

PROBLEMS ASSOCIATED WITH BIOMASS COMBUSTION IN INDUSTRIAL BOILERS

ION V. ION

“Dunărea de Jos” University of Galați

Abstract: This paper describes the technologies of biomass combustion and the associated problems. Biomass is plant matter such as trees, grasses, agricultural crops, residues from agriculture or forestry, and the organic component of municipal and industrial wastes. It can be used as a solid fuel, or converted into liquid or gaseous forms, for the production of electric power, heat, chemicals, or fuels. There are multiple techniques for the utilization of biomass for energy production, but today the dominant is biomass combustion. The key biomass combustion issues are efficiency, environmental performance and undesirable reactions in combustor and boiler such as ash fouling and slagging, which reduce the heat transfer and produce corrosion and erosion of boiler surfaces. These problems are caused by the presence of the inorganic material in fuel (metals, silica, sulfur and chlorine).

Keywords: Biomass, Combustion, Boiler, Emissions, Ash, Fouling, Corrosion, Slagging

1. INTRODUCTION

Energy is considered a prime agent in the generation of wealth and a significant factor in economic development. It is well known that eight countries have 81% of all world crude oil reserves, six countries have 70% of all natural gas reserves and eight countries have 89% of all coal reserves [1]. More than half of Asia, Africa and Latin America import over half of all their commercial energy. Most of these countries export crops at low prices, but import energy at high prices, which leads to a drain on foreign exchange earnings. This problem is worsened by the fact that power generation is continuously increasing in these countries. Additionally, the world population keeps increasing at 1.2-2% per year, so that we are doubling our population every 60 years. Therefore, in the year 2060, we expect our population will be in excess of 12 billion. The increase of CO_2 since 1760 is 20%, while methane increased by 7%. These situations led to global warming and a temperature rise of $1+0.5^\circ C$. It is established that if the temperature rises by $0.3^\circ C$ every 10 years, this will result in a 4 cm rise in sea level per decade. The Kyoto Protocol on climate change calls for an overall 5% cut in greenhouse gas emissions from industrial nations by 2010 and development of mechanisms to reduce these emissions substantially. It is thought that even with this reduction in carbon dioxide, the world will be subjected to global warming of $1+2^\circ C$ which results in a significant rise in sea level and a consequent impact on ecosystems and welfare. The decision on what types of energy sources should be utilized must be made on the basis of economic, social, environmental and safety considerations. Renewable energy is an abundant, well established technology and the cost of power generation from renewable sources has dropped significantly over the past decade and several technologies are now cost effective not only for off-grid applications, but for grid-connected power as well. The most important benefit of renewable energy systems is the decrease of environmental pollution. At the end of 2001 the total installed capacity of renewable energy systems was equivalent to 9% of the total electricity generation [2]. Biomass, wind and geothermal energy are commercially competitive and are making relatively fast progress. Currently, renewable represents about 14% of primary-energy consumption in the world, with

biomass being the major contributor (i.e. about 10%) [2]. Biomass can be economically produced with minimal or even positive environmental impacts through perennial crops.

Biomass as the solar energy stored in chemical form in plant and animal materials is among the most precious and versatile resources on Earth. Biomass can generally be classified into the following categories [3]:

- wood residues
- agricultural residues (from crops and farm animals)
- process wastes
- dedicated energy crops
- municipal solid waste (MSW).

The solar energy, which is stored in plants and animals or in the wastes that they produce is called biomass energy. This energy can be recovered by burning biomass as a fuel. Because the energy in biomass is less concentrated than the energy in fossil fuels, high-efficiency conversion technologies are necessary to make this energy resource cost competitive. Biomass is a complex resource that can be processed in many ways leading to a variety of products [5]. Biological routes can convert the carbohydrate portion of the lignocellulosic feedstock into ethanol, an oxygenate that can also be used as a fuel additive. The lignin component cannot be used this way and is combusted to generate heat and electricity. Gasification provides a way to generate syn-gas and from it the clean conventional fuels: Fischer–Tropsch liquids, methanol, and others (Fig. 1). The average majority of biomass energy is produced from wood and wood wastes (64%), solid waste (24%), agricultural wastes (5%) and landfill gases (5%) [4]. Direct combustion and co-firing with coal to produce electricity has been found to be a promising method in the nearest future. At present combustion is responsible for over 97% of the world's bio-energy production [4].

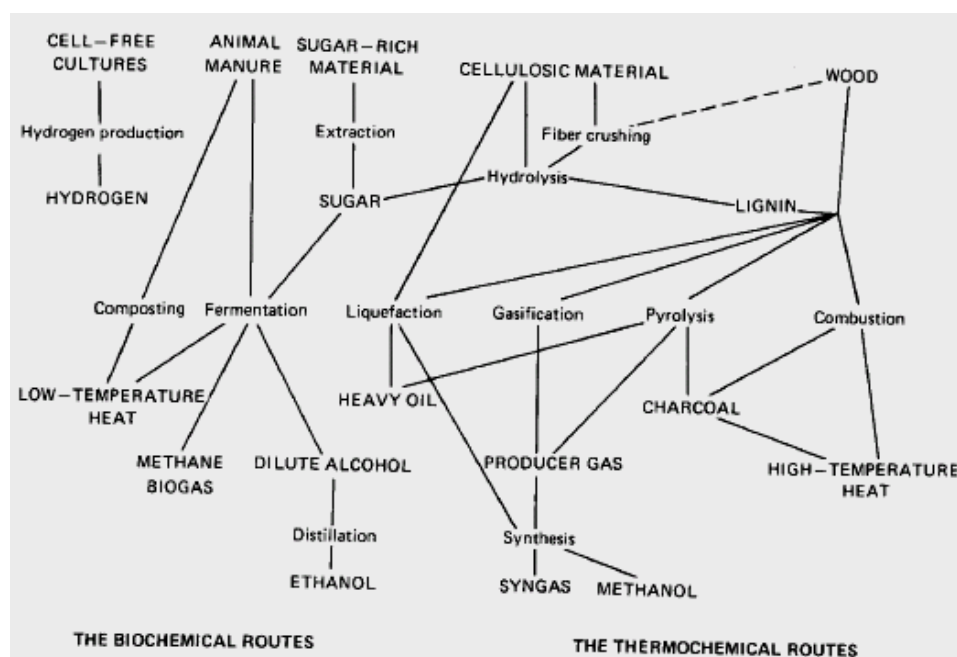


Fig. 1. Fuels and energy products from biomass [6].

2. BIOMASS COMBUSTION

Biomass fuels are considered environmentally friendly for several reasons. There is no net increase in CO_2 as a result of burning a biomass fuel. Biomass consumes the same amount of CO_2 from the atmosphere during growth as is released during combustion. The alkaline ash from biomass also captures some of the SO_2 and CO_2 produced during combustion [4].

Combustion can be utilized for power and/or heat generation. This technique is widely applied and has a great potential for improvement. In general, any organic fuel can be considered a biomass fuel. For the context of this

analysis, biomass is used to describe waste products and dedicated energy crops. Waste products include wood waste material (e.g. saw dust, wood chips, etc), crop residues (e.g. corn husks, wheat chaff, etc.), and municipal, animal and industrial wastes (e.g. sewage sludge, manure, etc.). Dedicated energy crops, including short-rotation woody crops like hard wood trees and herbaceous crops like switchgrass, are agricultural crops that are solely grown for use as biomass fuels.

The compositions of biomass among fuel types are considerable variable, especially with respect to inorganic constituents. Biomass differs from coal in many important ways, including the organic, inorganic, and energy content and physical properties. Relative to coal, biomass generally has less C, more O₂, more silica and potassium, less aluminum and iron, lower heating value, higher moisture content, and lower density and friability. Also, the Cl contents of certain bio-fuels, like straw, can exceed the levels of coal. As a class, coal has more Al, Fe, and Ti than biomass. Biomass has more silica, K, and, sometimes, calcium than coal. Biomass has a lower heating value in comparison with solid fossil fuels.

The biomass properties for the combustion analysis can be grouped into physical, chemical, thermal and mineral properties. Physical property values vary greatly and properties such as density, porosity, and internal surface area are related to wood species whereas bulk density, particle size, and shape distribution are related to fuel preparation methods. Some properties vary with species, location within the biomass fuels, and growth conditions. Other properties depend on the combustion environment.

Characteristics that influence the combustion are:

- *particle size and specific gravity.* These properties depend on the presentation form. For combustion application, due the low energy concentration, the biomass must be mechanical processed (chipping, cleaving, pelleting, briquetting, pressing). Thus the size varies from few millimeters for saw dust to maximum 80 cm for a wood log.
- *ash content.* Ash or inorganic materials in plants depend on the type of the plant and the soil contamination in which the plant grows varying from 0.5% (wt % dry basis) for wood to 20% (wt % dry basis) for rice straw. The ash can be divided into: *bottom ash* (it is produced in the primary combustion zone and remains on the grate - case of fixed bed furnace or remains in bed – case of fluidized bed furnace, due to the high density and the tendency to coalescence), *cyclone-ash* (the fine ash particles which are collected by the cyclone and *filter fly-ash* (the very fine ash particles that necessitate electrostatic precipitator, wet-scrubber or fabric filter to be collected). The of total ash production in the case of fixed bed furnace. For fixed bed furnace the bottom ash may represents 60% to 90% of total ash, the cyclone-ash 10-35% and filter fly-ash 2-10%.
- *moisture content.* Moisture in biomass decreases its heating value, the maximum combustion temperature, increases the volume of combustion gases, influences the behavior during pyrolysis and affects the combustor efficiency.
- *extractive content.* The combustible organic components in biomass (called extractives) rise the Higher Heating Value.
- *element (C, H, O and N) content.* The heat content is related to the oxidation state of the natural fuels in which carbon atoms generally dominate and overshadow small variations of hydrogen content. There is a linear relationship between HHV and carbon content.
- *structural constituent* (cellulose, hemicelluloses and lignin) content. Biomass fuels are composed of biopolymers that consist of various types of cells and the cell walls are built of cellulose, hemicelluloses and lignin. The HHV of biomass fuels increases as increase lignin contents.
- *content of N, S, Cl, K, Ca, Na, Mg.* Nitrogen from biomass fuels forms at 800-1100°C so-called fuel NO_x. Sulfur forms SO₂, SO₃ and alkali sulphate during combustion process. Sodium and potassium lower the melting point of ash and, hence, can increase ash deposition and fouling of boiler tubes [4]. Calcium and magnesium increase the ash-melting temperature. Sodium and potassium in combination with chlorine and sulfur are responsible for the high rates of ash fouling and slagging and. Chlorine, which is found in certain biomass types, such as straw (1.5%), may affect operation by corrosion.
- *content of heavy metals in ash.* The amounts of heavy metals are related to species of biomass, growing site of the sample, age of plant, and distance the source of pollution. The content of residual toxic metals (Cd, Pb, Hg) in treated biomass is in direct relation with the efficiency of the applied metal removal process. The composition of ash depends on plant species and variety, growth conditions, ash fraction and heating plant. Independent of the bio-fuel source, fly ash has generally higher concentrations of several heavy metals than bottom ash [4].

In table 2 are presented the characteristics of solid biomass fuel and their most important effects.

Direct combustion involves the employment of a wide variety of systems that most of them are similar to most fossil-fuel fired systems such as:

- ♦ fixed bed combustors
 - underfeed stoker
 - stoker (or grate-fired) combustors (co-current, cross-current, counter-current)
 - traveling grate
 - mobile horizontal/inclined grate
 - vibrating grate
 - cigar burner
 - underfeed rotating grate
 - rotating cone furnace
- ♦ fluidized bed combustors
 - Bubbling Fluidized Bed (BFB)
 - Circulating Fluidized Bed (CFB)
- ♦ dust firing combustors (suspension burners).

Table 2. Characteristics of solid biomass fuel and their most important effects.

Characteristics	Effects
Physical properties	
physical dimension, form	hosting and conveying, combustion technology, bridging, operational
bulk density	fuel logistics (storage, transport, handling)
size distribution	safety, drying, formation of dust
ash content	dust emissions, ash manipulation, ash utilization/disposal, combustion technology
ash melting behavior	operational safety, combustion technology, process control system
moisture content	storage durability and dry-matter losses, LHV, self-ignition, plant design
HHV, LHV	fuel utilization, plant design
volatiles	thermal decomposition behavior
fungi	health risks
fine parts (wood pressings)	storage volume, transport losses, dust formation
abrasion resistance (wood pressings)	quality changes, segregation, fine parts
Chemical properties element content	
Carbon, <i>C</i>	HHV
Hydrogen, <i>H</i>	HHV, LHV
Oxygen, <i>O</i>	HHV
Chlorine, <i>Cl</i>	HCl, dioxins and furans emissions, corrosion
Nitrogen, <i>N</i>	NO _x , N ₂ O emissions
Sulfur, <i>S</i>	SO _x emissions, corrosion
Flour, <i>F</i>	HF emissions, corrosion
Potassium, <i>K</i>	corrosion (heat exchanger, superheaters), lowering ash-melting temperature, aerosol formation, ash utilization (plant nutrient)
Sodium, <i>Na</i>	corrosion (heat exchanger, superheaters), lowering ash-melting temperature, aerosol formation,
Magnesium <i>Mg</i>	increase of ash-melting temperature, ash utilization (plant nutrient)
Calcium, <i>Ca</i>	increase of ash-melting temperature, ash utilization (plant nutrient)
Phosphor, <i>P</i>	ash utilization (plant nutrient)
Heavy metals	emissions, ash utilization, aerosol formation

Whole-tree energy method and co-firing (especially with coal) are examples of other alternative biomass-combustion technologies [7]. Industrial boilers range from 100 to around 300 MW_{th} output. Smaller scale versions are used in district heating and small processes down to as low as 10 MW_{th}, usually without the same level of emissions control. The pile burner is the original industrial process-scale biomass burner and can be viewed as a sort of enclosed fire. Pile burners have poor load-following characteristics and typically have low efficiencies in the range of 50% to 60%. Stoker grate combustors improve the operation of the pile burners by providing a moving grate, which permits continuous ash collection, thus eliminating the cyclic operation characteristic of traditional pile burners. In addition, the fuel is spread more evenly (in a thin bed, 5 to 15 cm deep), normally by a pneumatic stoker. The thinner layer in the combustion zone produces a more efficient combustion. More modern designs include a sloping reciprocating water-cooled grate. Reciprocating grates are attractive because of simplicity and low fly ash carryover. Furnace exit temperatures are about 980°C; staged combustion processes have been developed to minimize nitrogen oxide emissions and keep the furnace temperature below the ash deformation temperature of most biomass fuels. Stoker-fired moving grates range in

size from 20 to 300 MW_{th}. Since suspension burners require finely divided <1 mm particle size materials with very low moisture contents, they are relatively rare as the fuel preparation from green biomass is very energy intensive. Fluidized bed combustors are becoming the systems of choice for biomass fuels. One reason for this is that the fluid bed medium (silica sand, alumina, or olivine) provides a thermal “flywheel” that compensates for variation in moisture content and maintains constant heat output and flue gas quality. The medium also gives the advantage of extremely good mixing and high heat transfer, resulting in very uniform bed conditions. Despite the relatively low temperature of combustion, the three *T* rule (temperature, time, and turbulence) of high quality combustion is well met, with 99% to 100% carbon burnout being typical [8]. Fluidized beds are either bubbling beds (BFB) or circulating beds (CFB). In the former, the material stays in a fixed zone of the combustor, while in the latter, the flue gas velocity is such that the bed material is suspended and circulates through a return loop to the combustor, by means of a mass or cyclonic separator. In both BFB and CFB units, the ash removal is by means of complete ash carryover, necessitating the addition of cyclones and bag houses for particulate control. It is the emissions performance that is making these units more attractive. In fluidized beds, the uniform, low combustion temperature gives low NO_x emissions, while in the CFB it is easy to introduce a sorbent solid, such as limestone or dolomite, to control SO_x emissions without the need for back-end sulfur removal equipment. Circulating fluid bed temperatures are maintained at about 870°C, which helps to optimize the limestone-sulfur reactions. The alkali content of the fuels has to be maintained low as high alkaline content fuels cause particles in the bed to agglomerate and eventually plugging the system [8].

3. BIOMASS COMBUSTION PROBLEMS

There are some technological problems of biomass combustion in boilers.

The inorganic material in biomass fuel, especially *K* and *Na* provokes ash slagging and fouling. This issue plays an important role in the design and operation of combustion equipment [4]. Slagging and fouling reduces heat transfer and cause corrosion and erosion of combustor surface. The biomass fuels with high alkali indexes and high chloride and sulfate ratios are responsible for high rates of fouling and slagging.

The maximum particle size of a given biomass that can be fed to and burned in a given boiler through a given feeding mechanism requires additional studies.

Practical pulverizer performance needs to be examined. Biomass may require separate pulverizers to achieve high blend ratios and good combustion performance.

The low temperature corrosion of the air preheater is caused by a combination of the presence of hygroscopic species in ash deposits, particularly iron chlorides and temperature variations caused by intermittent plant operation. The chlorine present in ash deposit induces high temperature corrosion of superheater tubes. The corrosion is a function of total fuel *Cl* content, available (not total) alkali content and total *S* content.

The high moisture and ash contents in biomass can cause ignition and combustion problems. Because of the low heating values, biomass is accompanied by flame stability problems.

The metals present in biomass are of great biochemical interest and them nutritional, clinical and environmental importance. The content of residual toxic metals in treated biomass highly influences them refuse options. Absorption using activated carbon, post-precipitation, and ion exchange are several methods to reduce the concentrations of toxic metals (*Pb*, *Cd*, *Hg*) [4]. The fly ashes from solid waste combustion have the higher content of cadmium (270mg/kg), zinc (11 000 mg/kg) and lead (4 000 mg/kg). Inorganic elements and compounds in biomass fuels influence the combustion process and the composition of the ashes produced. Wood ash has generally higher *As*, *Cd*, *Pb* and *Hg* contents than agricultural residue, such as wheat straw and fruit shells. A solution to the recycling of solid product of biomass combustion is blending the cyclone-ash with bottom-ash and filter fly-ash and using the mixture in agriculture.

Biomass combustion, particularly combustion of salt-laden wood waste is considered as a major source of dioxins and furans emissions.

Biomass combustion emits CO₂ and when the combustion is incomplete, it also emits CO, N₂O, CH₄ other HCs and particulate matter. Smoke from low efficient wood fuel stoves has proved to be one of the important risk factors in many health problems. Significant environmental benefits can be obtained by using biomass fuels in direct combustion, gasification, or pyrolysis systems.

Wood offers advantages over fossil fuels with regard to emissions: the sulfur and nitrogen contents of wood are low, thus SO_x emissions are negligible, and, if temperature is controlled to reduce oxidation of nitrogen from the air, the overall NO_x will also be low [4].

Cofiring involves substituting biomass for a portion of coal in an existing power plant furnace. It is the most economic near-term option for introducing new biomass power generation. Because much of the existing power plant equipment can be used without major modifications, cofiring is far less expensive than building a new plant. Compared to the coal it replaces, biomass reduces sulfur dioxide, nitrogen oxides and other air emissions. After "tuning" the boiler for peak performance, there is little or no loss in efficiency from adding biomass. This allows the energy in biomass to be converted to electricity with the high efficiency (in the 33-37% range) of a modern coal-fired power plant. Blending of biomass with higher quality coal reduce the flame stability problems, as well as minimize corrosion effects.

4. CONCLUSIONS

The use of biomass energy has the following important benefits: can help mitigate climate change, reduces acid rain, soil erosion, water pollution and pressure on landfills, provides wildlife habitat and help maintain forest health through better management.

Direct combustion technology using biomass as the fuel is very similar to that used for coal.

Air toxic emissions from biomass combustion are very low as a result of the good air-fuel mixing and high furnace temperatures associated with pulverized coal combustion.

The ash deposition rate can be considerably reduced when blends of biomass with coal are burned.

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