Biomass and Bioenergy

Biomass Ash Characteristics and Behaviour in Combustion Systems

This Technology Report from Task 32: Biomass Combustion and Co-firing, was prepared by the Task Leaders Sjaak van Loo and Jaap Koppejan.

INTRODUCTION

Biomass materials contain significant levels of inorganic matter as impurities, and many of the practical problems encountered with the combustion of biomass materials are associated with the nature and behaviour of the biomass ash and the inorganic constituents. Practical problems encountered are:

- the formation of fused or partly-fused ash agglomerates and slag deposits at high temperatures within furnaces;
- the formation of bonded ash deposits at lower gas temperatures on the heat exchange surfaces in the boiler convective sections, and elsewhere;
- the accelerated metal wastage of boiler components due to gas-side corrosion and erosion;
- the formation and emission of sub-micron aerosols and fumes; and
- the handling and the utilisation/disposal of ash residues from biomass combustion plants, and of the mixed ash residues from the co-firing of biomass in coal-fired boilers.

In very general terms, the nature of the problems and the impact on plant performance depend both on the characteristics of the biomass fuel, i.e. principally on the ash content and the ash chemistry, and on the design and operation of the combustion equipment and the boiler.

There has been a good deal of technical research and development work on the nature and behaviour of biomass ashes and biomass-coal ash mixtures over the past 10-20 years, both at laboratory scale and in combustion test facilities. There is also increasing operational experience of the combustion and co-combustion of biomass materials, and of the behaviour of biomass ashes and biomass-coal ash mixtures. This experience is relevant to all scales of operation, i.e. in small domestic appliances, in industrial and commercial combustion equipment and boiler plants and in large utility boiler plants.

This report presents a summary of the key findings of the most relevant biomass ash-related development work and of the practical experience of the impact of ash-related problems on the operation of biomass combustion systems and boiler plants. For a more elaborate description of this topic, the reader is referred to the second edition of the Handbook of Biomass Combustion and Co-firing, prepared by Task 32. [1]

BIOMASS ASH CHARACTERISTICS

In very general terms, the inorganic materials in most solid fuels, including biomass, can be divided into two broad fractions. The inherent inorganic material is mainly in the form of simple inorganic salts, and principally as the oxides and hydroxides of silicon, and the nitrates, sulphates, chlorides, phosphates and oxalates of the alkali and alkaline earth metals. In addition, biomass may contain other contaminants such as sand, soil, or other mineral materials, tramp metal components, etc.
Clean woody materials, either in chip or in pellet form, are utilised as a fuel for a wide range of combustors for small domestic stoves and boilers, for commercial and industrial scale boilers and for co-firing in large coal-fired utility boilers. They have relatively low ash contents, less than 2%, and this is largely dependent on the amount of bark in the fuel. Clean white wood materials have very low ash contents, generally less than 1%.

Straw and grass materials and the solid residues from the vegetable oil producing industries are utilised in substantial quantities as fuels for industrial scale boilers and have ash contents in the 4-7% range. Poultry litter is utilised in significant quantities as an industrial boiler fuel with high ash content and particularly difficult ash behaviour.

All biomass ashes tend to be rich in a fairly similar suite of inorganic species, i.e. the compounds of Ca, K, Si, P, and Mg. The clean wood materials are particularly rich in Ca, Si and K. Waste wood materials can have significant levels of some of the heavy metals, particularly Pb and Zn. The ash chemistries of the other biomass materials vary significantly but all are dominated by Ca, K, and Si or P compounds.

One of the key properties of fuel ash materials in combustion systems is their behaviour at elevated temperatures and, in particular, their fusion behaviour. The sintering and fusion of the ash particles on the grates in stoker-fired combustors, and the sintering, fusion and agglomeration of the ash particles in fluidised bed-fired combustors, are important processes. The fusion behaviour of the ashes is also an important factor in determining the propensities of the fuels to form fused or partly-fused slag deposits on the furnace wall surfaces in all combustion systems, and may have an influence on the nature of the fouling deposits that can occur on the heat exchange and other surfaces in boiler plants.

The fusion behaviour of most fuel ashes is a complex phenomenon, which is best described in terms of a melting curve, where the percentage of fused ash by mass is plotted against the temperature. On the ash melting curves, two key temperatures are commonly identified and used to describe the behaviour of the ashes, viz:

- the \( T_{15} \) temperature, at which 15% of the ash material is molten. This is considered to be the temperature at which the surfaces of the ash particles or slag deposits begin to become sticky and receptive to incoming particles, and
- the \( T_{70} \) temperature, at which 70% of the ash is molten. This is the level at which the outer surface of an ash deposit on a vertical boiler tube will begin to flow.

A number of complex thermodynamic models have been developed and validated through experiments, which make it possible to predict the ash melting curve of given fuels relatively accurately. A number of slagging and fouling indices have been developed in the coal industry to obtain an indication of the propensity of fuel ashes to form deposits in combustors or furnaces, based on the chemical composition. Since the majority of slagging indices are thus based on the assessment of the fusion behaviour of alumino-silicate coal ashes, their application to biomass ash systems, which are chemically very different, can be problematic. For the co-firing of biomass at relatively low levels, the mixed ash is still predominantly an alumino-silicate system so that normal coal slagging assessment methods can be applied. If biomass is co-fired with coal in larger quantities, all of the significant components of most biomass ashes, principally the alkali and alkaline earth metals, are powerful fluxes for alumino-silicate systems. The introduction of biomass can therefore result in a reduction in the fusion temperatures, and hence an increase in the slagging potential. Care should be taken when interpreting the conventional slagging index values for pure biomass.

The fouling indices for biomass ashes are based on the total alkali content of the fuel. The deposition of the sodium and potassium compounds by a volatilisation/condensation mechanism is
considered to be the principal driving force for convective pass fouling in boilers.[2]

**Ash behaviour at elevated temperatures in combustion systems**

Some inorganic constituents of biomass materials are volatile at combustion temperatures, particularly some of the alkali metal (K and Na) compounds, the phosphates and some of the heavy metal species. These species can be released into the combustion gases in the form of a fume or as a condensable vapour. Other inorganic species, principally the compounds of calcium and silicon, can be released from the burning fuel particle as very finely divided, sub-micron particles.

The balance of the inorganic fraction of the biomass will undergo a number of chemical and physical transformations, depending on the chemical composition and the combustion temperature and residence time, to form the larger, residual ash particles.

The specific details of the ‘release mechanisms’ and ‘residual ash formation processes’ depend largely on the type of combustor, i.e. on the flame temperatures and the residence times at elevated temperatures. The majority of the laboratory and industrial-scale experimental work on these processes have recognised this, and are aimed specifically at one or the other of these types of combustor. For most solid biomass fuels, there are three general modes of combustion, viz:

- **Grate combustors**, which are generally employed for domestic, and small and medium-sized industrial/commercial application.
- **Fluidised bed combustors**, of the bubbling bed and circulating types, which are commonly employed for the medium-sized industrial/commercial applications.
- **Pulverised fuel combustors**, which are employed in the main for large industrial and utility applications. These are rarely used for 100% biomass firing, and the interest is principally in the co-firing of biomass in large pulverised coal-fired boilers.

A description of the ash behaviour in these combustion systems is provided below.

**Grate-fired combustors**: In grate-fired systems, the fuel particles are distributed over a moving or static grate to form a fuel bed, with some of the combustion air being supplied from underneath. The normal intention is to retain the majority of the ash on the grate to be removed, either manually or mechanically, to an ash pit, although a significant quantity of the ash will be released from the bed as fly ash particles entrained in the combustion gases or in the form of vapours and fine fumes.

The maximum fuel bed temperatures that apply in the grate combustion of biomass materials are generally of the order of 1000-1200°C, and the overall residence times on the grate are relatively long, commonly of the order of several minutes. Depending on the ash chemical composition and the local bed temperatures, a degree of sintering or fusion of the bed ash particles may occur. If the degree of fusion of the ash is excessive, relatively large ash agglomerates may form. This can interfere with the distribution of air through the fuel, and may affect burnout of the char. The bed ash composition is usually fairly similar to that of the laboratory-prepared fuel ash, although it can sometimes be depleted in the more volatile inorganic species, principally potassium.

The coarse fly ash particles are principally small particles of ash, of an aerodynamic diameter of up to 200-500µm or so, which are entrained with the upward flow of undergrate air and the combustion gases, and carried upwards through the furnace. The chemical composition of the coarse fly ash is normally similar to that of the bed ash. There is commonly condensation of volatile inorganic species, particularly alkali metal sulphates, and some heavy metal compounds, on the surfaces of the coarse fly ash particles.

Sub-micron aerosols are generated mainly by the condensation from the vapour phase of the volatile inorganic species, i.e. the alkali metal
and some heavy metal compounds, principally as chlorides and sulphates, as the flue gases cool in passing through the boiler. Although calcium compounds are not considered to be volatile under these conditions, they may be present in significant quantities in aerosols when burning wood, due to the release of very finely divided CaO particles from the bark during the combustion process. Both zinc and lead in wastewood may also be present in significant quantities in the fly ash. Because of the relatively low ash melting point, this may cause significant deposition problems.

**Fluidised bed combustors:** The relatively low combustion temperatures that apply in the bed and freeboard of fluidised beds (less than 900°C) results in reduced release of alkali metals by volatilisation, and a lower degree of fusion of the ash than that observed in grate combustors, where the ash is exposed to higher temperatures for longer residence times. The inorganic constituents of the biomass and the bed material may however undergo thermal decomposition reactions within the furnace. The key processes responsible for the formation of bonds between the bed particles in biomass-fired fluidised bed combustors are:

- Partial melting of the low melting point ash components to form a liquid phase of low viscosity, which, in turn, forms the necks between the bed particles. If the conditions are favourable, fairly extensive three-dimensional agglomerates can form. This type of sintering mechanism is of key importance for fuels with ashes rich in alkali metals, phosphates and some of the heavy metals. In some cases, the solid ash and bed particles, and particularly silicates and alumino-silicate species may be partially soluble in the liquid phase at the sintering temperature, and this can contribute to the strength of the particle-particle bonding. At higher bed temperatures, it is possible for a silicate melt of high viscosity to form on the surfaces of the bed material. The viscous liquid phase can also flow to form necks between the ash and bed particles.

- It is also possible for chemical reactions to occur at the surfaces of the bed particles, which can increase the strength of inter-particle bonds. For instance, the reaction of lime on the surfaces of the bed particles with SO₂ to form calcium sulphate is considered responsible for the sintering of bed particles in fluidised bed combustors firing high calcium biomass materials.

- Although fluidised bed combustors firing biomass materials operate at relatively low bed temperatures, the release of volatile inorganic species into the flue gases and the fouling of the surfaces of the boiler convective section do occur.

The avoidance of sintering is an important combustor design and operational issue. Excessive agglomeration of the bed particles can lead to poor air distribution and eventually defluidisation of the bed. In extreme cases, it may be necessary for the operators to bring the combustor off-line to remove and replace the bed material. During operation, the key issue is control over the bed temperatures and fuel distribution. The formation of agglomerates is often associated with the formation of fuel-rich hot spots in the bed. These can also be formed as a result of slag falls from the upper furnace surfaces or the detachment of pieces of furnace wall refractory material.

The ash residues from fluidised bed combustors are generally of two basic types, viz.

- The fly ash materials carried over from the combustor, and which are captured by the particulate emission abatement equipment. These materials generally comprise the smaller fuel ash particles, and particles of quartz sand or lime/limestone elutriated from the bed. The great majority of the ash discards from the system are of this type.

- The larger ash particles retained in the furnace, which can be removed periodically through the bed drains. These generally comprise agglomerated fuel ash and bed materials, and slag deposit material detached from the furnace
surfaces. When firing biomass materials, the quantities of bed ash discard materials tend to be relatively small.

**Pulverised fuel combustion systems:** Pulverised fuel combustion systems are generally associated with very large solid fuel boilers for power generation, and it is relatively rare for these to be fuelled with biomass alone, although there are a small number of pulverised wood-fired boilers in operation. For biomass co-firing, this is an important technology. In pulverised fuel systems, the peak flame temperatures are very high compared to those in most other combustion systems, commonly around 1600ºC, and residence times at these temperatures are relatively short, of the order of a few seconds. The principal concerns in this case are with the behaviour of the inorganic material associated with the biomass when subjected to very high temperatures and the conditions that apply in suspension flames, and with the impact of the co-firing of the biomass on the behaviour of the resultant ash, i.e. with the characteristics of the mixed biomass-coal ashes.

The key ash-related impacts of the co-firing of the biomass with the coal are potentially on the slagging and fouling deposit formation potential of the mixed biomass-coal ash, and on the efficiency of the particulate collection equipment installed. Biomass materials tend to have relatively low ash contents compared to most coals, however the biomass ash materials tend to be relatively rich in the alkali and alkaline earth metals and these are effective fluxes for the alumino-silicate coal ashes. In general terms, therefore, the co-firing of biomass with coal will tend to increase both the slagging and fouling propensity of the mixed fuel, depending on the chemistries of the coal and biomass ashes and the co-firing ratio. At low co-firing ratios, less than about 10% on a mass basis, recent plant experience has indicated that these effects tend to be modest.

**Ash deposit formation mechanisms**
Operational problems associated with the deposition and retention of ash materials may occur on all of the major gas-side components of combustors and boilers firing or co-firing biomass materials.

Particularly at high temperatures in the combustion system and furnace one may encounter the following operational problems due to slag formation at temperatures in excess of around 800ºC.
- The agglomeration of ash particles in the fuel beds of stoker-fired and fluidised bed-fired combustion equipment, leading to poor combustion conditions, de-fluidisation of fluidised beds, and problems with ash removal and downstream ash handling equipment.
- The deposition of ash materials on burner component and divergent quarl surfaces in large pulverised fuel furnaces can result in interference with burner light-up and operation.
- The build up of large accumulations of fused and partially fused ashes can interfere with the operation of stokers and fluidised bed combustors and can block ash hopper throats in pulverised fuel-fired furnaces. This can result in the need for unplanned outages for off-load cleaning.
- The deposition of fused or partially fused ash deposits on furnace heat exchange surfaces reduces furnace heat absorption, and leads to increased ash deposition and high metal temperatures in the convective sections of boilers, and it may be necessary to reduce load or to come off-load for manual cleaning.
- The accumulation and subsequent shedding of large ash deposits on upper furnace surfaces can lead to damage to the components of the lower furnace or the combustion system.

The accumulation of ash deposits at lower temperatures in the convective section of boilers also occurs. These are normally termed fouling deposits. Fouling reduces the heat absorption in the convective banks, and results in increased flue gas temperatures. Increased fouling also increases the gas-side pressure drop across the banks. Uncontrolled fouling will lead to ash bridging between the tubes. This further increases the gas-
side pressure drop and can result in the channelling of the flue gas. This, in turn, can result in local overheating of the heat exchange tubes and localised damage by particle impact erosion. The process involves the formation of deposits in which the ash particles are bonded by specific low melting point constituents, principally the alkali metal species of many biomass types. The gas temperatures are too low for significant sintering or fusion of the ash particles. In general terms, as the gas temperatures decrease through the boiler convective section, the deposits tend to be less extensive and physically weaker. This is reflected in the design of the convective section, i.e. it is possible to reduce the cross pitches of the tube banks as the flue gas temperatures decrease.

Ash deposits on heat exchange surfaces at very low flue gas temperatures tend to be relatively weakly bonded. They are commonly initiated by the physical accumulation of ash, often by the gravitational settling of ash material which has been dislodged from upstream primary deposition sites by the action of soot blowers. Low temperature fouling and corrosion of air heater surfaces in larger boilers are also common occurrences. These are complex processes and tend to be very specific to the design and operation of the air heater.

Deposit shedding and on-line cleaning
In all practical situations, the long-term accumulation pattern of deposits in furnaces and boilers involves competition between processes which tend to add to the deposit and those which remove material from deposits. Uncontrolled ash deposition, with no shedding or deposit removal would, in most plants firing solid fuels, very quickly result in operational problems, and most solid fuel furnaces and boilers are fitted with on-line cleaning systems of various types.

The natural shedding or detachment of deposits occurs when deposits grow too large for the adhesive forces to support them, or due to the effect of thermal expansion differences between the ash deposit and the boiler tube, during shutdowns and boiler load changes. Rapid boiler/combustor load changes can be deliberately used for deposition control. The detachment of large accumulations of slag in this way can, however, result in damage to components or in troublesome accumulations of ash lower in the furnace. Fly ash particle impact wear can result in the reduction of the thickness of fouling deposits, particularly on the sides of tubes.

The principal means of on-line control of deposition in most furnaces and boilers is the use of the installed soot blowers. These devices direct a high velocity jet of steam, water, or compressed air at the deposits, and employ a combination of mechanical impact and thermal shock to break up and remove them. Sonic soot blowers can also be deployed, particularly for the removal of relatively weak deposits in the cooler parts of the boiler convective section. In extreme circumstances, where very tenacious and troublesome ash deposits have formed, small explosive charges can be employed to break up the deposit material. The deposit material removed in this way may be carried forward with the flue gases, but can also accumulate elsewhere in the furnace or in the convective pass of the boiler.

Ash deposition control in biomass combustors and boilers is a fairly complex issue. It is important to carefully design the furnace and boiler convective section, to correctly recognise the characteristics and behaviour of the fuel ash. The incorporation of specific furnace and boiler design features, where appropriate, to minimise ash deposition, and to aid the removal of ash and the avoidance of ash accumulation within the system is also of key importance. Secondly, it is often preferable
to maintain the plants at a relatively low level of deposition, rather than to deploy the on-line cleaning systems only when there is evidence of significant deposition. Intensive cleaning of the furnace and boiler surfaces during outages can be very effective in increasing the operating times between outages. There are specialised on-line deposition monitoring and soot blowing control systems that are commercially available and that can assist significantly with the optimisation of the soot blower operations and the control of ash deposition.

**CORROSION, EROSION AND ABRASIVE WEAR**

Corrosion on the gas-side surfaces of boiler tubes is one of the most important issues in the design and operation of biomass combustion systems. There is increasing technical literature on this subject, particularly for fossil fuel-fired boilers [3], and increasingly for biomass boilers and for boilers co-firing biomass with fossil fuels, as the industrial importance of biomass utilisation for power generation and CHP applications has increased. It is of less importance for domestic and small commercial/industrial biomass boilers, which tend to operate at much lower heat exchanger temperatures.

**Corrosion mechanisms**

In general terms, it has been found that gas-side corrosion of boiler tubes is controlled by a number of factors:

- the tube material;
- the flue gas and metal temperatures, and the heat flux at the tube metal surface;
- the chemical composition of the ash deposit material at the metal-deposit interface;
- the chemical composition of the flue gases; and
- the operating regime of the plant.

For most biomass boilers that are well-designed and operated, the principal concern has been with the high temperature corrosion rates that apply in the superheater section of the boilers, principally because of the relatively high metal and gas temperatures that apply in these locations.

Compared to coal, the ash deposits that form on the superheater tube surfaces of a biomass-fired boiler tend to be rich in potassium salts (principally sulphates, chlorides, and phosphates, depending on the fuel composition and the gas and metal temperatures) with relatively high potassium contents and high chloride to sulphate ratios. This can have a significant impact on corrosion behaviour, particularly at high metal temperatures on superheater surfaces. In general, it is necessary, therefore, to design dedicated biomass boilers with final steam temperatures that are significantly lower than those that apply in large coal-fired boilers.

The most important corrosion mechanisms are:

- corrosion processes involving the reactions between the metal/metal oxides and gaseous chlorine species, i.e. Cl₂ and HCl;
- solid phase reactions involving alkali metal chlorides; and
- corrosion reactions involving molten alkali metal and other chlorides.

The experience from the operation of biomass boilers, particularly in Scandinavia, is that the most severe corrosion is commonly associated with ash deposits containing alkali metal chlorides on high temperature superheater surfaces. The deposits can be responsible for significant metal wastage rates at temperatures below the melting temperature of KCl. The corrosion mechanism is considered to be associated with the presence of low melting eutectic mixtures of salt and metal components.

Important and relevant information on these processes has been derived from plant experience and test work in three small straw-fired power plants using grates (Masnedo, Rudkobing and Ensted), the 80MWₜ CFB boiler at Grenaa where coal was co-fired with straw, and the 150 MWₑ pulverised coal boiler at Studstrup power station where straw was co-fired with coal, all in Denmark.
In the grate-fired units, corrosion rates for test materials of ferritic and austenitic steels varied between less than 50 nm/h at 470ºC to values in excess of 1000 nm/h at temperatures in excess of 600ºC [4],[5]. There were significant differences in the deposit morphologies and corrosion chemistry at different temperatures. At relatively low temperatures, up to around 520ºC, the normal, stable protective oxide layer was formed. At the higher temperatures, no stable protective oxide layer was formed, and rapid metal wastage by selective corrosion and grain boundary attack was observed. All of the alloys tested gave fairly similar corrosion rates, although there appeared to be a shallow optimum in corrosion resistance for alloys with chromium contents in the range 15-18%.

Similar experiences were obtained in the Grenaa CFB unit, where increased flue gas temperature due to increased thermal load led to excessive fouling and severe corrosion with selective chromium removal in the superheater metal. The suggested cause is sulphation of the solid phase KCl followed by the release of chlorine gas, or possibly HCl, adjacent to the metal surface.

The results of the corrosion test work performed during the straw:coal co-firing trials, at up to 20% straw on a heat input basis in a 150 MW, pulverised coal boiler at Studstrup power station are also relevant in this context. At Studstrup, however, the impact of co-firing straw at a co-firing ratio of 10% on the measured corrosion rates was modest. The evidence indicated that the potassium species released into the vapour phase in the flame reacted with silicate and alumino-silicate coal ash particles, to form potassium silicates and alumino-silicates, reducing the availability of the potassium for the formation of chlorides and sulphates local to the tube surfaces [6]. The chlorine released from combustion of the straw was present in the flue gases in the form of HCl, and possibly Cl₂.

The key difference between CFB at Grenaa and the pulverised fuel combustion at Studstrup is that the flame temperatures in pulverised fuel systems are considerably higher, and that this permits the interaction between the released potassium species and the other ash components (particularly sodium sulphates). Furnace gas temperatures in CFB systems are too low for substantial interaction of this type to occur. It should also be noted that the straw:coal co-firing ratio at Grenaa was significantly higher than at Studstrup and that the differences observed in the behaviour of the potassium and chlorine may also be related to the co-firing ratio.

It is clear, therefore, that the co-firing of biomass materials with coal introduces a risk of accelerated corrosion rates of high temperature boiler tubes, and that the risk is associated with the increased levels of available alkali metal species and chlorine released into the boiler flue gases. Under unfavourable circumstances, such as at Grenaa, the impact of the accelerated metal wastage can be dramatic and there can be significant impacts on the operation and integrity of the plant. These risks appear to be lower in pulverised fuel-fired boilers using biomass fuels with lower ash, potassium, and chlorine contents at low co-firing ratios.

Overall, therefore, there is evidence from both laboratory and plant scale experimental work, and plant experience (particularly at Studstrup Power Station in Denmark, where cereal straws and other baled materials are co-fired with coal at a co-firing ratio up to around 10% on a heat input basis) that the co-firing of biomass materials at low co-firing ratios has only had a very modest impact on the gas-side corrosion rates of high temperature boiler surfaces.

Preventive and remedial measures for fireside corrosion

The conventional approach to the control of superheater corrosion is by selection of the appropriate combination of tube materials and final steam temperatures for the fuel being fired. For instance, in modern incineration plants for municipal solid wastes, where the flue gases and ash deposits are extremely aggressive, it is common practice to limit the final steam
temperatures to around 400ºC, and to protect leading tubes in the final superheater against corrosion and erosion processes with SiC sleeving. Modern biomass-fired boiler plants commonly have final steam temperatures in the range 450-540ºC, depending principally on the characteristics of the fuel and the materials selected for the construction of the final superheater elements. These are design decisions taken by the boiler supplier, based on previous experience and the best technical information available.

The use of fireside additives to modify the chemistry of the ash deposits may be of some benefit. This is common practice, for instance, in oil-fired boilers, where magnesia-based additives are fairly commonly employed to reduce the rates of metal wastage associated with the relatively aggressive vanadium oxides and sulphates in the oil ash deposits. Vattenfall has recently developed a fireside additive which has been of some value in reducing the active chloride concentration in biomass-fired boilers and possibly waste incineration plants, and which may have wider application [7]. They reported the use of a proprietary liquid fireside additive, ChlorOut, which was effective in removing KCl from the flue gases, but had only a small effect on the SO₂ concentration and on the pH of the flue gas condensate. The results of 1000-hour corrosion tests in a 100 MWth bubbling fluidised bed boiler firing demolition wood, forestry residues and coal in Sweden indicated that there was a significant reduction in the measured corrosion rates when the additive was applied. Vattenfall are currently applying the ChlorOut system, comprising the liquid additive and delivery system, with an in-furnace alkali chloride measurement system, in biomass boilers and waste incineration plants.

**Erosion and abrasion**

The erosion and abrasion of boiler components and other equipment in solid fuel-fired plants, at all scales of operation, is associated predominantly with the presence of quartz particles in the fuels and ashes, which are harder than the steels and refractory materials employed for the construction of the interior surfaces in the boiler, as well as the fuel handling equipment. One example is rice husk, which has a particularly high quartz content.

The fly ashes from biomass combustion tend, in the main, to be in very fine particulate form and relatively soft, and are not considered to be particularly abrasive or erosive in nature on the boiler tubes and components of the ash handling systems.

The formation of fused ash material, particularly the bottom ashes from grate-fired systems, can cause erosion and abrasion damage to the components of both mechanical and pneumatic ash handling systems.

In biomass boiler systems that suffer severe convective section fouling problems, excessive rates of particle impact, erosive wear of boiler tubes and erosive wear associated with the regular use of convective pass soot blowers in an attempt to control the impact of the fouling are common.

In general terms, however, the experience has been that the ash abrasion and erosion problems associated with the utilisation of the great majority of biomass materials are significantly less important than those experienced when firing more conventional solid fuels.

**THE IMPACT OF ASH ON FLUE GAS CLEANING EQUIPMENT**

While the flue gas cleaning systems of dedicated biomass combustion systems are specifically designed to deal with the characteristics of the flue gas, problems may arise when co-firing biomass in an installation that was originally designed to burn other fuels. This is particularly the case when co-firing biomass materials at significant co-firing ratios in the larger scale combustion systems and boilers originally designed for the combustion of conventional fossil fuels. It particularly affects the following equipment/processes:
• total particulate emissions control, principally using dry electrostatic precipitators or fabric filters;
• NOx emissions control to concentrations, by both primary and secondary measures, with Selective Catalytic Reduction (SCR) being the most commonly applied secondary measure; and
• the control of SOx emission levels, principally by wet, dry, and semi-dry Flue Gas Desulphurisation (FGD) techniques.

ESP performance
With regard to the performance of electrostatic precipitators, the principal technical concern is that the fly ash particles generated from biomass combustion tend to be different chemically from pulverised coal ash, are significantly smaller than those from coal firing, with a greater tendency towards the generation of significant levels of sub-micron fumes and vapours. There may, therefore, be a tendency for the particle capture efficiency in electrostatic precipitators to decrease with increasing co-firing ratio and for the total particulate emission levels to increase accordingly. For the relatively low co-firing ratios (up to 10% of heat input) achieved today this is not problematic, but for higher co-firing ratios modifications to the installed particulate collection equipment may be required.

SCR catalyst deactivation
The performance and lifetime of SCR catalysts is influenced by a number of factors, many of which are fuel related [8]:
• thermal degradation by pore sintering;
• ammonia salt condensation inside catalyst pores due to low temperature operation;
• the surface blocking of catalyst pores by small ash particles;
• poisoning of catalyst surfaces by volatile inorganic species; and
• fly ash particle impact erosion of catalyst material.

Early experiences of the use of SCR catalysts in wood chip and peat-fired boilers in Scandinavia, and of boilers firing animal manures and sludges, indicated that deactivation of the catalysts by sodium and potassium salts, and by phosphorus and silica compounds was a significant issue, resulting in markedly reduced catalyst lifetimes and increased operating costs [9], [10].

A number of laboratory and plant tests on the impact of biomass co-firing at high percentages on the fouling and deactivation of catalysts clearly confirmed that the surface concentrations of calcium, sulphur, sodium, and phosphate compounds on the catalyst material increased after prolonged exposure to the flue gas, resulting in significant deactivation of the catalyst. At the biomass co-firing levels that currently apply in large power plants, i.e. generally lower than 10% on a heat input basis, there have not, as yet, been any significant operational problems, and the results of a number of side stream tests at low co-firing ratios on operating plants have been relatively encouraging in this regard.

In the event of significant catalyst deactivation, it is possible to water wash the catalyst blocks to remove soluble alkali metal and other salts, and hence largely recover the catalyst activity and catalyst life. At Avedøre power station in Denmark, where co-firing of wood pellets is done with heavy fuel oil and natural gas, a water washing system for the SCR catalyst blocks has been in successful commercial operation for a number of years [11].

The impact of biomass co-firing on FGD plants
The evidence to date from coal-fired power plants co-firing clean biomass materials, albeit at relatively low co-firing ratios, has been that co-firing has had no significant negative impact on the operation and performance of the FGD plants, including lime/limestone usage and waste water treatment. This is due to the typically lower amount of sulphur, chlorine, key trace elements, and heavy metal species than that found in coal.
CONCLUSIONS
Inorganic matter in biomass can have a decisive impact on the design and operation of a combustion installation. It is particularly important to select the right metals and steam conditions to minimise corrosion processes when burning a given fuel. The ash deposits that form on the superheater tube surfaces of a biomass-fired boiler tend to be rich in potassium salts, principally sulphates, chlorides, and phosphates, depending on the fuel composition and the gas and metal temperatures, with relatively high potassium contents and high chloride to sulphate ratios. This can lead to serious corrosion problems.

When biomass is however co-fired with coal in a pulverised coal power plant at modest percentages as is happening today (less than 10% on heat basis), typically no serious corrosion problems are to be expected as potassium species released into the vapour phase react with silicate and alumino-silicate coal ash particles, to form potassium silicates and alumino-silicates. This reduces the availability of potassium for the formation of chlorides and sulphates local to the tube surfaces. For higher percentages however, significant ash deposits and corrosion problems could in principle occur, depending on the chemistries of the coal and biomass ashes. The positive effect of sulphur in reducing chlorine corrosion and ash deposition is also used in ChlorOut, a sulphur-based additive used by Vattenfall.

However, when straw is co-fired in fluid bed furnaces, the combustion temperature is typically too low for the potassium species in the vapour phase to react with silicate and alumino-silicate coal ash particles. If a high chlorine-containing fuel is co-fired in large quantities, this may lead to serious corrosion if the boiler tube material is not properly chosen.

Slagging and fouling processes in boilers can also cause significant operational problems. This can particularly be expected when burning a fuel with a low ash melting temperature such as poultry litter. The deposition of the sodium and potassium compounds by a volatilisation/condensation mechanism is considered to be the principal driving force for convective pass fouling in boilers.

REFERENCES

