Electrical power generation potential of arhar pulse residue

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Abstract

Electricity is one of the basic infrastructures required for economic development of any nation. Even after 63 years of independence, there are still many remote villages in India without any electricity supply. Plenty of agricultural wastes are generated in countries like India which are based on agricultural economy. Lot of work is been done on their waste disposal and reutilisation. However, no work has been reported in literature for exploring the potential of agricultural wastes generated due to arhar crop for electrical power generation. In this work, experiments have been conducted for the proximate analysis and finding energy content of different components of residue of arhar. The net energy content in arhar was found to be satisfactorily high. Based on this experimental finding, their potential towards electrical power generation and corresponding land requirement for energy plantations have been calculated. The results show that approximately 4311 hectares of land are required to generate 20 MWh/day. The results have also been compared with that of coal samples obtained from six different local mines. This comparison reveals much higher power output with negligible emission of suspended particulate matters from this biomass material. The ash fusion temperatures of arhar residue have also been experimentally found out and it is observed that they can be used safely up to a temperature of 965^0 C without any clinker formation in the boiler of used in power plant.

Keywords: arhar, ash fusion temperature, calorific value, electricity generation, proximate analysis

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1. Introduction

Agriculture has always been India's most important economic sector contributing approximately 17.8 per cent of its gross domestic product during 2007-08 and providing employment to around 58.2% of the work force (Govt. of India, 2009). It is the backbone of rural India constituting 70% of total population. As a consequence, lot of agricultural wastes are generated, remain unutilized and add to waste management problem. Arhar is one of the most cultivated crop in India. It is grown over an area of 26.7 lakh hectares with a production of 19.2 lakh tons (Agro Ecommerce, 2010)

Even today there are many remote villages in India without any electricity supply. The remoteness and thin population make the grid supply of electricity highly uneconomical. Moreover, there is always a growing concern due to fast depletion of fossil fuel resources for power generation and corresponding pollution of the environment. Therefore, biomass is being considered as one of the alternative sources of electricity generation.

Biomass resources are potentially the world's largest and most sustainable energy source for power generation in the 21st century. The total potential of non-woody biomass available for energy production in India was estimated to be 472 pJ in 1996-97, and the proposed value for the year 2010 is 656 pJ (Ravindranath et al., 2005). As shown in Fig. 1, the estimated global electricity generation capacity of biomass is about 11,000 TWh which is greater than that of all other renewable energy sources (Akshay Urja, 2006). It clearly indicates that the current biomass use is much below the available potential. The estimated power generation potentials of various renewable energy sources in India have been outlined in Table 1 (Akshay Urja, 2005). It is fairly clear from Fig.1 and Table 1 that the power generation potential of biomass is considerably high in the world including India.

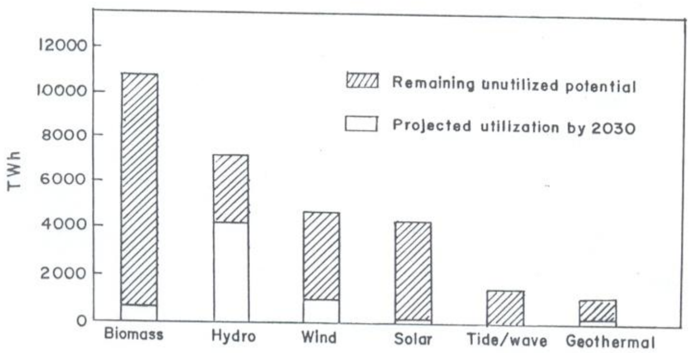

Fig.1 World Long-Term Renewable Energy potential for Electricity Geveration.

Sustainable production and utilization of biomass in electrical power generation can also solve the problems of rural unemployment, utilization of wasteland, and transmission losses in grid network. Accordingly, the system of biomass-based power generation is being given priority in most of the developing nations including India. Unlike other renewable substances biomass materials, pre-dried up to about 15% moisture content, can be stored for a considerably long period of time without any difficulty. Besides electricity supply to the national grids, biomass offers tremendous opportunities for decentralized power generation in rural areas at or near the points of use and thus can make villagers/ small industries self-dependent in respect of their power requirements.

Table 1 : Electricity Generation Potentials of Renewable Energy Sources In India

Source	Estimated potential (MW)	Cumulative installed capacity (MW)
Wind energy	45,000	4,434.00
Biomass energy	16,000	376.00
Bagasse	3,500	491.00
Small hydro (up to 25MW)	15,000	1,748.00
Waste-to-energy	2,700	45.76
Solar photovoltaic	20 MW/km^2	2.80

To exploit biomass species in electricity generation, it is necessary to find out their various properties like calorific value, chemical composition, reactivity towards oxygen, bulk density, etc. This paper deals with the experimental work on proximate analysis and calorific values of different components of arhar, and their impact on electricity generation. It also experimentally finds out the ash fusion temperatures to confirm its safe operation in the boiler.

2. Experimental

2.1 Material Collection

In this work, the waste residues of arhar were collected from the coastal area of Orissa state of India. Its botanical specie name is Cajanus Cajan. Its components like stalk, branch, leaf, corn cover and bark were removed separately and air dried in a cross ventilated room for about a month till their moisture contents were reduced to be in equilibrium with that of the atmosphere. The air-dried biomass were crushed into powders and then processed for their proximate analysis and calorific value determination.

2.2 Proximate Analysis and Calorific Value

Analyses for moisture, volatile matter, ash and fixed carbon contents were carried out on samples ground to –72 mesh size by standard method (Indian Standards, 1969). Moisture content in each sample was determined by heating it at 105 ± 5^0C for 1 h in an air oven, while the determination of volatile matter content involved heating the sample (contained in silica VM crucible) at 925^0C for 7 min. For the estimation of ash, 1 g of sample was burnt in a muffle furnace at 700^0C. The calorific values of the above ground samples were measured by Bomb Calorimeter (Agrawal and Jain, 1980).

3. Result and Discussion

3.1 Proximate Analysis and Calorific Value

The study of proximate analysis of fuels is important because it gives an approximate idea about the energy values and the extent of pollutant emissions during combustion. The biomass waste contains a large amount of free moisture, which must be removed to decrease the transportation cost and increase the calorific value. The proximate analyses of different components of arhar are presented in Table 2. The branch and corn cover have the maximum moisture content whereas the bark has the lowest. The volatile matter content is maximum in the bark and the lowest is in the leaf. The ash content is the lowest in the branch and the maximum in the leaf portion. The stalk has the highest fixed carbon content and the bark has the lowest.

The calorific value of a fuel is an important criterion in judging its quality for electricity generation since it gives an idea about the energy value of the fuel. As shown in Table 2, the calorific value of stalk is the highest among all its portion and the bark has the lowest. The major chemical constituents affecting the calorific values of carbonaceous materials are carbon and hydrogen. The above variation in calorific values of plant components is obviously related to the combined effects of their carbon and hydrogen contents.

Table 2 : Proximate Analysis and Calorific Values of Different Components of Arhar Residues

Component	Proximate analysis (wt.%, air-dried basis)				Calorific value (kcal/kg, dried basis)
	Moisture	Volatile matter	Ash	Fixed carbon	
Stalk	8.00	66.50	11.00	14.50	5664
Branch	11.00	69.00	7.50	12.50	3974
Leaf	10.00	65.00	11.50	13.50	5484
Corn cover	11.00	66.00	10.50	12.50	3956
Bark	7.00	71.60	10.00	11.40	3744

3.2 Ash Fusion Temperatures

Ash fusion temperature of solid fuel is an important parameter affecting the operating temperature of boilers. Clinker formation in the boiler usually occurs due to low ash fusion temperature and this hampers the operation of the boiler. Hence the study of the ash fusion temperature of solid fuel is essential before its utilization in the boiler. The four characteristic ash fusion temperatures were identified as : (i) initial deformation temperature (IDT) – first sign of change in shape; (ii) softening temperature (ST) – rounding of the corners of the cube and shrinkage; (iii) hemispherical temperature (HT) – deformation of cube to a hemispherical shape; and (iv) fluid temperature (FT) – flow of the fused mass in a nearly flat layer. These four temperatures are listed in Table 3 from which it may be concluded that the boiler operation with arhar residues can be carried out safely (without clinker formation) up to the temperature of 900^0C.

Table 3 : Ash Fusion Temperatures of Arhar Waste

Ash fusion temperature, ^{0}C			
IDT	ST	HT	FT
965	1105	1162	1193

IDT − Initial deformation temperature; ST − Softening temperature;

HT − Hemispherical temperature; FT − Flow temperature

3.3 Estimation of Decentralized Power Generation Unit

For the estimation of power generation to meet the electricity requirements of villages, a group of 10-15 villages consisting of 3000 families may be considered, for which one power station could be planned. The electricity requirement for lighting and domestic work in these villages may be 6 MWh/day. An additional 14 MWh/day (approx.) may be required for agriculture (irrigation) and small scale industries situated in a group of villages. Thus, a power plant should be capable of generating 20 MWh/day (i.e., 0.73 MWh/year) for a group of 10-15 villages.

The design of energy plantation of arhar for power plant of 20 MWh/day capacity has been presented in Table 4 and Appendix. The results indicate that in order to meet the yearly power requirement of the order of 7.3 MWh for a group of 10-15 villages, approximately 4311 hectare of land should always be ready for harvesting, in order to have perpetual generation of power.

Table 4 : Total Energy Contents From Fully Grown-up Arhar Plants

Component	Calorific value ($x10^3$ kcal/t, dry basis)	Biomass production (t/ha, dry basis)*	Energy value ($x10^3$ kcal/ha)
Stalk	5664	0.50	2832.0
Branch	3974	0.34	1351.2
Leaf	5484	0.10	548.4
Corn cover	3956	0.20	791.2
Bark	3744	0.05	187.2
Total energy from one hectare of land = $(2832.0 + 1351.2 + 548.4 + 791.2 + 187.2) \times 10^3 = 5710 \times 10^3$ kcal			

***** Data from field studies

3.4 Comparison with Coals

The results of proximate analysis and calorific values of six different types of locally available non-coking coals being used for electricity generation in Orissa (India) were reported by Kumar and Patel (2008) and shown in Table 5. This table also shows that the calorific values of arhar components are superior than that of coals of Hingola mine. The ash contents in all these coals are much higher (range : 39-60%) and they are expected to pollute the environment heavily with SPM (suspended particulate matter). This is a big problem and the solution is not easy. On the other hand, all components of arhar waste have ash content much less than all the available coals listed in Table 5.

Table 5 : Proximate Analysis and Calorific Values of Non-Coking Coals Obtained From Different Mines of Orissa, India

Coal mines	Proximate analysis (wt.%, dry basis)			Calorific value (kcal/kg) dry basis
	Volatile matter	Ash	Fixed carbon	
Lakhanpur	21.21	52.24	26.55	3938
Siding	30.62	44.30	25.08	4952
Hingola	21.90	59.83	18.27	3355
Yeurve	35.66	38.90	25.44	4682
Kalinga	24.77	50.77	24.46	4237
Jagannath	31.10	52.68	16.22	4660

4. CONCLUSIONS

The main conclusions made out of the present work are outlined below.

1. The stalk portion of arhar plant has the highest calorific value.
2. The waste of arhar crop can be safely used in the boiler up to a temperature of 965^0C without any risk of clinker formation.
3. Nearly 4311 hectares of land would be required for continuous generation of 20 MWh electricity per day from arhar waste.
4. There exists local coal mine of which coals used for power generation compared to which arhar waste has been found to have more calorific value. On the other hand, all components of arhar waste have much lower ash content than the coals of all the six local mines.
5. Thus, the present work could be useful in the exploration of arhar waste for power generation in small decentralised power plant suitable in rural areas.

5. APPENDIX

Calculation of Land Requirement for Energy Plantations:

Referring data from Table 4, on oven dried basis the total energy from one hectare of land = 5710×10^3 kcal

It is assumed that conversion efficiency of wood fuelled thermal generators = 30 % and overall efficiency of the power plant = 85 %.

Energy value of the total utilizable biomass obtained from one hectare of land at 30% conversion efficiency = $5710 \times 10^3 \times 0.30$ kcal = 1712.98×10^3 kcal = $1712.98 \times 10^3 \times 4.1868/3600 = 1.9922 \times 10^3$ kWh

Power generation at 85 % overall efficiency = $1.9922 \times 10^3 \times 0.85$ = 1.6933×10^3 kWh/ha

Land required to supply electricity for the whole year = $73 \times 10^5 / (1.6933 \times 10^{3})$ = 4311 ha

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