COFIRING WASTE BIOFUELS AND COAL FOR EMISSIONS REDUCTION

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ABSTRACT

Combustion tests have been performed in two pilot-scale combustion facilities to evaluate the emissions reduction possible while firing coal blended with several different biofuels. Two different boiler simulations, pulverized coal fired boilers and stoker coal fired boilers, were simulated. The pc-fired studies investigated the use of waste hardwood, softwood and sludge as potential reburning fuels and compared the results with coal and natural gas. The use of these wood wastes is attractive because: wood contains little nitrogen and virtually no sulfur; wood is a regenerable biofuel; wood utilization results in a net reduction in CO_2 emissions; and, since reburning accounts for 10-20% of the total heat input, large quantities of wood are not necessary. The results of this program showed that a reduction of 50-60% NO was obtained with approximately 10% wood heat input. Reburn stoichiometry was the most important variable. The reduction was strongly dependent upon initial NO and only slightly dependent upon temperature.

The stoker program investigated barriers for the successful blending of coal with waste railroad ties. Parameters evaluated included blending firing rate, chip size, optimum feed location, overfire/underfire air ratio, and natural gas addition. The results of this study demonstrated that NO emissions can be reduced by more than 50% without any significant increase in CO or THC emissions by the proper use of zoned reburning.

Both programs demonstrated several benefits of biofuel blends, including: 1) lower operating costs due to reduced fuel prices; 2) reduced waste disposal; 3) reduced maintenance costs; 4) reduced environmental costs; and 5) extension of the useful life of existing equipment.

INTRODUCTION

Reburning is a combustion modification technology which removes NO_x from combustion products by using fuel as the reducing agent. The concept was originally introduced by John Zink Company[1] and Wendt et al.[2], based on the principle of Myerson et al.[3] that CH fragments can react with NO. Reburning is accomplished by secondary fuel injection downstream of the fuel-lean primary combustion zone. The second stage or reburning zone is usually operated at overall fuel-rich conditions, allowing a significant fraction of the primary NO to be reduced to N_2 and other nitrogenous species. In the third zone, additional air is introduced to establish overall fuel-lean conditions and allow for the burnout of remaining fuel fragments.

Reduction of NO occurs primarily in the reburn zone by reaction of NO with hydrocarbon fragments (CH, CH_2). These reactions typically produce hydrogen cyanide which decays in the reburning zone along the chemical pathway

$$NO + CH_i \Rightarrow HCN \Rightarrow NCO \Rightarrow NH \Rightarrow N \Rightarrow N_2$$

This reburning concept is utilized in both experimental projects presented herein.

The waste biofuels that were tested include: pulverized hardwood and softwood waste from wood manufacturing, a wood-derived sludge, and chipped railroad ties. Discarded railroad ties represent a significant alternate energy resource and are available throughout the U.S. The wood manufacturing waste and wood-derived sludge materials are transportable but generally only available near the manufacturing locations. These and other similar products can be removed from the waste stream and can be significant alternative fuel sources. For example, approximately 16 million railroad ties are discarded or abandoned per year in the U.S., with a potential energy availability from RTDF of $2x10^{13}$ Btu/yr; equivalent to fueling a 350 MW power station.

Generally, the cost of these waste fuels is approximately 50 percent of coal on an energy basis. The wood-derived sludge is even less expensive, although its use may involve drying costs due to high moisture content (~65%). Although the cost incentive is apparent, the process parameters controlling the replacement of coal with biofuel wastes in boilers have not been defined. The purpose of these projects was to develop an understanding of the combustion of biofuels in conjunction with coal on stoker grates and in pc-fired boilers in order to define retrofit hardware that will allow replacement of coal and concurrent pollutant emissions reduction.

APPROACH

Experiments were carried out in two facilities which are described below. Gaseous and solid samples were withdrawn from both furnaces at various locations. Gas samples were withdrawn through a water cooled, stainless steel probe, then filtered and dried. The gas sample was analyzed for NO (chemiluminescence), O_2 (paramagnetic), CO (NDIR) and N_2O/NH_3 (FTIR). Temperatures are measured throughout each furnace with bare-wire, type-B thermocouples and a moveable suction pyrometer probe.

Pilot Scale Spreader-Stoker

The pilot-scale spreader stoker facility, shown in Figure 1, is 3.2 m high and the stoker has a 0.09 m^2 grate. The furnace was designed to fire at rates from 126,000 to 252,000 kcal/hr. The base of the furnace provides support and houses the ash drawer. Air is injected under the grate and at various heights above the grate. Ports vertically located along the furnace allow for the addition of fuel and air for secondary burning. Coal was fed from the hopper via a metering auger to a rotating multi-vane spreader. Railroad ties were weighed into discrete predetermined quantities and fed into the stoker via the coal chute. The spreader is located 0.8 m above the bed and distributes the solid fuels uniformly across the bed. All of the furnace sections contain multiple ports for sample extraction, observations, and overfire air or natural gas injection. Three different stoker configurations were used: industrial, 2-U, and 2-N. In the 2-U configuration, overfire air was through the main gas burner ports and 2.2 m above the bed; reburning natural gas was injected 1.8 m above the bed. In the 2-N configuration, overfire air was added 1.8 and 3.2 m above the bed; natural gas was injected 2.2 m above the bed.

Pilot Scale Pulverized Coal Furnace

Figure 2 shows the 38 kW, pulverized coal fired combustion research facility at the University of Utah. The main burner is located at the top left section and is down-fired. Access ports are available along the entire length of the furnace. The combustion chamber is 16 cm diameter and 7.3 m long and is constructed of composite refractory walls to minimize heat loss. The furnace is divided into three sections. The first section is the primary section where the main fuel burns at overall fuel-lean conditions. The second section is called the reburning section which begins at the point of injection of the reburn fuel (typically in the horizontal section of furnace as shown in Figure 2). The third section is the burnout section into which air is added to achieve overall fuel-lean conditions for burnout of the remaining fuel fragments.

Solid fuels were transported to the furnace by a transport fluid (usually air) which was laden with the solid fuel that was metered by a twin screw feeder. The feeder is a volumetric feeder with a variable speed motor that was calibrated for mass flow rates of each of the fuels tested.

Objectives

The objectives of this paper are to report on experimental results which: 1) determine the feasibility of cofiring coal with waste biofuels, 2) compare the effectiveness of these fuels to natural gas in reburning, and 3) establish performance goals for the co-firing of coal and waste biofuels for emissions and waste reduction in both spreader-stoker and pc-fired boiler environments.

RESULTS

Stoker Experiments:

Initially, coal alone, and coal blended with hogged railroad ties were evaluated under typical industrial conditions where the overfire air was divided into two approximately equal segments above and below the spreader. Hogged railroad ties were fired with coal in an 80/20 coal/railroad ties ratio. Figure 3 presents the NO_x and CO emissions measured for these tests.

Under clean operating conditions (greater than 50 percent excess air and CO emissions less than 20 ppm), the NO_x emissions were lowered by about 30% with coal/railroad tie co-firing. This is likely due in part to the fact that the railroad ties contained essentially no nitrogen (0.22 percent).

The CO data (Figure 3) suggests that at low excess air levels the RTDF mix burns more completely. This is likely due to the presence of increased fines and the partially oxygenated nature of the wood fuel. The corresponding total hydrocarbon data for these fuels, tested at the commercial practice conditions, indicated there was little difference in the total hydrocarbon emissions for the co-firing case compared to the coal only case (the total hydrocarbon emissions were less than 20 ppm).

Application of Low NO_x Concepts - Reburning

To evaluate the applicability of the low-NO_x concepts described earlier, a series of co-firing experiments was conducted with 20 percent railroad ties in conjunction with natural gas addition. Figure 4 shows the NO_x and CO emissions for the RTDF/coal blend at an overall stoichiometric ratio of 1.28 and varying amounts of natural gas injection in the upper furnace. With 15 percent natural gas co-firing, the NO_x emissions were reduced to about 0.25 lbs NO_x/MBtu in this configuration and the CO was approximately 50 ppm. The baseline NO_x emissions were approximately 0.45 lbs/MBtu with a CO level of about 50 ppm for the coal only case. Also, CO concentrations decrease significantly with increased gas utilization.

The experience in this study suggests that a properly designed system could likely accommodate railroad tie feed rates higher than 20%. No problems with either bed slagging or other pollutant emissions were observed at the rates tested in this study. In a future test program, it would be desirable to investigate waste fuel firing rates up to 50 percent in this small scale unit to determine whether there are important scientific or practical reasons to limit the waste-fuel firing.

PC-fired Experiments:

Experiments conducted in the pc-fired facility (Figure 2) were preformed without blending of the primary fuel with the waste biofuel. The biofuels were fired separately (and individually) in the reburning zone in each case.

Reburn Stoichiometry

The parameter that most dramatically influences the effectiveness of wood reburning is the stoichiometry in the reburn zone. The stoichiometric ratio (SR) in the reburn zone is determined by calculating the amount of oxidant required to convert all of the elements of the wood, the wood carrier, and the baseline products from the primary zone to carbon dioxide and water. Stoichiometric ratios less than 1 indicate fuel-rich conditions, while $SR > 1.0$ indicates excess air conditions. Figure 5 presents the effect of reburn stoichiometry for reburning with hardwood at various temperatures. The variation in temperature was accomplished through movement of the position of the reburning zone in the furnace, with higher temperatures corresponding to reburn zones that are closer to the primary zone. In each of the cases the residence time in the reburn zone is held constant at about 400 ms. Notice that wood reburning is more effective at lower stoichiometries corresponding to increased wood reburning rate. The NO reduction achieved by hardwood reburning improves with increasing temperature as shown in Figure 5.

Reburn Fuel Comparisons

Figure 6 presents a comparison of hardwood, softwood, and wood sludge at the lower reburn temperature of 1398 K. The NO reduction achieved by the two wood types is very comparable except at stoichiometries less than 0.95 where the softwood performs slightly better than the hardwood. Each of the woods performs better than the wood sludge except at low stoichiometric ratios (0.85). A comparison of softwood, hardwood, wood sludge, coal and natural gas is presented in Figure 7 for the higher temperature reburning condition of 1721 K. At these high temperature conditions all of the fuels perform quite well leading to a reduction in NO of around 60% for $SR \leq 0.9$.

Figure 7 presents the very surprising result, that wood seems to reduce NO just as well as coal and natural gas at the high temperature reburn fuel injection condition of 1721 K. The wood sludge performs slightly worse except at low stoichiometries. This is surprising since wood is not expected to produce the same number of CH-radicals that are required to begin the process of NO reduction to N_2. The similar performance of these fuels may be due to different factors, including possible enhanced mixing, and a delayed release of hydrocarbon species for the solid fuels compared to the natural gas. Although the fuels all seem to perform well as reburning fuels for the standard conditions investigated, they do not perform equally as well when NO levels into the reburning zone are lowered from 500 to 200 ppm, as indicated in Figure 8. For the case of only 200 ppm NO entering the reburn zone, wood and natural gas are significantly better reburning fuels than coal. This is most likely due to the increased nitrogen content of the coal (compared to the wood and gas).

SUMMARY

These experimental studies have demonstrated that:

1) NO_x emissions can be reduced by more than 50 percent without any significant increase in CO or total hydrocarbon emissions by the proper use of natural gas in conjunction with appropriate tailoring of the stoichiometry distribution throughout the combustion zone in a pilot-scale stoker.
2) Railroad ties can be used as a co-firing fuel up to at least the 20 percent level without any detrimental effect on the pollutant emissions. Further, no combustion related operating problems were observed during the experimental studies.
3) To minimize overall NO_x emissions, one must control both the bed stoichiometry and the stoichiometry in the suspension phase combustion zone of a stoker.
4) Wood wastes (including a wood-derived sludge) can be used effectively as reburning fuels in a pc-fired furnace.
5) Reburn stoichiometry is the single most important parameter which determines the effectiveness of reburning with the waste biofuels, with optimal stoichiometric ratios around 0.85.
6) These biofuel waste streams can be utilized in a manner that reduces operating costs, and reduces environmental costs (including reductions in NO and CO emissions, and a net reduction in CO_2 emissions) which makes them excellent candidates for practical application.

REFERENCES

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3 Myerson, A.L., Taylor, F.R. and Faunce, B.G., *Sixth Symposium (International) on Combustion*, The Combustion Institute, p 154, 1957.

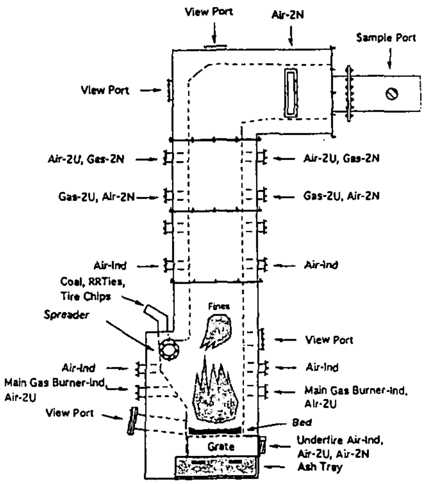

Figure 1. Pilot Scale Spreader-Stoker Facility.

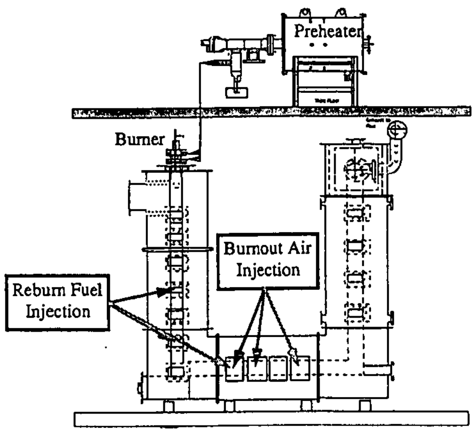

Figure 2. Pilot Scale Pulverized-Coal Fired Facility.

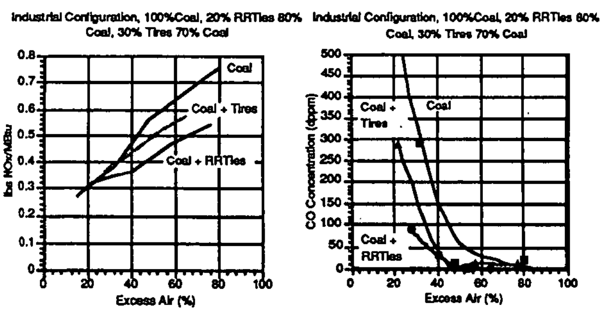

Figure 3. NO_x and CO emissions for coal and coal/RTDF blend.

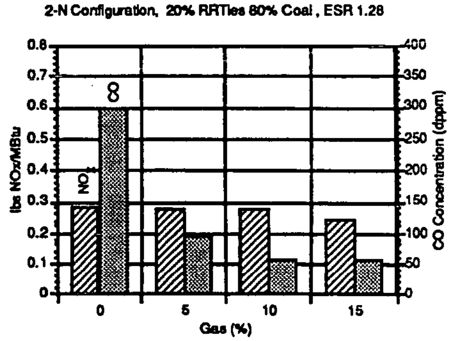

Figure 4. NO_x and CO emissions for coal/RTDF blend with reburning.

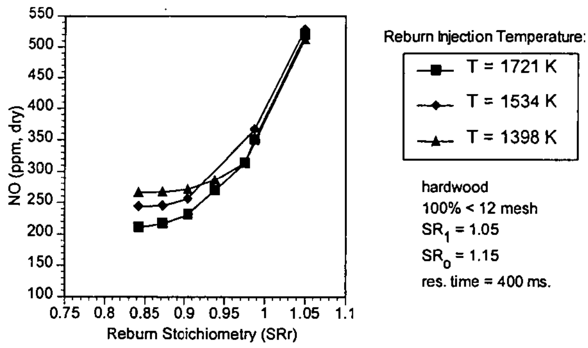

Figure 5. Effect of reburn zone stoichiometry on NO emission for hardwood at three reburn fuel injection temperatures.

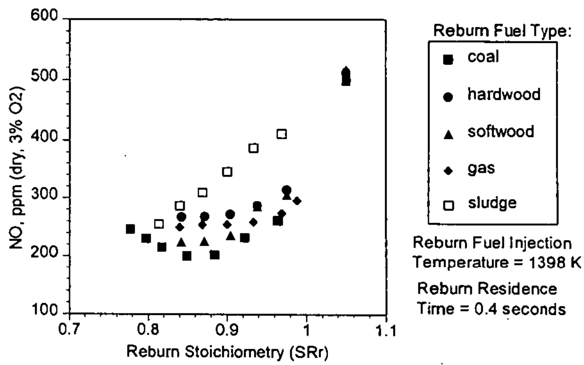

Figure 6. Reburn fuel comparisons at a reburn fuel injection temperature of 1398 K.

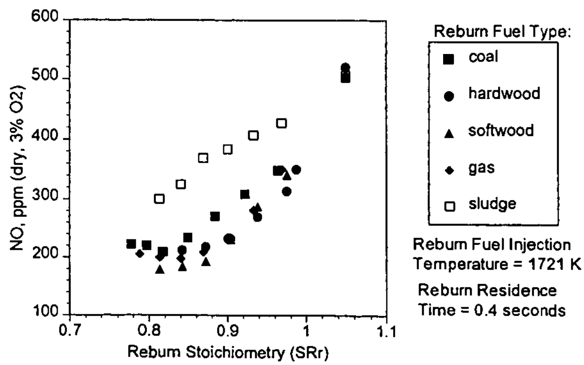

Figure 7. Reburn fuel comparisons at a reburn fuel injection temperature of 1721 K.