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Biomass Co-firing: A transition to a low carbon future

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Abstract : *Biomass Co-firing is defined as simultaneous combustion of different fuels in the same boiler, provides one alternative to achieve emission reductions. This is not only accomplished by replacing fossil fuel with biomass, but also as a result of interaction of fuel reactants of different origin, e.g. biomass and coal. Co-firing of biomass with fossil fuels provides means to reduceSO2, and CO2 emissions and it also may reduce NOx emissions. It is assumed that there is no net emission of CO2 from biomass combustion as plants use the same amount of CO2 during growth that is released in combustion On the other hand utilisation of solid biofuels and wastes sets new demand for boiler process control and boiler design, as well as for combustion technologies, fuel blend control and fuel handling system. Cofiring with biomass offers a cheap and practical means of reducing carbon emissions using existing infrastructure. The capital costs for cofiring are generally low and usually limited to retrofitting boilers with modified delivery systems. Compared to other forms of renewable energy, the up-front investments needed for co-firing in existing boilers are fairly small. These retrofits are often substantially less expensive than the costly overhaul that would otherwise be needed to meet increased emissions standards.*

Keywords - *Biomass, Fuels, combustion, Boiler, co-firing*

I. Introduction

Global climatic change is the biggest threat facing the world today. Climate change has the potential to produce wide spread and devastating environmental changes, many of which may be difficult to predict and impossible to reverse. The primary driver of climate change is the emission of greenhouse gases, including carbon dioxide, methane, and nitrous oxide. Of these carbon dioxide poses the greatest threat. These emissions arise from a number of human activities, including land use change and the burning of fossil fuels. Biomass co-firing refers to the simultaneous combustion of biomass fuel and a base fuel to produce energy, usually electrical power. This provides one alternative to achieve emission reductions. The most common sources of biomass fuel include low value wood from forestry activities, crop residues, constructions debris, municipal waste, storm debris, and dedicated energy crops, such as switch grass, willow, and hybrid poplar. Most biomass feedstock must undergo significant processing before they can be utilized for co-firing. Co-firing was found to significantly reduce the environmental footprint of the average coal-fired power plant. At the rates of 5% and 15% by heat input, co-firing reduces greenhouse gas emissions on a CO2 equivalent basis by 5.4% and 18.2%, respectively. Emissions of SO2, NOX, non-methane hydrocarbons, particulates, and carbon monoxide are also reduced with co-firing. The total system energy consumption is lowered by 3.5% and 12.4% for the 5% and 15% co-firing cases respectively. Resources consumption and solid waste generation were found to be much less for system that co-fires. The biomass co-firing fly ash mixture has lower water demand than the coal derived mixture. Biomass co-fired fly ash does not impact concrete setting behaviour and it can have useful applications for light weight concrete.

II. BIOMASS FUEL CHARACTERISTICS

The characteristics of biomass are very different from those of coal. The content of volatile matter in wood-based biomass is generally close to 80%, whereas in coal it is around 30%. Wood char is highly reactive, which results in complete combustion of wood fuels in fluidized bed combustion. Nitrogen and sulphur contents of wood are low. This implies that blending wood biomass with coal lowers emission simply because of dilution. Further, one important difference between coal and biomass is the net caloric value. Biomass fuels often have high moisture content which results in relatively low net caloric value. Biomass also contains less ash than coal, thus decreasing the amount of solid waste generated. Table 2.1 shows the typical properties of the solid fuels.

Table 1: Typical properties of solid fuels

TYPICAL PROPERTIES OF SOLID FUELS

Property	Coal	Peat	Wood without bark	Bark	Forest residues (coniferous tree with needles)	Willow	Straw	Reed canary grass (spring harvested)	Olive residues
Ash content (d)	8.5-10.9	4-7	0.4-0.5	2-3	1-3	1.1-4.0	5	6.2-7.5	2-7
Moisture content, w-%	6-10	40-55	5-60	45-65	50-60	50-60	17-25	15-20	60-70
Net calorific value, MJ/kg	26-28.3	20.9-21.3	18.5-20	18.5-23	18.5-20	18.4-19.2	17.4	17.1-17.5	17.5-19
C, % (d)	76-87	52-56	48-52	48-52	48-52	47-51	45-47	45.5-46.1	48-50
H, % (d)	3.5-5	5-6.5	6.2-6.4	5.7-6.8	6-6.2	5.8-6.7	5.8-6.0	5.7-5.8	5.5-6.5
N, % (d)	0.8-1.5	1-3	0.1-0.5	0.3-0.8	0.3-0.5	0.2-0.8	0.4-0.6	0.65-1.04	0.5-1.5
O, % (d)	2.8-11.3	30-40	38-42	24.3-40.2	40-44	40-46	40-46	44	34
S, % (d)	0.5-3.1	<0.05-0.3	<0.05	<0.05	<0.05	0.02-0.10	0.05-0.2	0.08-0.13	0.07-0.17
Cl, % (d)	<0.1	0.02-0.06	0.01-0.03	0.01-0.03	0.01-0.04	0.01-0.05	0.14-0.97	0.09	0.1*
K, % (d)	0.003	0.8-5.8	0.02-0.05	0.1-0.4	0.1-0.4	0.2-0.5	0.69-1.3	0.3-0.5	30*
Ca, % (d)	4-12	0.05-0.1	0.1-1.5	0.02-0.08	0.2-0.9	0.2-0.7	0.1-0.6	9	

III. VARIETY OF WOOD FUELS AVAILABLE FOR CO-COMBUSTION

Wood fuel resources available for co-combustion are diverse: sawdust, cutter chips, demolition wood, recycled wood, bark, logging residue chips, or even more refined biofuels, such as pellets (Fig 3.1). Fluidized bed and great boilers can use any type of wood fuels, whereas pulverized fuel boilers are more selective. The maximum share of wood in the fuel blend has been small, only about 5-10%. The properties of wood biomass set demanding requirements for power plant operation. These properties include total ash content, ash melting behavior and the chemical composition of ash. Alkaline metals that are usually responsible for fouling of heat transfer surfaces are abundant in wood fuel ashes and will be easily released in the gas phase during combustion. In biomass fuels, these inorganic compounds are in the form of salts or bound in the organic matter, but in peat, for example, inorganic matter is bound mostly in silicates, which are more stable at elevated temperature. The elemental compositions of ash, as well as the chemical concentration of the compounds affect ash melting behaviour. During combustion the behaviour of biomass fuel is influenced by the presence of other fuels. Even a small concentration of chlorine in the fuel can result in the formation of harmful alkaline and chlorine compounds on boiler heat transfer surfaces. This can be prevented by co-firing fuels such as containing sulphur and aluminium silicate peat or coal with chlorine bearing fuels.

Fig 1: variety of wood fuels

IV. FUEL HANDLING AND PRE-TREATMENT IN THE PLANT

Each combustion method needs specific handling and feeding operations and therefore it is impossible to give detailed overall design basics for handling and feeding operations. Basically, the handling and conveying system should be designed according to the fuel properties. Because of the obscure dimensioning parameters and the fact that several fuel types have to be fed into the boiler either through the same or separate lines depending on the case, the investments become rather expensive and the systems complicated.

4.1. Fuel receiving

Solid biofuels are delivered normally by trucks or truck containers. In most cases the fuel supplier is responsible for delivery and unloading. High shear strength and low energy density of biofuels have lead to the design of receiving pits and pre-screens that are as open as possible, enabling sufficient unloading for the boiler capacity. Usually different fuel fractions will be blended during transportation and in the receiving station. There are very few separate units for mixing. In large plants, fuels are blended sufficiently also in handling and conveying, especially in the loading and unloading of silos.

4.2. Screening

The high shear strength and fibre content emphasis the design of screening. One of the best screening devices is a disc-screen where the critical factors are the feeding, screen aperture dimensions, disc-shape and rotation velocity when optimizing the proportion of acceptable fuel from over-sized reject material. The normal metal separation based on ferromagnetic character is sufficient if the proportion of demolition wood is not extensive. In some cases where the fuel flow has increased, the capacity of magnetic separation has been adjusted accordingly.

4.3. Conveying and storing

The transport capacity of conveyors and declaimers is very important when fuel quality reduces. The handling of more fibrous materials has affected the design of crossing points, chutes and openings and especially silos and stores. The principal design methods are not as valid as practical experience and feedback from plant operators. The store sizes (of intermediate storages) have grown larger due to lower calorific values. At the moment the largest round-bottom intermediate store equipped with a slewing screw reclaimer is 5,000 m^3. The volume of a single A-shape store can exceed 10,000 m^3. Present stores are often provided with flow distributors, which prevent segregation and direct flow.

4.4. Boiler measurements

The most reliable boiler hopper or silo has been proved to be a cylindrical silo equipped with an unloading screw turning on the bottom. This structure ensures also the most accurate and adjustable discharge of fuel. Fuel will be unloaded mostly on chain conveyors on both sides of the boiler. The mass flow rate is measured from conveyors but the primary information for fuel feeding control comes from steam pressure and combustion chamber measurements, which provide faster response for adjustments. Most electric motors have variable speed control (VSC). This is done with frequency converters, which can be controlled externally or locally for example by rotation speed, level, space, position, and torque using modern control methods.

4.5. Control, fire and occupational safety

Control, fire and occupational safety are based on a modern distributed control system. A lot of research has been done to study fuel safety properties. Experience has shown that the most critical parts of the process are the receiving, screening, crushing and feeding line near the boiler. The use of modern monitoring (also cameras utilising broader wavelengths), detection and preventive technology has been significantly increased.

V. CHOICE BETWEEN DIRECT, INDIRECT OR PARALLEL CO-COMBUSTION

There are basically three options for co-combustion: direct, indirect and parallel co-combustion. Direct co-combustion is combustion of biomass together with fossil fuel in a single combustion chamber. Indirect co-combustion means combustion of fossil fuel with previously gasified biofuel, and parallel combustion requires at least two boilers as biomass is burned in one and fossil fuel in another.

VI. CO-FIRING BENEFITS

6.1. Co-firing is a renewable technology

As long as biomass is harvested in accordance with a sustained yield (in which annual harvests do not exceed annual growth), production of energy from that biomass will produce no net carbon emissions above those used in harvesting, processing, and transportation. Although the majority of energy produced in Co-firing derives from fossil fuels, the biomass fraction of the total energy load is fully renewable.

6.2. Co-firing provides means for emission reduction

Co-firing of biomass with fossil fuels provides means to reduce SO_2, and CO_2 emissions and it also may reduce NOx emissions. It is assumed that there is no net emission of CO_2 from biomass combustion as plants use the same amount of CO_2 during growth that is released in combustion. Typical consequences of co-firing are modest reductions in boiler efficiency that limit the economic value of biomass fuels. NOx reduction is due to strengthening of reactions reducing NO in the furnace and/or lower nitrogen content in biomass. The SO_2 reduction results from both substituting sulphur bearing fuel for sulphur deficient and calcium deficient fuel for a calcium bearing fuel. Every tonne of biomass co-fired directly reduces fossil CO_2 emissions by over a tonne. If the biomass would otherwise be disposed of in a landfill without methane collection and flaring, the fossil CO_2 emission reduction (Fig. 10.1) can be the equivalent of approximately three tonnes of fossil for CO_2 every tonne of biomass burned.

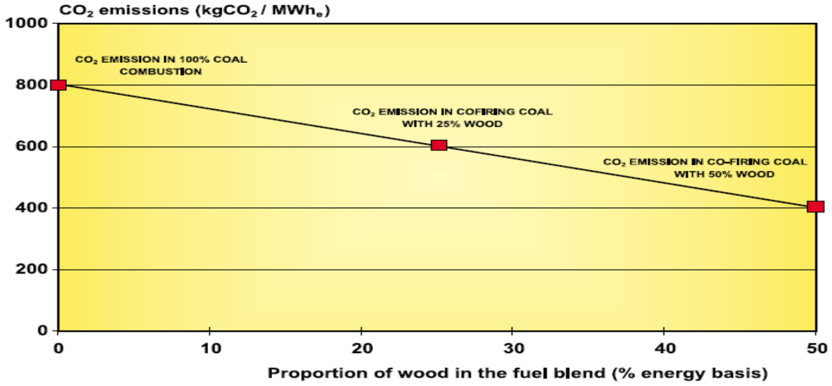

Fig .2: Theoretical decrease in CO_2 emissions by cofiring of wood with coal

6.2.1. Reducing NO_X and N_2O emission

In chemical terms, nitrogen oxides should constitute all oxides of nitrogen (NxOy), including nitric oxide (NO), nitrogen dioxide (N_2O) and nitrous oxide (N_2O). NOx is generally defined as the sum of NO and N_2O. NO is the main contributor of NOx in both pulverised fuel and fluidised bed combustion. In fluidised bed combustion, the amount of NO (in NO + N_2O) is 90-98 %. One nitrogen-containing compound that is often omitted in the context of greenhouse gas emissions is N_2O. Compared to pulverised fuel combustion, the lower combustion temperature in fluidised bed combustion provides an advantage in reducing the formation of thermal NOx. On the other hand, N_2O emissions seem to be higher in fluidised bed combustion. If lower NOx levels are required adding ammonia or urea into the flue gas stream can be done.

N_2O emissions from fluidised bed combustion can vary from less than 5 up to 200ppm. Because of the adverse effect of N_2O on the atmosphere, a considerable amount of research has focused on N_2O formation/destruction mechanisms in fluidised bed combustion. N_2O emission is strongly dependent on temperature and fuel composition. Contrary to NOx, N_2O concentration in combustion gases decreases as the temperature rises. Adding biomass to the fuel mixture clearly decreases the N_2O emission. A higher O/N ratio of biomass has a positive impact on N_2O emissions. The large amounts of calcium, potassium and sodium in biomass have a catalytic effect on N_2O reduction. The effect of biomass on N_2O reduction is more significant at lower temperatures.

6.2.2. Biomass blending decrease SO_2 emissions

By blending biomass with coal, SO_2 emissions decrease because of the lower sulphur content of biomass. The reduction can be even higher than this due to interaction of fuel constituents of different origin, i.e. biomass and coal. The ash in biomass is often very high in calcium. Fuel-bound calcium compounds can work as sorbents as they can react with SO_2 and SO_3 to form calcium sulphate. The efficiency of sulphur reduction in combustion processes depends on several variables such as combustion temperature, excess of air, air staging, fly ash recirculation (in FBC), fuel type, limestone characteristics, limestone and fuel feed distribution and Ca/S ratio. It has been shown in laboratory- scale CFB combustion tests where coal and bark blends were burned that sulphur removal efficiencies from 15% (no bark) up to 80% (80% bark) can be achieved.

6.2.3. Heavy metals, dioxins and furan emissions

When recycled fuels are used, halogen, heavy metal, dioxin and furan emissions may need to be controlled by means of combustion temperature, bed composition, dust removal or flue gas scrubbing. Separation of suspended solid particles from the flue gases can be very costly. The standard solution is to equip plants with electric precipitators. On the other hand, the sulphur and aluminium silicates in coal have been shown to reduce the chlorine content of fly ash particles.

6.3. Co-firing complements sustainable land management

Biomass utilization will benefit forests, agricultural landscapes and other ecosystems. For example, harvesting of excess biomass in fire-prone forests (‘hazardous fuels reduction’) is commonly done to reduce the frequency and intensity of catastrophic wildfires. These activities are now more important than ever as the cost of fighting wildfires has increased dramatically. In the western United States alone, there are 28 million acres of forest currently in need of thinning. Small budgets and lack of a market for small-diameter logs are the main impediments to these necessary treatments; co-firing has the potential to expand markets and make thinning treatments affordable. Thinning and removal of small-diameter, low quality biomass can also be an important component of wildlife habitat management, timber stand improvement, and other forest stewardship activities. On agricultural lands, the cultivation of perennial, low-input crops (such as switch grass or willow) can conserve soil resources and reduce need for water and nutrients. By adding value to working lands and rural landscapes, demand for biomass resources can help reduce urban sprawl, deforestation, and development of open lands.

6.4. Co-firing makes economic sense

Co-firing with biomass offers a cheap and practical means of reducing carbon emissions using existing infrastructure. The capital costs for co-firing are generally low and usually limited to retrofitting boilers with modified delivery systems. Compared to other forms of renewable energy, the up-front investments needed for co-firing in existing boilers are fairly small. These retrofits are often substantially less expensive than the costly overhaul that would otherwise be needed to meet increased emissions standards. For older boilers, especially, co-firing may be the most cost-effective way to reduce emissions. In addition to the low initial investment, the annual fuel costs are often lower in co-fired plants than in plants burning pure coal. In a future characterized by climate legislation and/or renewable energy mandates, co-firing can reduce carbon emissions while maximizing the revenue potential of sunk investments in existing coal-fired facilities.

In addition to aiding the power generation industry, co-firing would also generate increased demand for sustainable biomass, adding value to unmerchantable byproducts, creating new market opportunities, and supporting rural economies. The use of wastes and residues for energy generation would result in lower costs and reduced environmental impacts associated with waste removal and landfill dumping.

VII. BARRIERS AND PROBLEMS IN BIOMASS COFIRING

7.1. Costs

Although initial investments for co-firing may be low, they are not zero. Total costs vary depending on the type and condition of boiler being modified, as well as the biomass delivery system that is selected, with separate feed systems costing up to four times as much as a blended delivery system. The costs associated with feedstock preparation ultimately depend on the type and condition of biomass being used, the boiler specifications, and the processing equipment available, and is greatly dependent upon the blending ratio, as biomass has a fuel density roughly 1/10th that of coal. The cost structure of feedstock is an important consideration and gives fuel from agricultural residue an advantage over dedicated fuel crops, as residue is produced essentially for free (ignoring transportation and treatment costs) whereas fuel crops are custom grown and sold.

7.2. Ash contamination

Many power companies derive additional income from the sale of fly ash, a byproduct of coal combustion and an important additive in cement used in ‘green buildings’ and other applications. Although fly ash from biomass co-firing is a comparable product, the current ASTM standard (C618) requires that only pure “coal fly ash” be used in cement manufacture. Until this standard is amended, co-firing facilities will be unable to market this product, effectively producing pure, valueless waste.

VIII. CONCLUSION

Co-firing can lead to significant reductions in the environmental impacts of coal-based electricity production. The amount of nearly all air emissions are reduced by feeding even small amount of biomass in the boiler. Additionally, because of avoided decomposition emissions, net green house gas emissions are reduced at rate greater than the rate at which wood is added. The net energy balance of the system is improved because of a reduction in the amount of coal that burned and because, on an energy equivalent basis procuring biomass residue for the biomass consumes less energy than mining and transporting coal. Consumption of non-renewable resources cut substantially from those levels required when firing coal alone. Finally, solid waste emissions are reduced not only at the plant in the forms of boiler ash and flue gas cleanup waste, but also because land filling of available biomass resources is avoided. While existing coal-fired power plant will incur some capital expenses to co-fire biomass, the environmental benefits are significant and may be justified by emission restrictions and consumer desire for cleaner power.

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