

Fireside Issues Associated with Coal-Biomass Cofiring

**A. Robinson, L. Baxter, H. Junker,
and C. Shaddix**
Sandia National Laboratories

M. Freeman and R. James
Federal Energy Technology Center

D. Dayton
National Renewable Energy Laboratory



National Renewable Energy Laboratory
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Golden, Colorado 80401-3393
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FIRESIDE ISSUES ASSOCIATED WITH COAL-BIOMASS COFIRING*

A. Robinson; L. Baxter; H. Junker; C. Shaddix; M. Freeman;

R. James; and D. Dayton.

National Renewable Energy Laboratory, Golden, CO

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Abstract

This document describes the motivations for and the effects of cofiring biomass with pulverized coal (pc) in pc-fired boilers. Such cofiring represents a near-term, low-risk, low-cost option for reducing the net CO₂ emissions from the power generation sector. This document focuses on four of the critical fireside issues associated with cofiring: ash deposition, NO_x production, corrosion, and carbon burnout. Specific guidelines are suggested in each of these areas.

Pilot-scale data indicate that biomass ash deposition rates and NO_x emissions can either exceed or be less than those of coal, depending on the type of biomass used. The potential for chlorine-based corrosion is seen to be less significant for cofire blends than for pure biomass fuels in most cases, but may not always be negligible. Biomass particles much larger than coal particles can be consumed in a pc boiler, but at sizes of 1/8 inch or larger there is increased chance of incomplete combustion.

Prudent choices of fuels, boiler design, and boiler operation should lead to little or no fireside problems during cofiring. Less prudent choices can lead to significant boiler damage and operational costs.

INTRODUCTION

Concerns regarding the potential environmental impact of fossil fuel use for power generation and other energy supplies are increasing in the US and abroad. One resolution of these concerns is increasing the fraction of renewable and sustainable fuel in the national energy budget. Traditionally, renewable energy sources struggle to compete in the open markets with fossil energy. Furthermore, many renewable energy technologies suffer from low efficiencies and/or high technical risk. This investigation examines

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cofiring, a technology that utilizes a combination of renewable and fossil energy to derive the greatest benefit from both fuels. By utilizing existing coal-fired utility boilers, cofiring dramatically increases the potential market for renewable energies significantly beyond the realistic market for dedicated biomass systems. In addition, the efficiency of power generation from biomass will increase relative to existing and many future stand-alone biomass power systems. Ancillary benefits include increased use of local resources for power, decreased demand for disposal of residues, and continued use of the large, reliable, and proven coal-based capacity that is the current backbone of the US power system.

The advantages associated with cofiring can be realized in the very near future with very low technical risk. However, improper choices of fuel, boiler design, or operating conditions could minimize or even negate many of these advantages while putting the boiler at risk. This investigation reviews the primary fireside issues associated with coal-biomass cofiring and provides guidelines regarding its implementation.

FUEL CHARACTERISTICS

The fuels investigated in the experimental portions of this work range from woody (ligneous) to grassy and straw (herbaceous) materials. The former are generally the most easily adopted to pc-firing conditions while the latter represent opportunity fuels presently available in large quantities as agricultural residue sources. Biomass fuel properties vary significantly more than those of coal do. As examples (see Figure 1 and Figure 2), ash contents vary from less than 1% to over 20% and fuel nitrogen varies from around 0.1% to over 1%. Other notable properties of biomass relative to coal are: high moisture content (usually greater than 25% and sometimes greater than 50% as-fired), potentially high chlorine content (ranging from essentially 0 to 2.5 %), relatively low heating value (typically half that of hv bituminous coal), and low bulk density (as little as one tenth that of coal per unit heating value). These and other properties must be carefully considered for successful implementation of cofiring.

RESULTS AND DISCUSSION

The fireside issues examined here center around pollutant production, ash deposition, carbon conversion, and corrosion. Highlights, representative data, and major conclusions and guidelines in each of these areas are summarized. More detailed discussions and descriptions of the experimental facilities appear elsewhere [1]. The data presented here are derived from pilot- and bench-scale experiments, but the results and conclusions are consistent with commercial experience both in the US and abroad [2-6].

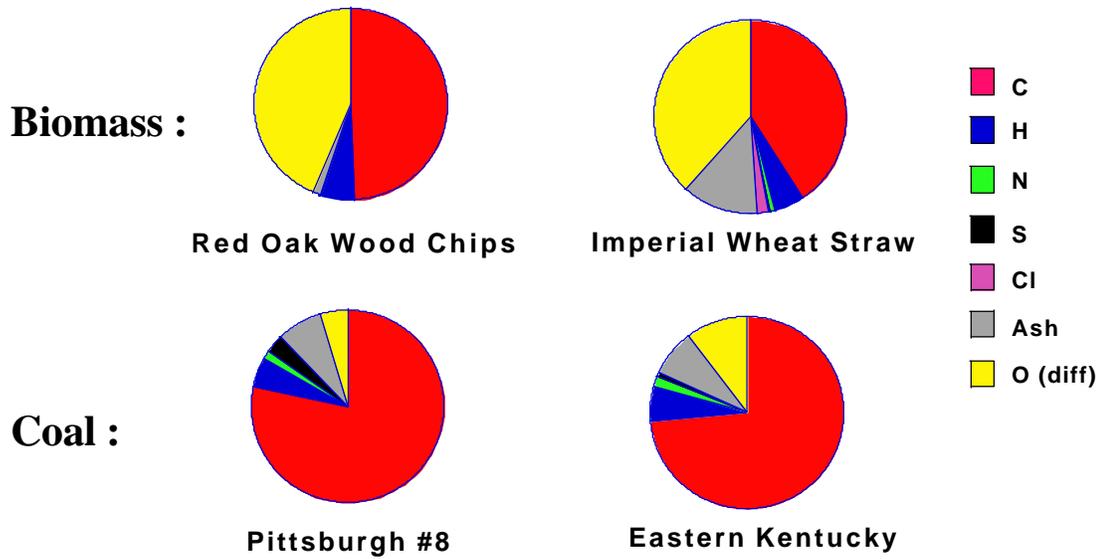


Figure 1 Typical ultimate analyses of biomass and coal fuels.

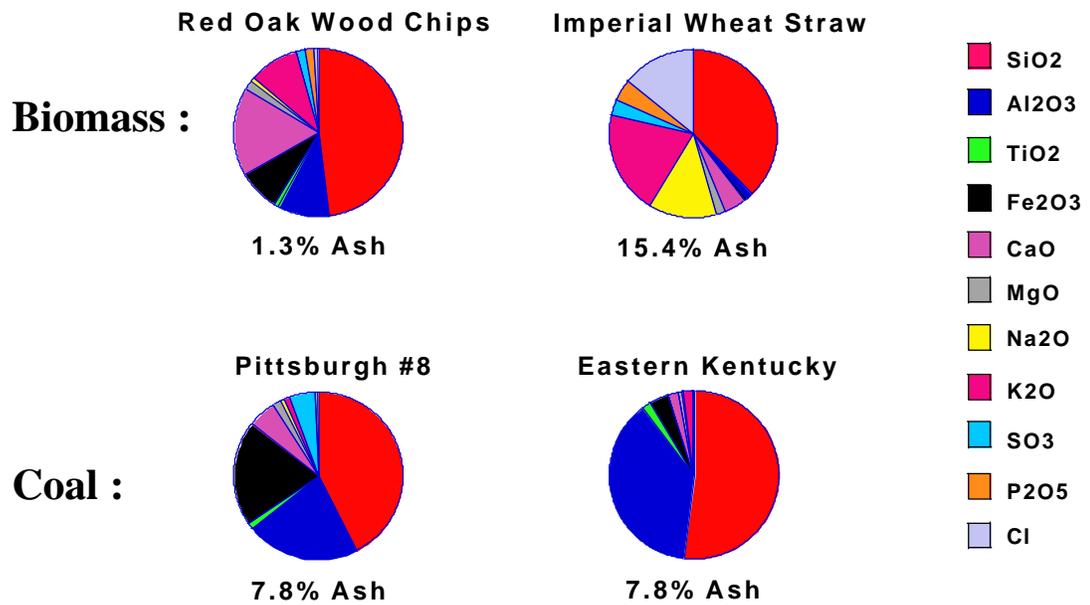


Figure 2 Typical inorganic composition of biomass and coal fuels.

Pollutant Production

Pollutant production investigated here includes emissions of both SO_x and NO_x . Because of the negligible sulfur content of most biomass fuels, SO_x emissions almost uniformly decrease when cofiring, often in proportion to the biomass thermal load. An additional incremental reduction beyond the amount anticipated on the basis of fuel sulfur content is sometimes observed and is based on sulfur retention by alkali and alkaline earth metals in the fuels [2]. Some forms of biomass contain high levels of these materials. The SO_x emissions are straightforward and are not illustrated in detail here.

NO_x emissions are more difficult to anticipate than SO_x . Experimental characterization of NO_x emissions during combustion of neat coal, neat biomass, and various blends of the fuels in a pilot-scale facility illustrate that NO_x emissions from biomass can either exceed or be less than those of coal. Figure 3 presents data for blends of switchgrass (a herbaceous fuel) and coal. These data indicate that NO_x emissions produced while cofiring can vary in fairly complex manner with stoichiometry. Firing low-nitrogen wood fuels typically results in lower NO_x emissions than most coal fuels. When analyzed on a lb. NO_x per unit energy production basis instead of a ppm basis, NO_x emissions from biomass fuels increase disproportionately compared to coal due to the lower energy content of biomass fuels. Still, even on an energy basis, wood fuels generally produce low NO_x emissions than coal and herbaceous fuels may be higher or lower, depending on overall combustion stoichiometry and fuel nitrogen content.

The large difference in fuel oxygen contents between biomass and coal suggest that blends of coal and biomass could produce quite different results than would be expected based on the behavior of the individual fuels. However, our data suggest there is no significant chemical interaction between the off-gases. Figure 4 compares the measured NO_x emissions for a variety of coal-biomass blends with those predicted from the behavior of the pure fuels. Points that fall along the diagonal indicate no significant interaction. Importantly, all of these experiments were conducted without low- NO_x burners, fuel/air staging, reburning, etc. The results indicate that NO_x emissions from blends of coal and biomass interpolate quite accurately between the measured behaviors of the neat coal and biomass fuels if no low- NO_x burner, fuel staging, or boiler technology is used. Since biomass produces a significantly larger volatile yield than coal, there is potential for biomass to be effective in creating large fuel-rich regions useful for NO_x control. The biomass fuels best suited for use in pc boilers are woods; most of which reduce total NO_x emissions significantly below that from coal.

The guidelines relative to NO_x emissions include: (1) there is insignificant chemical interaction between the offgases from biomass and coal that would alter NO_x emissions; (2) NO_x emissions from the most well-suited biomass fuels for cofiring (wood residues) generally are lower than those from coal, leading to some overall NO_x reduction relative to coal during cofiring; and (3) the large volatile yield from biomass can be used to lower NO_x emissions during cofiring through well-established, stoichiometric-driven means.

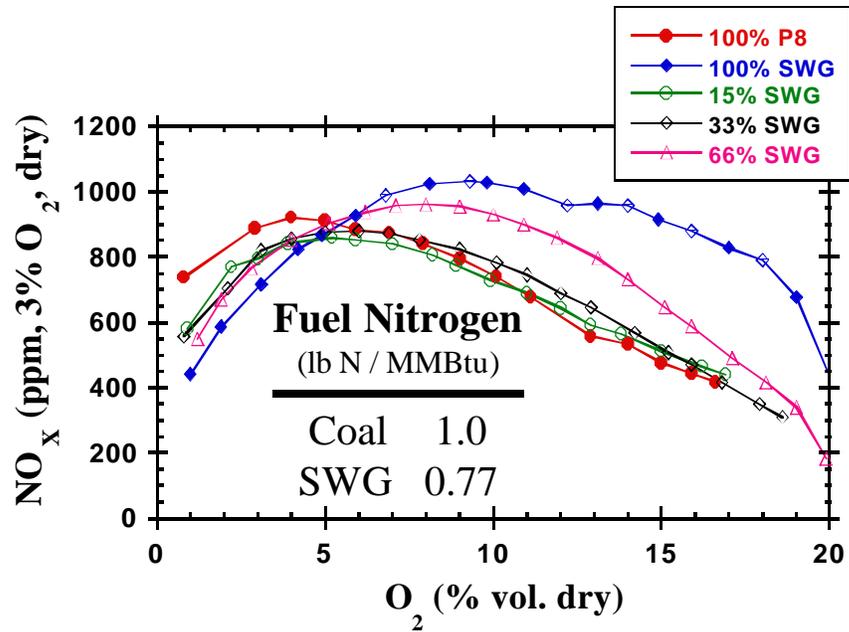


Figure 3 NO_x emissions during coal and biomass cofiring as a function of furnace exit gas oxygen content. No NO_x mitigation techniques such as low- NO_x burners, reburning, air/fuel staging, were used during these experiments.

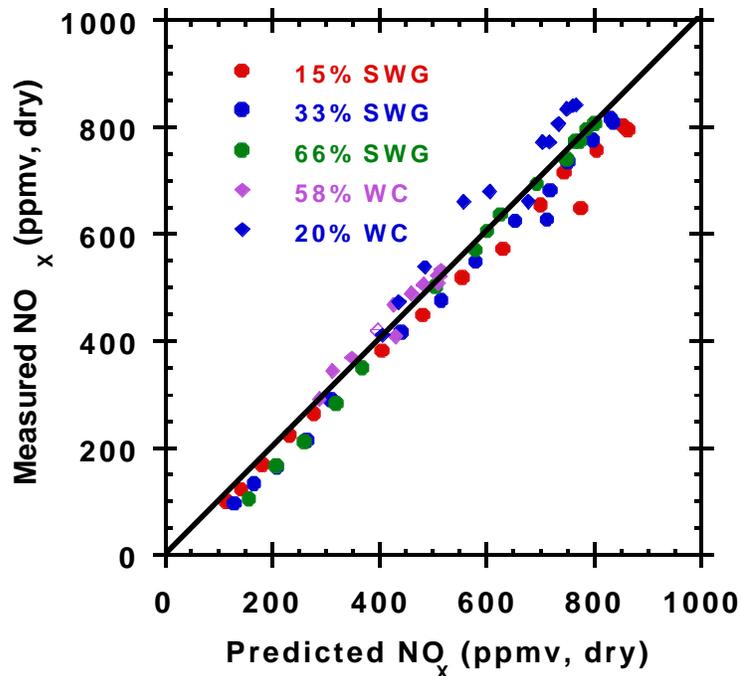


Figure 4 Comparison of measured NO_x concentrations to concentrations interpolated (predicted) from the measured behavior of the pure fuels. Data along the diagonal line indicate no interaction between the fuels.

Ash Deposition

Ash deposition rates from biomass fuels can greatly exceed or be considerably less than those of coal. Figure 5 illustrates rates of deposit accumulation during standardized experiments on simulated superheater tubes. Absolute deposition rates from some herbaceous fuels exceed that of coal under identical conditions by about an order of magnitude whereas deposition rates for high-quality woods are nearly an order of magnitude less than that of coal. These trends are in part attributable to the ash contents of the fuels. When normalized for differences in ash content, ash deposition efficiencies of herbaceous materials still exceed those of coal whereas that of wood is lower. These trends can be described in terms of ash particle sizes and chemistry. Deposition rates from blends of coal and biomass lie between the observed rates for the neat fuels but are generally lower than one would expect if interpolating between the behavior of the neat fuels. Experimental evidence supports the hypothesis that this reduction in ash deposition occurs primarily because of interactions between alkali (mainly potassium) from the biomass and sulfur from the coal. Some of these data are presented in the discussion of corrosion.

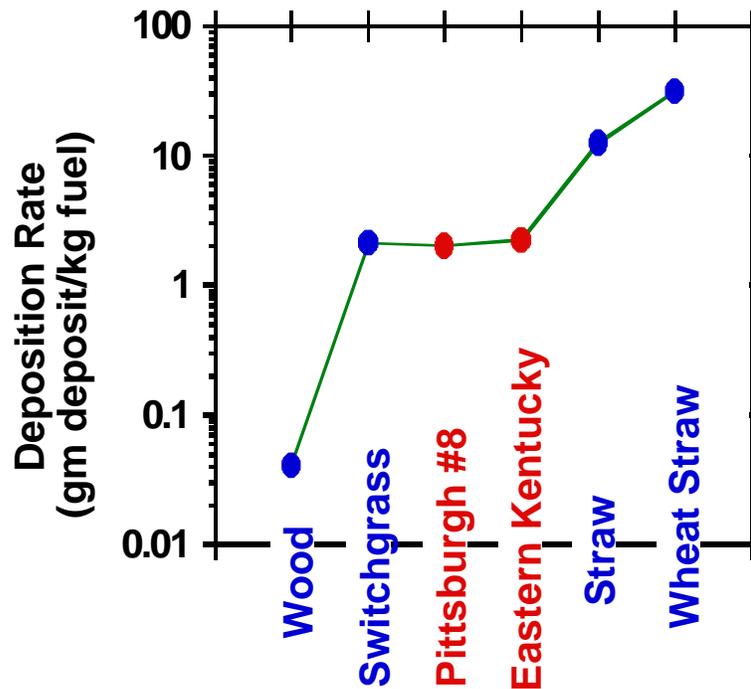


Figure 5 Rates of deposit accumulation during standardized investigations on simulated superheater tubes in the Multifuel Combustor.

The guidelines relative to ash deposition include: (1) deposition rates should decline when cofiring wood or similar low-ash, low-alkali, low-chlorine fuels; (2) deposition rates

should increase when cofiring high-chlorine, high-alkali, high-ash fuels, such as many herbaceous materials; and (3) deposition rates depend strongly on both individual fuel properties and interactions between the cofired fuels.

Carbon Conversion

It is impractical to reduce most biomass fuels to the size of pulverized coal. A small fraction of such fuels, such as sander dust, are available in small sizes because of upstream processing. The great majority of fuels will require size reduction. Size reduction of biomass is nearly always more energy intensive than for coal. A concern regarding overall burnout of the biomass fuel arises because pulverized coal particles are much smaller than the practically achievable sizes for biomass fuels.

Biomass and coal are consumed by both thermal decomposition (devolatilization) reactions and by char oxidation (Figure 6). A larger fraction of biomass is released as volatile gases during combustion (85-95 % of initial particle mass) than is released from coal (50-65%). This large volatile yield occurs over a relatively short time and significantly decreases the time required for complete combustion compared to a coal particle of similar size. The largest fraction of biomass and coal combustion history involves char oxidation. Experimental data indicate that biomass chars burn under strongly diffusion controlled conditions, as is consistent with theory. However, the rates of combustion differ from that of coal owing to its generally nonspherical shape and lower char density, both of which effects can be reasonably well modeled (Figure 7). Furthermore, the slip velocity between char particles and local gas is higher for biomass than coal, increasing the effective residence time of a char particle for combustion.

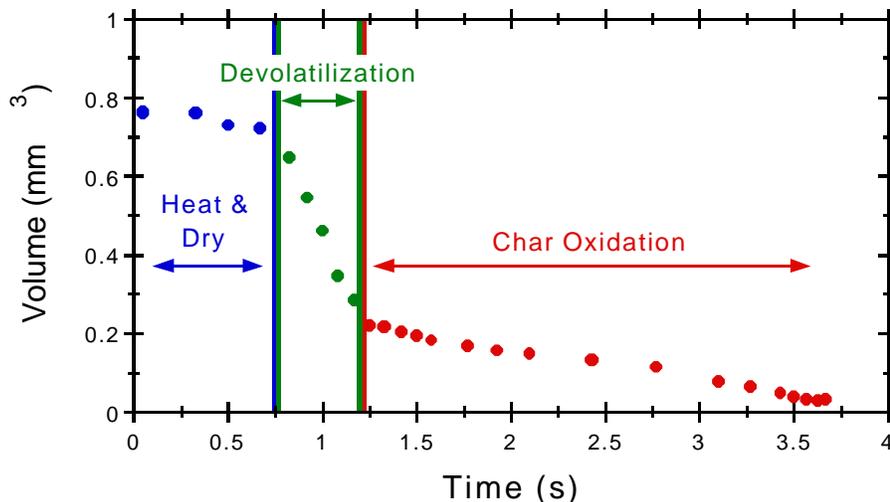


Figure 6 Combustion history of a typical biomass fuel particle (switchgrass in this case) illustrating the major stages of combustion. Coal has a similar history.

Moisture content also significantly impacts biomass burnout time. Devolatilization, while slower for biomass than coal, is generally much shorter than either drying or char combustion. The increased time for biomass devolatilization relative to coal is hypothesized to be associated with intra-particle temperature gradients in the relatively large biomass particles.

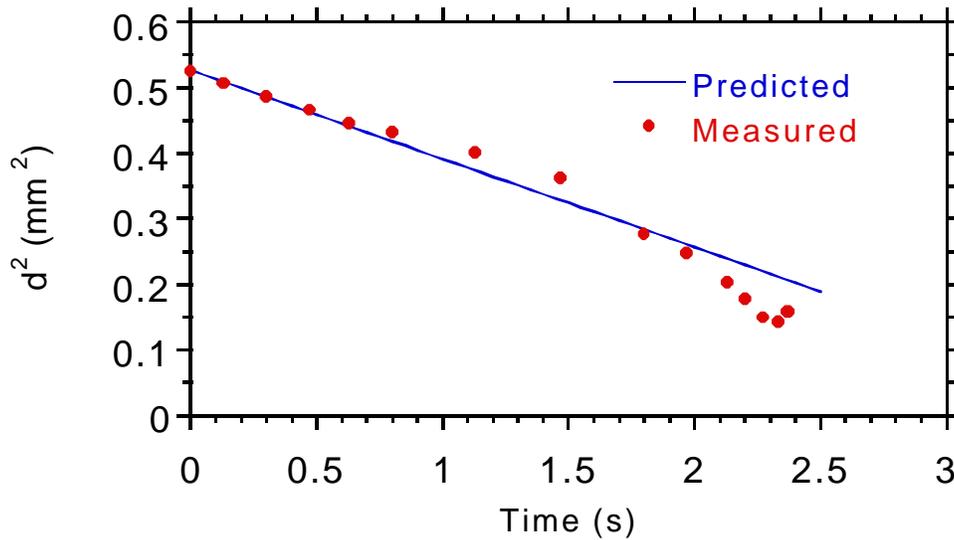


Figure 7 Comparison of measured biomass char (switchgrass) combustion history and that predicted by a recently developed theoretical model.

The guidelines relative to carbon conversion derivable from this work include: (1) particles prepared with top sizes greater than 3 mm (1/8 inch) will experience increasing difficulty completing combustion, with significant residual carbon expected at sizes greater than 6 mm (1/4 inch) as measured by the smallest dimension in the typically nonspherical particles; (2) fuels with moisture contents exceeding 40% will need to be reduced further in size to achieve complete combustion; and (3) biomass char burning rates are controlled by geometry and size, not kinetics, making burning rates essentially fuel independent if size, shape, density, and moisture contents are the same.

Corrosion

The high chlorine and alkali contents of some biomass fuels raise concerns regarding corrosion. The greatest concern focuses on high-temperature corrosion of superheater tubes induced by the presence of chlorine on the tube surface. The corrosion aspects of this investigation characterized chlorine concentration in the deposit and its dependence on operating conditions. The data indicate that the amount of chlorine in the deposit decreases sharply with increasing sulfur content, and that cofiring a high-chlorine, low-sulfur biomass fuel with a sulfur-containing coal often results in deposits with very low chlorine concentration. The stoichiometry of the overall chemical reaction between alkali chloride and sulfur defines a parameter describing the potential chlorine concentration in a

deposit as a function of fuel properties (Figure 8). At values greater than unity, this parameter indicates that very little chlorine should remain on the heat transfer surface. As values decrease from unity, significant chlorine is predicted to remain on the surface. As indicated in the figure, the data support this theory. This parameter provides a quantitative guideline for preventing chlorine deposition on surfaces, and hence accelerated corrosion. It is a function of total fuel chlorine content, available (not total) alkali content and total sulfur content.

The guidelines relative to avoiding chlorine-based corrosion in a boiler are; (1) fuel chlorine should be minimized in all cases; (2) the parameter discussed above should be maintained at values above about 4; and (3) tube surface temperatures should be kept as low as possible.

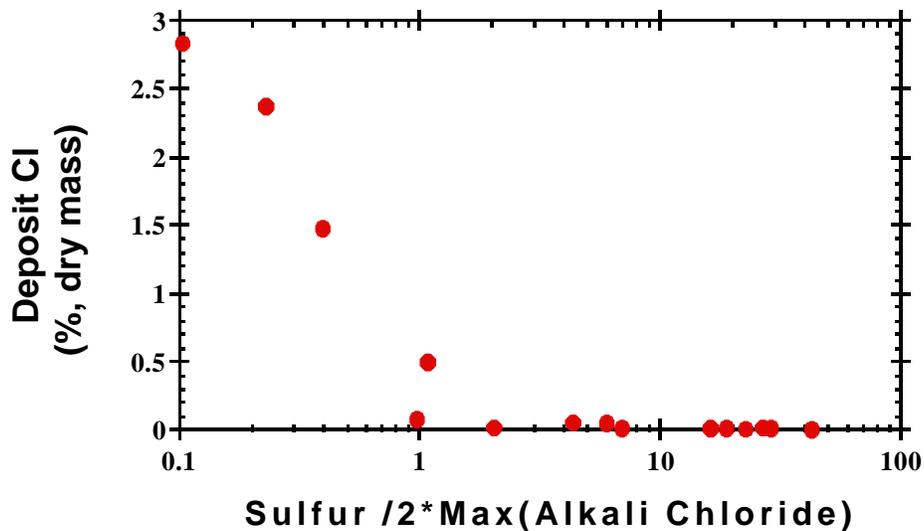


Figure 8 Illustration of deposit chlorine content as a function of a parameter determined from the fuel sulfur, chlorine, and available alkali content.

CONCLUSIONS

This work demonstrates that the potential advantages of biomass-coal cofiring, as outlined above, can be achieved without risk to the boiler if judicious choices regarding fuel selection, boiler operation, and boiler design are made. Conversely, non-judicious choices can lead to potential risk for the boiler and troublesome operation. The most promising fuels for cofiring are high-quality woods. Careful attention to boiler operation and fuel selection is required as fuel properties move more toward those typical of some high-alkali, high-chlorine, high-ash, and high-nitrogen forms of biomass.

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