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Cofiring of Biomass with coal: A Perspective

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Depletion of fossil fuels and its associated environmental hazards necessitated the attention towards renewable energy generation. Biomass is one of the renewable sources and available throughout the year. It includes wastes from farm and field, agro and allied industries. Utilization of these resources can generate a significant energy contribution as solid, liquid and gaseous fuels, chemicals and electricity. It had low sulfur content and reduces the reliance on fossil fuels and emissions. It can be used directly or indirectly in the existing and retrofitted systems as a substitute fuel for coal by the cofiring technology. The combined use of biomass and coal can reduce the emission as well as coal use and give value addition to the biomass. This paper reviews the cofiring of biomass with coal, technological issues and the emission reduction benefits of cofiring.

Keywords: Renewable energy, Biomass, Cofiring

Introduction

Coal is the most widely used fuel in the world. Power plants are the main consumer of coal and absorb about 80% of the coal with a plant efficiency[1] of 29%. The huge loss may increase the consumption of coal in the power plants and emissions. Hence, there is a need to reduce the global CO_2 emissions, especially from the coal use and demand for coal. There are two ways to solve these problems: increasing the plant efficiency of the existing coal power plants can reduce the coal consumption and CO_2 emissions by 3%[2] and utilization of non commercial - renewable energy sources for the energy production[2]. As per the second option, biomass is one of the renewable energy sources and has the largest potential to meet the energy requirements[3]. In India, biomass fuels lead the rural energy consumption patterns, accounting for more than 80% of total energy. Fuel wood, crop residues and livestock dung were the biomass fuels used in rural areas. These biomaterials have many advantages such as, availability and reduced emissions. But the biomass fuels are not traded and not competing with commercial energy sources, due to the absence of a developed energy market and low cost[4]. Hence, utilization of these resources is one of the ways to tackle the energy need of the growing population and economic growth.

In order to reduce CO_2 emissions from the coal power plants and to fulfill the increasing energy demand, cofiring of biomass with coal is the best possible option[5]. This paper reviews the characteristics of biomass, issues related to the biomass handling, cofiring of different biomass with coal and its impact on the environment and the technological constraints associated in cofiring.

Biomass resources

The biomass resource includes residues from crop, wood product, waste from agro-industries, farm and forest wastes. The most important recovery from biomass is the energy substitution for coal. The recovery depends on the efficiency with which the biomass is converted to electricity. Availability of biomass resources in India along with their coal equivalent is given in Table 1.

Biomass properties

The suitability of biomass for energy generation is depends on the chemical and physical properties. The properties of biomaterials have to be considered during subsequent processing as an energy source is related to:

Moisture content

The relationship between the moisture content of biomass and conversion technology should be appropriate.

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For the thermal conversion, low moisture content feedstocks (< 20%) were preferred. The bioconversion can utilize high moisture content feedstocks.

Fixed carbon and volatiles

The significance of volatile matter content and fixed carbon is the measure of the tendency with which biomass can be ignited or oxidized[6].

Ash/Residue content

The thermo chemical breakdown of a biomass fuel produces a solid residue which can reduce the plant reaction area. The relative proportions of cellulose and lignin is one of the determining factors in identifying the suitability of plant species for processing as energy crops. Cellulose is generally the largest fraction, representing about 40-50% of the biomass by weight and the hemicelluloses represents 20-40% of the material by weight. The characteristics of biomass were presented in Table 2. Most of the biomass generated in our country would be used as fodder, fuel or stored as waste. Utilization of these resources properly can meet a remarkable percentage of the country's demands for energy. For the generation of energy and utilization of resources the following approaches can be adopted:

- Collection, segregation and proper utilization of biomaterials.
- Energy plantation for use as energy feed stock.
- Appropriate techniques and efficient equipment should be developed as per the requirement economically.

Table 1—Major biomass resources in India

S. No	Biomass	Availability (T/Yr.)	Coal equivalent (T/Yr)
	Agricultural residues		
1	Rice straw	9	58.4
2	Rice husk	19.9	15.7
3	Jute sticks	2.5	2.3
4	Wheat straw	50.5	37.5
5	Cattle dung	1,335	128
	Agro-industrial by-products		
1	Bagasse	28.1	22.4
2	Molasses	2.1	0.8
3	Oil seed cakes	6.7	0.9
4	Saw dust	2	3.4
	Forest products		
1	Mahua flowers	1	0.4
2	Leaves, tops etc.	3.3	3

Issues related to biomass supply

Biomass supply chain consists of the following elements: transportation, handling, drying, pre-treatment, storage and feeding. These elements can cause problems such as odor or spore element emissions[7,8]. Preparation, storage and handling of biomass is difficult due to high moisture content, hydrophilic and non-friable character, particle size variation and high fiber content as well as susceptibility to rotting and heating[9].

Preparation of biomass includes drying and sizing. Drying of biomass is applied to improve the fuel efficiency

Table 2—Characteristics of biomass

Feed stocks	Cellulose (%)	Lignin (%)	Ash(%)	Sulfur (%)	Ash melting temperature (°C)
Corn stover	30 – 38	17 - 21	9.8-13.5	0.06 - 0.1	-
Sweet sorghum	27	11	5.5	-	-
Sugarcane bagasse	32-43	23 - 28	2.8 - 9.4	0.02 - 0.03	-
Sugarcane leaves	-	-	7.7	-	-
Hardwood	45	20	0.45	0.009	900
Softwood	42	26	0.3	0.01	-
Hybrid poplar	39-46	21 - 8	0.4-2.4	0.02 - 0.03	1350
Bamboo	41-49	24-26	0.8-2.5	0.03 - 0.05	-
Switchgrass	31-34	17 - 22	2.8-7.5	0.07 - 0.11	1016
Miscanthus	44	17	1.5-4.5	0.1	1090
Giant Reed	31	21	5-6	0.07	-
Bioethanol	NA	NA	-	<0.01	N/A
Biodiesel	NA	NA	< 0.02	<0.05	N/A
Lignite	NA	NA	5-20	1.0 - 3.0	~1300
Bituminous/anthracite	NA	NA	1-10	0.5 - 1.5	~1300
Oil (typical distillate)	NA	NA	0.5-1.5	0.2 - 1.2	N/A

N/A: Not applicable

Table 3—Utility testing of cofiring biomass with coal

Utility	Generating station	Cofiring approach	Boiler Capacity	Coal type	Biomass Type
TVA	Allen (cyclone)	Blending biomass and coal;5–20% by mass	272 MWe	Illinois basin, Utah bituminous	Wood waste
TVA	Kingston (T-fired PC)	Blending biomass and coal; 1–5% by mass	190 MWe	Eastern bituminous	Wood waste
TVA	Colbert (wall-fired PC)	Blending biomassand coal; 1–5% by mass	190 MWe	Eastern bituminous	Wood waste
GPU, Genco	Shawville (T-fired and wall-fired PC)	Blending biomass and coal; 3% by mass	190 MWe; 138 MWe	Eastern bituminous	Wood waste, hybrid poplar
GPU, Genco	Seward fired PC)	Separate injection of biomass Blending	32 MWe 469 MWe	Eastern bituminous	Wood waste Urban wood
NIPSCO	Michigan city (cyclone)	biomass and coal; 10% by mass		PRB, Shosho	waste
MG&E	Blount St. (wall-fired PC)	Separate injection of biomass;5–20%	50 MWe	Midwest bituminous	Switchgrass
NYSEG	Greenidge station (T-fired PC)	Separate injection of biomass; 10–20% by mass	104 MWe	Eastern bituminous	Wood waste
Southern Plant	Hammond (T-fired PC)	Blending biomass and coal;5–14% by mass	120 MWe	Eastern bituminous	Wood waste
Southern	Plant kraft (T-fired PC)	Separate injection of biomass; 20–50% by mass	55 MWe	Eastern bituminous	Wood waste
ELSAM	Studstrup (wall fired)	Separate injection of biomass; 0–20% on energy basis	150 MWe	Bituminous	Straw

by reducing the decomposition[10]. Preparation of biomass for co-firing in a boiler requires reducing the material to a smaller size. Sizing the biomaterials to a small uniform size will improve the combustion. Following sizing options for biomass fuels[11]:

- Grinding to 0-80 mm pieces
- Chipping to particle size 5-50 mm

During storage, biomass can change in its moisture and energy value. If the stored biomass are smaller in size, more the microbiological activity. When the temperature of the biomass heap rises, the material starts to decay[12].

Feeding of biomass can be done using existing coal infrastructure or by a separate line. Small amounts of biomass can be used in the existing coal handling system[13]. For the higher cofiring ratios, feeding becomes difficult. There are different types of feeding systems e.g. wheel loaders, belt conveyors, chain conveyors, screw conveyors, hydraulic piston feeders, bucket elevators[11].

Level of cofiring

Patricia *et al*[14] conducted the cofiring test using petroleum coke with wood. CO, hydrocarbon and SO_3 emissions were in the range of 2-6, 1.5-4.5 and 6-13 ppmvd, respectively. The furnace exit gas temperature decreased and it resulted in less thermal NO_x being formed in the primary furnace. Hansena *et al*[15] evaluated the co-combustion of coal and straw in pulverized coal fired power boilers. The tested coal-types are low in chlorine (< 0.10%) whereas the concentration in straw is in between 0.2 and 0.6%. Emission of HCl increased and the fly ash analysis indicated that the sulphur capture increases from about 3 to 4% when cofiring straw with coal.

Joseph *et al*[16] conducted the cofiring using saw dust (up to 15% by mass) by varying the excess O_2 from 3 to 4.5%. The SO_2 was reduced about 7% and the NO_x emissions decreased dramatically. As reported by Martin *et al*[17] cofiring the biomass at the rate of 10% increases the system's net energy ratio by 8.9% and reduced the net global warming potential by 7–10%. Net SO_2 emissions are reduced by 9.5% and a significant reduction in NO_x emissions is expected.

Scott *et al*[18] tested coal, fuel oil and bagasse in a spreader stoker-type boiler operating at a steam flow rate of 46.5 Th^{-1} at 62.3 atm and 400°C. Coal, Coal: fuel oil and Coal: fuel oil: Bagasse contributed 100%, 83:17% and 25:13:62% of fuel energy input, respectively. Boiler efficiency was 82, 54, and 50%, respectively while using the three feeds in the mentioned proportion. Particulate matter emission factor ranged as 0.11 to 0.13 kg GJ^{-1}.

Narayanan *et al*[19] cofired the bagasse, wood chips, sugarcane trash, and coconut shell with bituminous coal in power plant with a traveling grate boiler in three proportions of 20, 40 and 60% by mass. The significant reduction in SO_2, NO_x and SPM was obtained in the proportion of 40% coal and 60% biomass.

Chicken waste, wood pellets, coffee residue, and tobacco stalks were cofired at 30 wt% with sub-bituminous coal in a fluidized bed combustor. Cofiring chicken waste largely reduced the mercury emissions by 80%. When cofiring wood pellets with coffee residue, the mercury emissions reduced by about 50%[20]. Cofiring of biomass with coal was existed in various power plants and their details were given in Table 3.

Dairy biomass is cofired with coal at the proportions of 90:10, 80:20 and 100:00 coal: DB blend. The NO_x emission for equivalence ratio varying from 0.9 to 1.2 was 0.4 to 0.13 kg/GJ for pure coal. For 80:20 blend NO_x ranged from 0.375 to 0.05 kg/GJ. Blends produced less NO_x than pure coal under rich conditions even though the DB contained more nitrogen. This result is probably due to the fuel bound nitrogen in dairy biomass is mostly in the form of urea which reduces NO_x to N_2[21].

Technical issues

- Feeding of biomass is a problem due to the presence of lignin
- Volatiles in the biomass may raise the amount of flue gases which may change the flow pattern of combustion gases.
- Biomass ash contains potassium, phosphate and calcium, these elements generating ashes with lower melting point, which can form sticky layers. This can result in bed agglomeration, slagging, de-fluidization and erosion[22, 23, 24].

Conclusion

Cofiring of biomass with coal is an effective approach to meet the country's energy demand. Also, it is considered to be a prospective option for the reduction of CO_2 emissions in a cost effective way using existing power plant. The conclusion of the review was given as i) Energy plantation and biomass based power generation has to be developed ii) Improving the biomass characteristics is required to increase the boiler efficiency iii) Incentives may be given to biomass cofiring to reduce the selling price of electricity-produced from biomass cofiring anad iv) Developing partnerships among the industry, fuel processors and users is an effective way.

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