

Biomass Characterization and its Use as Solid Fuel for Combustion

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Abstract: The power industry is confronting challenges with seemingly conflicting goals. They provide the economy of scale needed to minimize the cost of production. Consumers, including industry, rely on affordable, dependable electrical energy. It's an important part of our economy and our daily lifestyle. However, reducing emission levels and conserving our finite resources are key components for achieving a sustainable environment. Biomass is a resource that can be substituted for coal, in varying degrees for existing pulverized coal plants. New, large power plants are being designed to utilize biomass as the primary fuel. Biomass is available now and biomass based new products and sources are being developed, as the market unfolds. However, fuel properties and characteristics are important to boiler design and operation. Different boilers have unique design and fuel requirements. Heating value, percent volatiles, total ash and moisture content, ash constituents and particle size are all key parameters considered by the boiler designer. Some biomass products have unique utilization issues. The chemical fraction behavior of biomass materials is quite different from that of typical coals. For co-firing applications, the properties of biomass and coal can be blended as a designer fuel. The objective is to best meet boiler, combustion, emission and economic requirements. Fuel degradation and spontaneous combustion are more important concerns for biomass fuel products. This is a moisture-dependent issue. Dry biomass can be stored for longer periods. High moisture levels become a concern for degradation and spontaneous combustion. Therefore, the paper deals with the biomass characterization in terms of its physico-chemical properties which can be useful to understand biomass combustion related issues.

Key words: Ash; Biomass; Corrosion; Combustion; Fouling; Proximate Analysis; Slagging

INTRODUCTION

Biomass is defined as the biological degradable fraction of products, waste and residues from agriculture (including animal and vegetable materials), forestry and the biological degradable fraction of industrial and household waste [1].

Biomass is a renewable energy resource derived from the carbonaceous waste of various human and natural activities [2]. Currently, the biomass sources contribute 14% of global energy and 38% of energy in developing countries [3]. It is derived from various sources, including the by products from the timber industry, agricultural crops, raw material from the forest, major parts of household waste and wood. Globally, the energy content of biomass residues in

agriculture based industries annually is estimated at 56 exajoules, nearly a quarter of global primary energy use of 230 exajoules [4].

Biomass does not add carbon dioxide to the atmosphere as it absorbs the same amount of carbon in growing as it releases when consumed as a fuel [5-6]. Its advantage is that it can be used to generate electricity with the same equipment or power plants that are now burning fossil fuels. It is an important source of energy and the most important fuel worldwide after coal, oil and natural gas.

Availability of biomass in large quantity and scarcity of fossil fuel coal, oil and gas lead industries to use the biomass as fuel. The absolute consumption of biomass energy has however risen unabatedly during past two decades, growing at an annual rate of over 2 percent [7].

Table 1: Classification of biomass

Woody Biomass	Non-Woody biomass	Process Waste	Processed Fuel
<ul style="list-style-type: none"> • Tree • Shrubs & Scrub • Bushes like Coffee and Tea • Sweepings from forest floor • Bamboo • Palms 	<ul style="list-style-type: none"> • Energy crop like sugarcane • Cereal straw • Cotton, Cassava, tobacco stem and roots • Grass • Bananas, plantains etc. • Soft stem such as pulses and potatoes • Swamp and water plants 	<ul style="list-style-type: none"> • Cereal husks and cobs • Bagasses • waste from pineapple and other fruits • But shells, flesh and the like • plant oil cake • saw mill waste • industrial wood bank and logging wastes • Black liquor from pulp mills • Municipal waste 	<ul style="list-style-type: none"> • Charcoal (wood & residues) • Briquette/ density biomass • Methanol/ethanol (wood alcohol) • Plant oils from palm, rape, sunflower etc. • Producer gas • Biogas

Development of technologies for multiple fuel firing option made biomass as cheap and effective fuel. However, large amount of impurities in various biomass made lot of nuisance to boiler operation. A major problem observed due to fouling and corrosion of boiler heat-exchange surface by deposits [8]. These are often hard, strong adherent and not easily removed by on-load cleaning techniques such as sequence soot blowing. They affect all surfaces from the tubes in the combustion chamber to the coolest metal surface of the air heater where they may be so corrosive that frequent air heater maintenance is necessary. As deposits develop, gas passages may be reduced until the load can no longer be maintained.

A large variety of biomass fuels are available in market. Depending on the homogeneity of fuels, conversion technology used and plant design the right fuel is chosen. Different standardization is used to produced energy from biomass fuel [9-10]. In broad way biomass can be classify as shown in Table 1.

These products are directly used as a fuel in a specially designed boiler. Some of the biomass products are directly use as a fuel, but some biomass required some process [11 -12]. In this method biomass such as wood or other first cut into small pieces and latter these pieces are crushed in a machine to get fine powder. This powder is used as a fuel for furnace. As the cost of heating with natural gas and fuel oils continues to rise business is being pushed towards the use of biomass fuels for heat generation. This gives the user two major tasks to undertake sourcing of an economic, readily available biomass fuel and sourcing of the required firing equipment to burn this fuel.

For effective utilization of biomass fuel, the knowledge of their characterization is essential [13]. The constituents of biomass fuel varies from region to

region. Constituents of biomass depends upon sources from which biomass is collected and method of preparation of biomass. The papers deals with the various biomass related properties and combustion related problems.

Testing Procedure: Biomass samples were collect from Ahmedabad district of Gujarat State. Authenticity of sample were confirm with the agricultural expert team of our R & D division. Collected biomass were chopped in small piece and kept in oven at 105 °C for overnight. Next day remove the sample cool in open atmosphere and subjected to analysis as described methods by Speight [14].

RESULTS AND DISCUSSION

Proximate Analysis: It gives moisture, ash and volatile matter on percentage weight basis. Table 2 shows proximate and calorific value of few biomass samples.

Moisture: Moisture in the fuel has following effects. It absorbs a part of heat liberated in the combustion process. As a result net useful heat available from fuel reduces, furnace temperature reduces and heat loss from stack increases [15]. If stack temperature is below 150°C the chances of vapor condensation are higher. If the fuel contains Sulfur then the risk of H_2SO_4 corrosion of heat recovery unit, ID fan, ducting and chimney is higher. Moisture also lowers the rate of combustion, particularly in case of large size of fuel pieces. High amount of moisture may pose problem in fuel sizing, conveying, feeding etc [16]. In terms of moisture content, the biomass fuel can be made into two categories one is high moisture (>40%) Biomass fuel consist of bagasses, sludge, wood bark, etc, the other one of low moisture (~6 to 16%) group

Table 2: Proximate and calorific value of biomass samples

Sr.No	Feedstock	Moisture %	Volatile matter %	Ash %	Fixed Carbon %	Gross Calorific Value Kcal / kg
1	Saw dust	13.8	72.9	0.6	12.7	4028
2	Groundnut shell	10.1	68	2.8	19.1	4008
3	Bamboo leaves	7.7	68.7	12.3	11.3	3756
4	Cotton Stalk	7.5	70.3	2.5	19.7	3991
5	Prosopis	7.7	78.9	0.5	12.9	4237
6	Coconut husk	13.4	56.7	2.4	27.5	3800
7	Jatropha cake	7.3	65.1	8.3	19.3	4725
8	Rice Husk	7.2	61.8	16.4	14.6	3729
9	Sugarcane Bagasse	4.5	77.1	2.4	16	4547
10	Elephant Grass	11.5	63.4	5.4	19.7	3601
11	Typha	8.2	71.4	4.6	15.8	3789
12	Castor Stalk	20.5	63.5	2.1	13.9	3496
13	Ipomea	11.7	66	3.4	18.9	3670
14	Sunhemp	17.1	58.7	4.9	19.3	3800
15	Sesbania	14.8	62.3	6.3	16.6	3434
16	Sesbania seeds	11.3	68.6	3.3	16.8	4090
17	Sunhemp seeds	13.2	68.7	3.4	14.7	3763
18	Bringle residue	19.2	50.9	11.6	18.3	2945
19	Tomato residue	19.4	54.1	11.2	15.3	2694
20	Capsicum residue	21.4	51	7.5	20.1	3105
21	Kanjaru -weed	21.7	48.4	13.3	16.6	2335
22	Su Baval	9.8	74	0.5	15.7	4018
23	Perry grass	15.6	59.7	5.6	19.1	3477
24	Okhara residue	19.5	59.2	9.8	11.5	2953
25	Eucheuma -seaweed	13.4	50.4	19.3	16.9	2126
26	Spirullina powder	7.6	71.5	7	13.9	4666
27	Date Palm Seed	11.3	64.7	1.7	22.3	4273
28	Algae powder – Spirogyra	5.9	32.4	57.9	3.8	1214
29	Algae powder – Pithopora	3.9	47.4	45.8	2.9	1495
30	Pamarosa	6.6	72.7	4.4	16.3	4244
31	Sun hemp K12	12.5	67.6	2	17.9	4074
32	Puwad	6.6	72.8	3.4	17.2	4071

will have Juliflora, cotton and chilly stalk, rice husk/straw etc. The high moisture content in biomass will impact the overall feasibility of the energy production by following ways:

The more water content would lower heating value resulting into lower fuel efficiency. The more water fuel contains would require bigger boiler volume resulting into more expansive boiler. Transportation of water is not feasible. Further most automation systems can not react to rapid variations in moisture content resulting in incomplete combustion which increases emissions.

Ash: Ash is the incombustible solid mineral matter in the fuel. It mainly contains silica (SiO_2), Alumina (Al_2O_3), Iron oxides (FeO , Fe_2O_3), CaO and MgO etc. At higher temperature, the ash fuses/soften and forms clinker that entraps combustible matters and prevents proper air distribution. This lowers combustion efficiency [12].

It sticks to grates and refractory walls and causes damage. Fuel firing and ash removal also becomes difficult. Ash characteristics includes type of ash which is basic indicates that the fuel is alkaline in nature. The ash analyses shown in Table 2 are from typical biomass samples collected and analyzed. Variations particularly on the % (Na_2O & K_2O) in the fuel ash will persist typically from 10 to 45%, since these are great dependent on soil condition, type and quality of fertilizers used for cultivation. Higher the alkalies, higher are the fouling of connective surfaces. Ash composition together with sulfur and chlorine contents in biomass fuels are the main factors which have an impact on the risk of bed agglomeration in fluidized bed boilers and on the rate of boiler fouling, deposit formation, slagging and superheater corrosion. Significant differences in combustion properties of biomass is observed on the basis of their ash composition [17].

Table 3: Mineral content of few biomass samples

Biomass Feedstock	Sulphur (S) %	Nitrogen %	Chloride content %	Potassium (K ₂ O) %	Phosphate (PO ₄) %
Cotton Stalk	0.17	0.5	1.27	1.67	0.18
Prosopis	0.1	1.02	0.21	0.62	38.21
Sugarcane Bagasse	0.21	0.48	0.56	1.79	0.99
Elephant Grass	0.1	0.4	0.77	2.65	25.19
Typha	0.72	0.87	1.61	0.91	0.48
Castor Stalk	0.26	0.4	0.28	1.9	0.27
Ipomea	0.46	0.72	0.5	1.49	0.44
Sunhemp	0.4	0.63	0.38	0.89	0.23
Sesbania	0.2	1.15	0.84	1.51	0.32

The ash fusion and clinker formation formation depends upon melting point of the lowest melting component, the distribution of minerals in the fuel, reaction condition in the furnace (In reducing atmosphere, Fe₂O₃ is reduced to FeO that reduces ash fusion temperature at the surface of fuel particles causing agglomeration and clinker), duration for which fuel/ash is exposed to high temperature. Longer the duration of exposure, higher the chance of clinker formation, Supply of pre-heated primary air increases bed temperature leading to clinker formation.

Volatile Mater: On heating of biomass fuels, volatile matter (flammable gas and smoke) is liberated. This burns as visible flame on supply of sufficient air, time, temperature and turbulence [12]. If volatile matter in the fuel is higher, then large amount of secondary air with high pressure need to be supplied at strategic location for effective combustion. Complete combustion of volatile matter leads to dark smoke, heat loss, pollution hazard and soot deposition on boiler surfaces.

Ultimate Analysis: Ultimate analysis of fuel gives its chemical constituents such as carbon, Hydrogen, Oxygen, Nitrogen and Sulfur and total mineral matter [13]. This analysis helps in estimating theoretical air required for complete combustion, fuel gas generated per kg of fuel fired, water vapor content in the flue gas, sulfur content of flue gas and calorific value of fuel which depends upon carbon and hydrogen content of fuel. Table 3 shows mineral content of few biomass samples which are important for combustion of biomass.

Combustion: The mechanism of biomass fuel combustion is quite complex and varies with type of biomass, its constituents of proximate analysis, type of boiler, distribution of air, temperature in the furnace and fuel bed, residence time, reducing or oxidizing atmosphere, amount of excess air, sizing and segregation of fuel, etc. [15],

Broadly there are three stages of combustion: Evaporation of moisture from fuel, Distillation of volatile matter from fuel and its subsequent combustion in the furnace space and finally combustion of fixed carbon.

Biomass Combustion Problems: When biomass is burned, ash is formed. Ash passing through the boiler is subjected to various chemical reactions and physical forces that lead to deposition on the heat absorbing surfaces. The process of deposition and the structure of deposits are variable due to a number of factors like particle composition, particles size and shape, particles and surface temperature gas velocity flow patterns and other factors influence the extent and nature of deposits [15]. Mainly two types of combustion problems take place. (1) Agglomeration, fouling and slagging and (2) corrosion.

Agglomeration, Fouling and Slagging: Agglomeration, fouling and slagging are the three different deposition mechanism takes place at high temperature area of boiler. Agglomeration: Modern agricultural techniques involves large amount of fertilizer usage for more and more yield. Potassium and Sodium are the main constituents of these fertilizers. When agrowaste of the fuel are used as fuel in the boiler for stem generation, the main characteristic of the ash content high amount of alkali mainly potassium and sodium oxides [15]. These alkalies causes agglomeration and sintering of ash leads to clinker formation when fired on grates where combustion temperatures exceed more than 1000°C [18, 19].

Fouling: Ash analysis of various fuels indicate presence of alkalies which are mostly high concentration of Sodium and Potassium oxides. Presence of high silica along with these high alkalies creates problem of agglomeration as well as fouling on super heater/convection bank tubes. Basic components of ash are CaO, MgO, Fe₂O₃, Na₂O, K₂O while acid components are SiO₂, Al₂O₃ and TiO₂.

Slagging: Slagging is the formation of molten, partially fused or re-solidified on furnace walls and other surfaces exposed to radiant heat [5, 19]. Slagging can also extend into the convection section if gas temperature are not sufficiently reduced. Over a period of time, a base deposit begins to develop on the heat transfer surfaces. The settling of fine ash particles or the gradual accumulation of the particles initiates the base deposit with very low melting point constituents. As the base deposit thickness increases, the temperature at the outside face increases significantly above the tube temperature. Eventually the melting point of more of the ash constituents is exceeded and the deposit surface becomes molten. The process then becomes self-accelerating and the plastic slag trapping all the impinging ash particles.

Corrosion: Corrosion problem in biomass fired boiler is largely due to the high potassium and chlorine content and low sulfur content in the biomass fuels [5]. The major ash forming elements (Al, Si) and the composition of gas phase (O_2 , N_2 and H_2O , etc.) have significant influence on the behaviour of chlorine and alkali metals and formation of corrosion in heating units [20]. The salts KCl and K_2SO_4 are quite volatile and the release of these components may lead to heavy deposition on heat transfer surfaces, resulting in reduced heat transfer and enhanced corrosion rates. Severe deposits may interfere with operation. The releases of alkali metals, chlorine and sulfur to the gas-phase may also lead to generation of significant amounts of aerosols (sub micron particles) along with relatively high emission of HCl and SO_2 [21-22]. These gases lead to corrosion at the cold end zone like air pre-heater, economizer etc. Straw has been found to be one of the most corrosive type of biomass not previously encounter with combustion of fossil fuels [8, 23]. It has been seen that during co-firing with straw as straw % increased the corrosion rate increase.

Without knowing such detail combustion chemistry, variety of biomass in big quantum are being use in India for energy generation. It is confined primarily to traditional uses such as cooking in rural households and heating in rural industries. Most types of biomass is not available in market, but it is collected at ground to full fill daily energy needs by families. To trap these biomass potential several strategies and policy are being applied like; rural energy planning [24], new energy programmes with current technology survey [25, 26] and future responses to such policies [27, 28]. At present it is too

premature to judge the effectiveness of the present policies for renewable energy in India. But proper understanding of biomass with their contribution in energy generation, applied policies would enhanced biomass penetration and bring environmental & social benefits.

CONCLUSION

Biomass samples from different sources and its types needs to be characterized for its proximate analysis and other metal impurities. Different agricultural biomass residues have high alkali matter and therefore creates combustion related problems during firing in various boilers. Prior knowledge of biomass type and its chemical composition would help in understanding combustion related problems for biomass based energy generation.

REFERENCES

1. FAO, Regional wood energy development programme in asia (RWEDP) Report No. 39, 1997, available at <http://wgbis.ces.iisc.ernet.in/energy/HC270799/RWEDP/acrobat/rm39.pdf>.
2. Grubler, A., N. And Nakicenovic, 1988. The Dynamic Evolution of Methane Technologies, in Lee T.H, H.R. Linden, D.A. Dryefus and T. Vasko, (eds.), The Methane Age, Kluwer Academic Publishers, Dordrecht.
3. Woods, J. and D.O. Hall, 1994. Bioenergy for Development - Technical and Environmental Dimensions, FAO Environment and Energy Paper, 13, Rome, Italy.
4. WEC, 1994. Biomass Energy, Chapter 5 in New Renewable Energy Resources- A Guide to the Future, World Energy Council, London, UK.
5. Blasiak, W., 2008. Best Paper Award 2008 Highly Commended. POWER-GEN Europe, 3-5 June, Milan, Italy. pp: 1-16.
6. Zanchi, G., N. Pena and N. Bird, 2010. The upfront carbon debt of bioenergy, Joanneum Research. Transport and Environment.
7. FAO, 1997. Review of Wood Energy Data in RWEDP Member Countries, Field Document, No. 47, Bangkok.
8. Johansson, T.B., H. Kelly, A.K.N. Reddy and R.H. Williams, 1993. Renewable Fuels and Electricity for a Growing World Economy - Defining and Achieving the Potential, in Renewable Energy-Sources of Fuels and Electricity, Island Press, Washington D.C., U.S.A.

9. Badger, P.C., 2002. Processing cost analysis for biomass feed stocks, General Bioenergy.
10. Per Dannemand, A., C. John and K. Jjens, 2000. Emerging and future bioenergy technologies. Risø Energy Report, 2: 18 -22.
11. Robert, D.P., L.W. Lynn, F. Anthony, R.L. Turhollow, B.J.S. Graham and C.E. Donald, 2005. Biomass as feedstock for a bioenergy & bioproducts: technical feasibility of a billion – ton annual supply, Oak Ridge National Laboratory, U.S. Department of Energy.
12. Miller, B.G., S.V. Pisupatia, D. Johnsona, D.J. Clifforda, M.W. Badgera, R.W. Wascoa, S.F. Millera, G.D. Mitchella and D. Tillmanb, XXXX. Enhanced biomass characterization: A Foster Wheeler Energy Corporation/ Penn State initiative.
13. Shukla, P.R., 1997. Energy for Sustainable Development: A Social Engineering Perspective. *The Social Engineer*, 6(2): 1-21.
14. James, G.S., 2005. Hand book of Coal Analysis, Wiley-Inter science, New York, USA.
15. Livingston, B. and M. Babcock, 2006. Ash related Issues in biomass combustion, 2006. Thermal Net Workshop proceedings, Glasgow, Scotland.
16. Parmar, R.S., M. Welling, M.O. Andreae and G. Helas, 2008. Water vapor release from biomass combustion, *Atmospheric Chemistry and Physics*, 8: 6147-6153.
17. Matti, H., 2008. Combustion of Different Types of Biomass in CFB Boilers, Presented at 16th European Biomass Conference, Valencia Spain.
18. Tortosa-Marisa, A., R. Buhre, R. Gupta and T. Wall, 2007. Characterizing Ash of Biomass and Waste, *Fuel Processing Technology*, 88: 1071-81.
19. Miles, T.R., T.R. Miles Jr., L.L. Baxter, R.W. Bryers, B.M. Jenkins and L.L.O. Alkali, 1996. Deposits Found in Biomass Power Plants; A Preliminary Investigation of Their Extent and Nature. NREL/TP-433-8142. Golden, Colo.: National Renewable Energy Laboratory.
20. Wei, X., U. Schnell and K. Hein, 2005. Behaviour of gaseous chlorine and alkali metals during biomass thermal utilisation, *Fuel*, 84: 841-848.
21. Werkelin, J., 2002. Ash-forming elements and their chemical forms in woody biomass fuels, Academic Dissertation Laboratory of Inorganic Chemistry, Process Chemistry Centre, Åbo Akademi University, Finland.
22. Duong, D.N.B., D.A. Tillman, N.A. Foster Wheeler and N.J. Clinton, XXXX. Chlorine Issues with Biomass Cofiring in Pulverized Coal Boilers: Sources, Reactions and Consequences.
23. Roger, K., E. Houshfar, W. Musinguzi, M. Becidan, Ø. Skreiberg, F. Goile, L. Terese and L. Sørsum, 2011. Experimental Investigation on Corrosion Abatement in Straw Combustion by Fuel Mixing, *Energy Fuels*, 25(6): 2687-2695.
24. Sinha, C.S., P.V. Ramana and V. Joshi, 1994. Rural Energy Planning in India: Designing Effective Intervention Strategies, *Energy Policy*, 22(5).
25. Sinha, C.S., 1994. Renewable Energy Programs in India: Some Recent Developments, *Natural Resources Forum*, 18(3): 213-24.
26. Ravindranath, N.H., 1993. Biomass Gasification: Environmentally Sound Technology for Decentralized Power Generation: A Case Study from India, *Biomass and Bioenergy*, 4(1): 49-60.
27. Ramana P.V., C.S. Sinha and P.R. Shukla, 1997. Environmental Issues in Rural Energy: Policy Responses for the Future, in *Energy Strategies and Greenhouse Gas Mitigation* (Ed. P.R. Shukla), Allied Publishers, New Delhi.
28. Strategic plan for new and renewable energy sector for the period 2011-17., 2011. Ministry of New and Renewable Energy, Government of India.