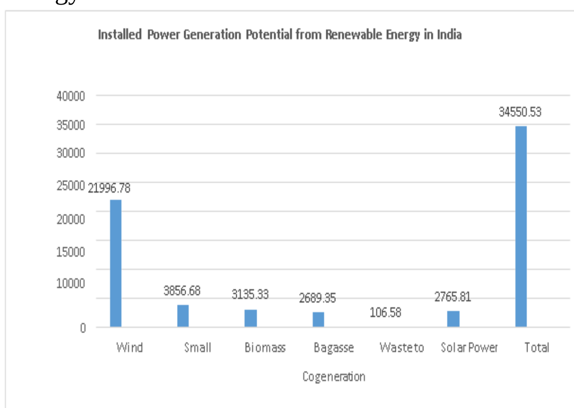
Biomass energy is an attractive energy source due to various reasons such as:

a. It is a renewable energy source derived by natural processes as well as a byproduct of human activity and a surety of long-term supplies.
b. It is distributed more evenly all over the world than fossil fuels and can be harnessed by using more cost-effective ways.
c. It provides an opportunity to be more energy self-sufficient and helps in reducing climate change.
d. Decentralized power generation from biomass offers rural job opportunities. It helps farmers, ranchers, and foresters in managing the waste material in a proper way in order to harness energy.

Electric Power Generation Potential of Renewable Energy in India



Installed Power Generation Potential from Renewable Energy in India



Benefits of Utilizing Biomass for Power Generation

There are various advantages of using biomass for power generation as listed below.

a. Biomass can be utilized throughout the year whereas solar and wind are periodic in nature. Moreover, the uniform distribution of biomass worldwide compared to the presence of conventional fossil fuels in specific places on earth makes it more significant and valuable source of energy.
b. Biomass takes carbon dioxide from the atmosphere and converts it into oxygen during photosynthesis reaction. Thus, the utilization of

biomass for generation of power will certainly lower the carbon dioxide concentration in environment and consequently the greenhouse effect.

c. As compared to coal, biomass has low ash content, and its utilization will reduce the levels of suspended particulate matters in the atmosphere in considerable amount.
d. Some of the biomass has higher calorific value than that of coals which are mostly used in Indian power plants.
e. The high reactivity of biomass towards oxygen and carbon dioxide than that of coal allows the boiler to operate at lower temperatures ensuring significant energy saving.
f. The installation of biomass gasifies is viable in any locality particularly near villages and decentralized power generation cuts down the transmission losses.
g. Decentralized power generation from biomass helps local farmers to manage waste material in a proper way so that it can be exploited to its true potential. It also provides opportunities for rural employment and new socio-economic possibilities.
h. Plantation of biomass will prevent soil erosion and proper exploitation of biomass in generation of power will direct the attention of scientists and researchers towards better usage of barren lands.

LITERATURE REVIEW

Biomass and its Potential

The outcomes regarding the combustion of agricultural residues giving attention to the glitches accompanied with the properties of the residues such as bulk density, ash melting points, volatile matter contents and the presence of nitrogen, sulphur, chlorine and moisture contents were discussed extensively. Agricultural residues which account 33 % of total residues has surplus significance as concerned to global warming as its combustion has the potential to be carbon dioxide emission neutral. Low bulk densities of agricultural residues suggested them to opt an effective transportation, storage and firing or usage of residues at the point of generation. Low melting point of ash possesses the threat of agglomeration, fouling, slagging and corrosion, but this can be eradicated by choosing proper combustion system. High content of volatile matter and low densities of particles resulted in emission of unburnt pollutants and flue gas. To solve this problem, an apt furnace design and application of staged combustion should be incorporated [16].

The availability and potential of solid biofuels was discussed and the chemical mechanisms for the formation of pollutants during combustion were outlined. Williams et al [22] The fusion characteristics stalks of capsicum, cotton and wheat showed that softening temperature, hemispherical temperature, and fluid temperature were not affected by the concentrations of each element and the ash temperature, and initial deformation temperature may be considered as an evaluation index of biomass ash fusion characteristic. From the results Niu et al [21]

OBJECTIVES

The objectives of the present project work are as follows:

a. Proximate analysis of different components such as leaf, stem, shell, pith coir, stalk and husk of some selected agriculture-based biomass residues.
b. Characterization of these biomass components on the basis of their gross calorific values.
c. Characterization of coal mixed biomass components on the basis of their gross calorific values, and analysis of samples of coal and biomass mixed in different ratios.
d. Determination of fusion temperatures of ashes obtained from some selected agricultural biomass residues.
e. Ultimate analysis of some selected components of agricultural residues
f. Developing regression equations to predict gross calorific values from proximate and ultimate analyses data of the biomass samples.
g. Estimation of power generation potentials and land area requirements for the studied agricultural biomass species for decentralized power generation.

EXPERIMENTAL WORK

Proximate Analysis

Proximate analysis is a method for the qualitative analysis of different components in a mixture and gives a rough idea of its chemical composition. The analysis was carried out on the samples ground to -72 mesh size by standard method. In other words, the size of powder should be so small that it can easily pass through a screen having a mesh of 72 openings per 1 square inch. Proximate analysis is the most often used analysis for characterizing a fuel in connection with their utilization. It consists of the determination of the followings:

1. Percentage of moisture content

$$\text{Percentage of moisture content} = \frac{Wt.\ loss \times 100}{Intial\ wt.\ of\ sample}$$

2. Percentage of ash content

$$Wt.\ \%\ of\ ash\ content = \frac{Wt.\ of\ residue\ obtained \times 100}{Initial\ wt.\ of\ sample}$$

3. Percentage of volatile matter

$$Wt.\ \%\ of\ volatile\ matter = \frac{Wt.\ loss\ - \%\ of\ moisture\ content}{Initial\ wt.\ of\ the\ sample}$$

4. Percentage of fixed carbon content

$$Fixed\ carbon\ content\ (wt.\ \%) = 100 - wt.\ \%\ of\ (moisture\ content + ash\ cotent + volatile\ matter)$$

Calorific Value Determination

Calorific value is the amount of energy per unit mass liberated upon complete combustion in presence of oxygen. It is a crucial criterion in estimating the quality of a material for its better utilization in generation of electricity as calorific values is an indication of the energy chemically bound in the material. It is conventionally measured by using a bomb calorimeter and expressed in kcal/kg or MJ/kg.

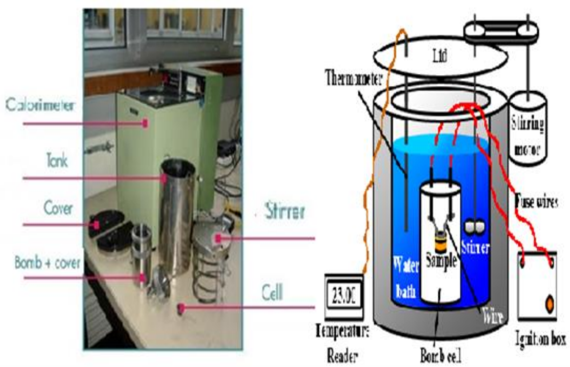
The calorific value of a substance can be classified as:

1. Gross calorific value:

It is also known as higher heating value. Water vapour is produced when the hydrogen present in the fuel reacts with oxygen during the combustion process. The condensation of this water vapour to liquid water inside the bomb takes place at the condensation temperature and it will liberate latent energy. This latent heat of water is an addition to the energy liberated by unit mass of fuel and the measured value is known as gross calorific value.

2. Net calorific value:

It is defined as the amount of heat generated when a unit weight of the fuel is completely burnt and water vapour bequeaths with combustion products without being condensed. The latent heat of vaporization of water in the reaction products is not recovered. Net calorific value is calculated by subtracting the latent heat of vaporization of water from the gross calorific value and it is estimated that net calorific value is 90 % of gross calorific value. Thus, it is also known as lower heating value.



gross calorific value of the sample was calculated [53]

GCV = $\left[\frac{W.E.X\ \Delta T}{W}\right]$ - (heat released by cotton thread + heat released by fussed wire)

where, W.E. = water equivalent of apparatus = 1.987 kcal/0C

ΔT = maximum rise in temperature in 0C

w = initial weight of the dried sample in gram

Ultimate Analysis

The ultimate analysis gives an idea about the elemental composition of the carbonaceous materials. The weight percentage of various elements like carbon (C), hydrogen (H), nitrogen (N), oxygen (O) and sulphur (S) in a fuel can be determined quantitatively by this analysis.

Uncertainty of Measurement

Uncertainty of measurement is the imperfection inherent in the results of measurement. In order to quantify an uncertainty, two numbers are required, one is width of margin or interval and other is confidence level.

RESULTS AND DISCUSSION

Proximate analysis

The knowledge of the proximate analysis of the selected agricultural residues is vital as it provides an approximate idea about the energy values and extent of pollutant emission during their combustion. The proximate analysis of different components of the selected biomass species are presented in Table 1, it can be observed that moisture content of palm leaf is highest (i.e., 12 wt.%) among all the selected biomass species whereas the stem of banana plant exhibited lowest moisture content (i.e., 5 wt.%). The presence of high moisture content in the biomass is expected to reduce the overall thermal efficiency. Palm shell is the lowest (i.e., 3 wt.%) and rice stalk has the highest (i.e., 33 wt.%) ash content among all the agricultural residues taken for this project work. The efficiency of the boiler is affected by high ash content and also tends to cause clinkering and slagging problems in boiler. In comparison to coals, the ash contents of the studied biomass species were found to be much lower. It is quite clear from the volatile matter results that huge amount of gases will be generated inside the boilers during the utilization of biomasses in appreciable amounts in them. Hence, special attention needs to be given in designing of boilers for the utilization of biomasses. In general, the solid fuels having higher fixed carbon content generates higher amount of heat energy inside the boilers. Fixed carbon content differs from the total carbon content in that the total carbon content is the sum of carbon content of fixed carbon content and volatile matter.

Samples	Proximate analysis (wt.%, dry basis)			
	Moisture Content	Ash content	Volatile matter	Fixed carbon content
Banana				
Leaf	6	17	63	14
Stem	5	10	65	20
Coconut				
Leaf	6	16	67	11
Shell	9	9	73	9
Pith	8	11	64	17
Arecanut				
Leaf	8	16	66	10
Coir	9	9	64	18
Gram				
Stalk	9	12	62	19
Palm				
Leaf	12	6	65	17
Shell	8	3	72	17
Rice				
Stalk	10	33	45	12
Husk	7	19	62	12

Ultimate analysis

The ultimate analysis gives an idea about the chemical elements (carbon, hydrogen, nitrogen, sulphur, and oxygen) and ash content of a carbonaceous material. This analysis provides the composition of the sample, which is important to define the energy content, and to determine how clean and efficient the sample is for the purpose it is used for.

$$GCV=\frac{1}{100}\left[8080\ X\ C+34500\ \left(H-\frac{O}{8}\right)\right]+\ 2200\ X\ S\ \ (1)$$

Samples	Ultimate analysis (wt. %, dry basis)			
	Carbon	Hydrogen	Oxygen	Nitrogen
Banana				
Stem	35.351	4.162	36.334	1.142
Coconut				
Leaf	45.456	5.656	37.146	0.839
Shell	43.996	4.799	38.699	0
Pith	37.497	4.605	40.958	0
Arecanut				
Leaf	41.755	5.499	34.725	2.240
Gram				
Stalk	34.532	4.892	34.922	1.211
Palm				
Leaf	43.598	5.381	37.366	1.200
Rice				
Stalk	24.826	3.381	21.310	1.687
Husk	37.357	5.269	31.463	2.208

Calorific Value

Power generation potential of any energy source can be estimated on the basis of its calorific value. The results obtained for the gross calorific values of the studied biomass samples have been listed in Table 3.

Sl. No	Sample	Gross Calorific Value (MJ/kg)
1	Banana Leaf	17.406
2	Banana Stem	17.523
3	Coconut Leaf	19.763
4	Coconut Shell	18.898
5	Coconut Pith	17.124
6	Arecanut Leaf	17.879
7	Arecanut Coir	16.565
8	Gram Stalk	18.821
9	Palm Leaf	17.752
10	Palm Shell	18.155
11	Rice Stalk	14.242
12	Rice Husk	16.872

Bulk Density -The study of bulk density of solid fuel is important for its utilization in power generation through the boiler route as it gives an idea about the amount of solid carbonaceous material to be accommodated in a given volume of the boiler. Higher bulk density facilitates the accommodation of large amount of carbonaceous material in a given volume of the boiler. Not only this, higher bulk densities of solid fuels reduces their cost of transportation and handling. The bulk density of gram stalk has been found out to be the good (i.e., 340.325 kg/m3) and that of palm shell is the lowest (i.e., 108.673 kg/m3) among all the studied biomass samples as seen from Table 4.

Sl. No	Sample	Bulk Density (kg/$m3$)
1	Banana Leaf	175.925
2	Banana Stem	120.370
3	Coconut Leaf	296.290
4	Coconut Shell	164.814
5	Coconut Pith	173.611
6	Arecanut Leaf	248.015
7	Arecanut Coir	187.982
8	Gram Stalk	340.325
9	Palm Leaf	223.784
10	Palm Shell	108.673
11	Rice Stalk	156.364
12	Rice Husk	336.257

CONCLUSIONS

Based on the experimental results carried out in this work, the following conclusions can be summarized.

1. The ash content of rice stalk i.e., 33 wt.% has been found to be the highest among all the studied samples. This is a matter of concern, as the high values of ash content affects the efficiency of the boiler and causes clinkering and slagging problems.
2. The coconut shell has been found to have the highest volatile matter (i.e., 73 wt.%) among the agricultural wastes studied. A high value of volatile matter contributes towards high value of its gross calorific value and also gram stalk has good volatile matter.
3. Banana stem has been reported to have the highest fixed carbon content i.e., 20 wt% among the studied biomass samples which suggests that it will generate higher amount of heat inside the boiler.
4. The leaves and shells of coconut have been found to have calorific values (i.e., above 18 MJ/kg) as well as their corresponding carbon (i.e., above 43 wt.%) and hydrogen (i.e., above 4.5 wt.%) contents in the higher range among all the studied samples. Hence, they can also have significant contribution towards power generation.
5. Initial deformation temperatures (IDTs) of all the studied samples are found to be in the range 938-1137 0C which is considerably above the safe boiler temperature i.e., around 800 0C. This indicates that all the studied samples can be safely used as solid fuels for combustion in boilers without any possibility of clinker formation and other ash related problems up to a temperature of around 900 0C.
6. The mixed briquette of coal-palm leaf in the ratio 85:15 showed the highest calorific value among the selected samples which suggests that a portion of fossil fuel can be replaced effectively by biomass without affecting the design parameters of the boiler.
7. Regression equations developed were found to be with error within acceptable limits. Recommended regression equations are GCV= -3.114 + 0.124×AC + 0.288×VM + 0.03×FC (on the basis of proximate analysis) and GCV= 9.412 + 0.286×C - 0.555×H – 0.006×O – 0.078×N (on the basis of ultimate analysis).
8. Approximately 4931, 524, 1757, 814, 3043 and 1146 hectares of land area are required for harvesting banana, coconut, arecanut, palm, wheat, and rice biomass species in order to have uninterrupted generation of electricity at the rate of 15 MWh per day. Coconut is found to be the prime candidate with the lowest amount of land requirement (i.e., 524 hectares) for energy plantation and its exploitation as a fuel in power generation.
9. On the basis of the energy value and land requirement results obtained in the present study, gram biomass appears to be the best candidate as compare to rise for exploitation in power generation.

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