Fuel-Lean Reburn with In-Situ Gasification of Coal, Biomass and Biomass-Coal Mixtures and with Biomass-Derived Gases

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Introduction

Fuel-lean reburn is a patented process[1] by which locally fuel-rich gaseous injection jets are mixed into the lower temperature, NO_x reburn region of the upper furnace. The gaseous fuel injection stream breaks into mixing eddies which serve the same purpose as total fuel-richness in a conventional reburn system. This break-up and mixing history is carefully designed by using both CFD steady state and LIM non-steady state mixing models[2] to provide:

1) maximum fuel-richness NO_x reduction coverage, with
2) subsequent mixing to provide complete burn-out within the upper furnace, while
3) remaining overall fuel-lean at all times in the upper furnace thus using minimum gaseous fuel.

Full-scale utility boiler installations have demonstrated reductions of greater than 30% on down-fired, tangentially-fired, face-fired, opposed-fired and cyclone-fired boilers on a total of thirteen units. On several of these units, enhancement of the reburn chemistry with simultaneous amine injection led to reductions of up to 60%. However, the currently high price of natural gas in relation to coal causes the current high cost, in $/ton of NO_x removed, for fuel-lean gas reburn.

Biomass-based Fuel Lean Reburn Process

At one installation involving three 100 MW units, the economic decision to install fuel-lean reburn was made based on the anticipated availability of landfill gas. In general, the economics of the process would be favored by utilization of either coal gasification products or other economically favored gaseous fuels derived from biomass or waste; at the same time, the process chemistry can be favored by the presence of amine-type nitrogenous compounds in biomass. In order for the sophisticated reburn process to complete mixing of the fuel-rich eddies, without causing upper furnace soot formation and increased particulate matter, the reburn eddies must be composed of an easily combustible gaseous or gasified fuel.

Breen Energy Solutions has received several patents[3] that disclose techniques for the injection of mixtures of water with solid fuel (slurries) into the upper furnace region. In these processes, in-situ gasification takes place through the well known "carbon/water shift gasification" reaction, generating CO and H_2 gases which are easily combustible and smoke-free. The lower volumetric heating value of the gasification products compared to natural gas is an advantage in this process, as the increased volume helps mixing. Proof of the in-situ gasification of coal/water slurry concept was demonstrated in a 100 MW unit, where injection of 5% coal/water slurry heat input gave NO_x reductions up to 25% and reduced average excess O_2 levels by 1% without increasing fly ash carbon. Only short term tests were done to prove that in-situ gasification occurred and that coal/water slurry could be used as a reburn fuel without increasing fly ash unburned carbon levels, and the process was not optimized to determine the maximum NO_x reductions achievable.

Biomass-based Fuel Lean Reburn Laboratory Tests

Laboratory-scale biomass reburn experiments were conducted at the Center for Sustainable Environmental Technologies at Iowa State University during 2000-2002 under DOE Award Number DE-FG26-00NT40811. These experiments attempted both the in-situ gasification of injected switchgrass/water and alfalfa/water mixtures and also the external gasification of biomass. These biomass-based fuels were used to obtain upper furnace NO_x reductions in an attempt to make the Fuel Lean Reburn process more economically viable.

Biomass reburn rates of 4-20% heat input were tested using switchgrass as the reburn fuel. At initial excess O_2 levels of 4% or less, NO_x reductions of 30-70% were demonstrated. As the initial excess O_2 level decreased, both NO_x reductions and CO levels increased. CO burnout is often a problem in laboratory-scale reburn simulations because of residence time limitations. At a typical operating excess O_2 level of 3%, 14% reburn fuel heat input gave a 32% NO_x reduction with relatively low CO emissions. Increasing the reburn rate to 16% heat input gave a large increase in NO_x reduction to 48% but caused CO emissions to quadruple.

Biomass reburn was also tested with alfalfa as the reburn fuel. Again, NO_x reductions up to 70% were obtained with high CO levels. Because of the higher nitrogen content of alfalfa in comparison to switchgrass, NO_x emissions actually increased at excess O_2 levels of 4% or above as the fuel-bound nitrogen was oxidized. Initial excess O_2 levels of 2% or less gave the best NO_x reduction performance, albeit with high CO emissions.

Summary

In the biomass reburn experiments, switchgrass proved the better reburn fuel. Nitrogen in the alfalfa did not provide amine enhancement of the reburn chemistry; rather, NO_x emissions increased due to oxidation of fuel bound nitrogen above initial excess O_2 levels of 2%.

Economic evaluation showed installation of a full-scale biomass injection system is economically feasible with the NO_x reductions demonstrated. Renewable Energy Credits (RECs) and renewable energy portfolio standards make biomass-based fuel lean reburn more economically attractive. At biomass heat input rates of 10% as reburn fuel, 10% of the total boiler capacity can be considered as renewable energy capacity in many states.

Footnotes

[1] Fuel Lean Reburn licensed from Gas Technology Institute (GTI), US Patent 5,665,899 and US Patent 5,908,003

[2] "Full Scale Validation and Application, Advanced Modeling of Natural Gas Injection for NOx Control," Breen, B.P., Urich, J.A., Dahm, W.J.A., and Frederiksen, R.D.,

[3] US Patent 5,746,144, US Patent 6,030,204 and US Patent 6,357,367