A Novel application of Feedlot Biomass (Cattle Manure) as Reburning Fuel for NOx Reduction in Coal Fired Power Plants

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Abstract

Oxides of nitrogen from coal-fired power plants are considered to be major pollutants, and there is increasing concern for regulating air quality. Another environmental issue that needs to be addressed is the rapidly growing feedlot industry in the United States. The production of manure from one or more animal species is in excess of what can safely be applied to farmland in accordance with nutrient management plans and the stockpiled waste poses economic and environmental liabilities. In the present study, the feasibility of the application of cattle manure as fuel in existing coal fired power plants is considered. As the cattle manure is used for power generation it is referred to as feedlot biomass (FB). It is expected to utilize biomass as a low-cost, substitute fuel and an agent to control emission via the reburning process. The successful development of this technology of using biomass as reburn fuel will create an environment-friendly, low cost fuel source for the power industry and provide means for an alternate method of disposal of biomass and a possible revenue source for the feedlot operators. In the present study, the effect of FB and its blend with coal on their ability to reduce NOx emissions were investigated in the Texas A&M University 29.3 kW (100,000 Btu/h) reburning facility. The facility used a mixture of propane and ammonia to generate the initial NOx at the primary zone. The reburn fuel was injected with air or a mixture of air and nitrogen. The stoichiometry at the reburn zone was varied between 1.0 and 1.2. Two types of injectors were studied: circular jet and flat spray injectors. The injection of FB with air as carrier medium for circular injector the maximum NOx reduction was observed as 29.9% and with flat spray injector was 62.2%. When the carrier medium was switched to air mixed with nitrogen, the maximum NOx reduction was observed as 59.5%.

***Key Words**: Cattle Manure, Reburn, Nitric Oxide, Combustion, Feedlot Biomass*

Introduction and Objectives

Power generation is a significant source of air pollution that contributes toward the impairment of human health and the environment. The International Energy Outlook projects growth in coal use for power generation at an average annual rate of 1.5 % (on a tonnage basis) between 2001 and 2025 [1]. The combustion of coal produces several types of emissions that adversely affect health and environment. Oxides of nitrogen from coal-fired power stations are considered to be major pollutants, and there is increasing concern for regulating air quality and offsetting emissions generated from the use of energy. NOx, a generic term for the various oxides of nitrogen like nitrogen dioxide (NO_2), nitric oxide (NO) and nitrous oxide (N_2O), is a key issue due to its impact on the environment and health.

Reburning is an in-furnace, combustion control technology for NOx reduction. The reduction is achieved through the staged introduction of fuel into the combustion device. The overall reburning process occurs within three delineated physical zones, namely, primary zone, reburn zone, and burnout zone [2]. The extent of reduction of NOx achieved from reburning varies from 10 to 90 % depending on the operating conditions of the system.

Another environmental issue that needs to be addressed is the rapidly growing feedlot industry. In the United States, 94 million total head generated 110 million tons of waste in 1997 and the increase in animal waste generation was 12% for the previous decade [3]. Each animal leaves approximately one ton of collectible biomass over a five month period [4]. In many cases, the production of manure from one or more animal species is in excess of what can safely be applied to farmland in accordance with nutrient management plans, and the stockpiled waste poses economic and environmental liabilities. Hence, manure can contribute to surface or ground water contamination and air pollution problems with the release of greenhouse gases. Disposal of the vast quantity of

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manure produced as a by-product of the cattle feeding industry is one of the major operating tasks of the industry. It is both an economic burden on the industry and a potential environmental hazard to air, water, and land.

Cofiring literature has been reviewed by Sami wet al [5]. The previous work concentrated on cofiring coal and cattle manure [6-8] in suspension fired mode, combustion in fluidized beds [9] and gasification of manure and blends of coal and manure [10]. The use of manure as the sole source of energy reported in the literature has met with limited success [4, 9].

In the present study, the feasibility of using of manure as a reburn fuel in existing coal fired power plants is considered. It is expected to utilize manure as a low-cost, substitute fuel and an agent to control emission. As the cattle manure is used as a source of energy it may also be referred to as feedlot biomass (FB). The present study aims to investigate the effect of use cattle manure or FB and its blend with coal on NOx reduction ability under different injection geometries and carrier media.

Fuel Characteristics

Detailed FB fuel characteristics for raw and partially composted states have been recently reported [11]. The ultimate and proximate analyses of the fuels used in the reburning experiments on an as-received basis are given in table 1.

Table 1: Ultimate and proximate analyses of fuels

Parameter	Coal	Cattle Manure or FB
Dry Loss	15.12	7.10
Ash	5.33	15.58
FC	42.38	15.58
VM	37.17	63.56
C	60.30	39.13
H	3.62	6.14
O	14.44	38.56
N	0.96	2.99
S	0.23	0.56
HHV (kJ/kg)	23710	16473

It can be observed that FB is a high ash and low heat value fuel as compared to coal but have high volatile content and low fuel nitrogen. The higher ash content, higher fuel feed-rate, and higher chlorine content are likely to pose problems of ash deposition on boiler tube walls when biomass is used as the primary fuel. For limited data on fouling potential when FB (10 % by mass) is cofired with coal in a 150 kW (500,000 BTU/hr) DOE-NETL Facility, the reader is referred to reference [8]. The results from previous co-firing studies indicated that the higher nitrogen content of biomass did not necessarily lead to higher NOx production [6, 7] at low excess air %. This makes FB a good choice as reburn fuel.

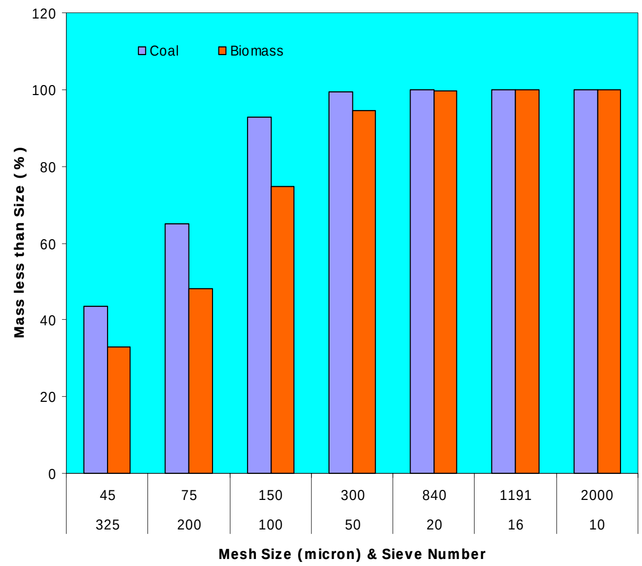

Figure 1: Particle size distribution for coal and cattle manure (FB)

The particle size distribution of the FB is given in figure 1. The size analysis of coal and biomass indicate that biomass is coarser than coal. In coal, 70 % of the sample was below 100 μm in size, whereas in biomass only 50 % of the sample was below 100 μm in size. The higher fiber content of the biomass during the process of collection renders the grinding process difficult and finer grains were not produced as the fibrous materials of biomass were not broken into powder during the grinding operation but rather compressed. The difference in size distribution between coal and biomass might lead to differences in combustion characteristics.

Experimental setup and procedure

The reburning experiments with coal and FB blends were conducted in the small-scale facility at Texas A&M University. The down-fired reactor is constructed of eight modular refractory sections of inside dimension 152.40 mm (6”) enclosed by a layer of ceramic blanket within a steel shell and it is rated at 29.3 kW_t (100,000 Btu/h). A schematic of the test facility with its support systems is given in figure 2.

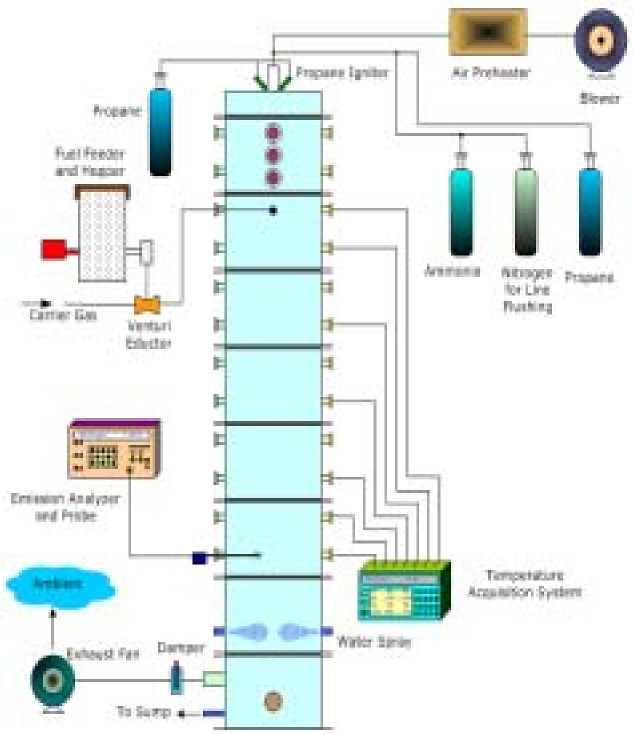

Figure 2: Schematic of 30 kW (100,000 BTU/hr) TAMU Reburn Facility.

The initial NOx at the primary zone was simulated through the combustion of propane doped with small amounts of ammonia [12]. The ammonia was assumed to be fully converted into NOx in the primary zone, and by regulating the flow of ammonia different primary NOx concentrations were obtained.

The reburn fuel fed by a commercial volumetric feeder is educted with the aid of air or a mixture of air and nitrogen and injected into the reactor. Two types of injectors were used: circular jet and flat spray injector. These different injectors produce different mixing patterns and degree of mixing within the reactor.

The monitoring systems consist of Rota meters to indicate the flow rates of air, manometer to measure the back pressure at exhaust, and thermocouples to read the temperature at locations axially down the reactor. As the fuel burns, the condition of the product gases was measure at gas ports located at 152.40 mm (6”) intervals from the location of injection by emission analyzers. At the last section of interest, the measurement was made using ENERAC 3000 E emission analyzer that measured the dry volume percentages of the gases NO, NO_2, and O_2. Since the reburn zone is operated at slightly richer mixtures, CO values exceed the limit of instrument; reliable values of CO were not made due to operations at the higher limit of the sensor. An opposed jet water spray is at the lowest section traps the particulate and ash content as the combustion products exit the reactor. The typical trial parameters are given in table 2.

Table 2: Typical experimental parameters

Parameter		Value
Total Burner Rating		29.31 kW (100,000 Btu/h)
Reburn Rating		8.79 kW (30,000 Btu/h)
Primary Zone	Propane flow rate	27.7 SCFH
	Air flow rate	700 SCFH
	Equivalence Ratio	0.95
	O_2 %	1.00
	NOx	600 ppm @ 3% O2
Reburn Zone	Fuel flow rate	18-27 g/min
	Motive air flow rate	118-143 SCFH
	Aspiration	~ 50 % of motive air
	Equivalence ratio at reburn zone	1.00-1.20
	Equivalence ratio of reburn supply	1.15-1.42

Results and Discussion

The dry gas analysis depends on the ultimate analyses of the fuel fired, the air supplied for combustion, and the measured exhaust gases. The EPA guideline requires the NOx emissions to be expressed for an exhaust O_2 of 3 % for typical boilers. The reduction is typically calculated based on NOx values corrected on the basis of 3 % oxygen in the exhaust as given below.

$$NOx \cdot (reference \cdot O_2) = NOx \cdot (measured \cdot O_2) \cdot \left[\frac{ambinet \cdot O_2 - reference \cdot O_2}{ambient \cdot O_2 - measured \cdot O_2} \right]$$

$$NOx \cdot reduction \cdot (\%) = \left(\frac{NOx \cdot (reference \cdot O_2) - NOx \cdot (initial)}{NOx \cdot (initial)} \right) \times 100$$

A comparison of effect all the different reburn fuels on % NOx reduction with the use of circular injector is shown in figure 3. The NOx reduction exhibited an increasing trend with increased reburn zone equivalence ratio. From the figure it may be observed that at higher equivalence ratio biomass had better ability to reduce NOx whereas, at other values it did not reduce as well as coal. The maximum reduction of about 30% was observed for FB reburning.

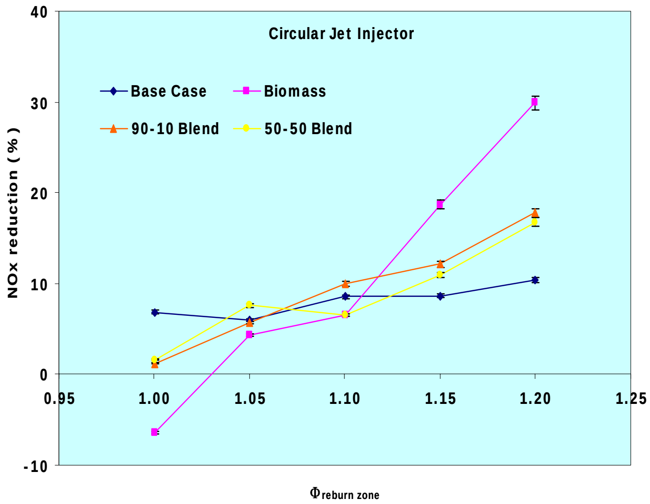

Figure 3: NOx reduction with different fuels carried by air through circular jet injector

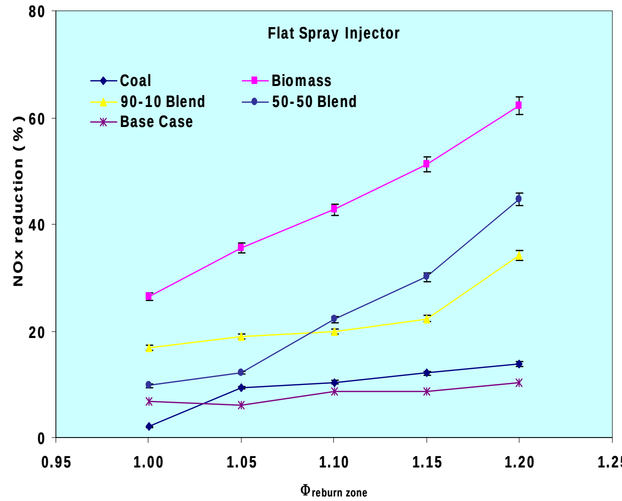

Figure 4: NOx reduction with different fuels carried by air through flat spray injector

The form of the release of fuel bound nitrogen during oxidation plays an important role in the amount of reduction. With coal the fuel bound nitrogen may have been released in the form of HCN and in the case of biomass there might have been a higher proportion of NH_3. Both HCN and NH_3 are reducing agents for the conversion of NOx into molecular nitrogen but, the reaction rates differ. The NH_3 reduction mechanism proceeds at a much faster rate than HCN reactions. Further the volatile matter of biomass is higher compared to coal. Thus, under similar residence times for both coal and biomass, biomass exhibited twice as much capacity to reduce NOx. Thus, it may be inferred that biomass can be used as reburn fuel but it is required that the reburn fuel should be dispersed well within the reburn zone. The need for sufficient dispersion of reburn fuel implied that when temperature effects were eliminated, the stoichiometry of the reburn zone and the generation of local fuel-rich regions were significant factors to achieve high NOx reduction.

To achieve better dispersion, a flat spray injector was designed and fabricated. The flat spray spread the reburn fuel at a wider angle of 11° than the circular injector at the reburn zone. The flattening of the nozzle to produce an elliptical cross section also increased the momentum of the spray. The even spreading of the fuel at the reburn zone may have created more regions of localized fuel-richness that were ideal sites for NOx reduction. Also the better dispersion with a flat spray led to better combustion and faster release of volatiles in the case of biomass. All the fuels were tested with the flat spray to determine the effect of mixing. The NOx reduction with flat spray injector is depicted in figure 4.

The use of flat spray for coal reburning showed that the NOx reduction improved at all equivalence ratios except at near stoichiometric conditions of the reburning zone. The maximum reduction of 62% occurred at an equivalence ratio of 1.20 which was over five times higher than that produced with coal as the reburning fuel. It was observed that coal had the least reduction and biomass showed the highest reduction at all equivalence ratios. The reduction with blends lay between that of biomass and coal. When the percentage of biomass was higher in the blend then the NOx reduction was higher at higher equivalence ratios.

The NOx reduction ability is also influenced by the O_2 concentration at the reburn zone. To determine the effect of this, the reburn fuel carrier air was diluted with nitrogen gas such that the O_2 concentration was reduced from the ambient value of 20.9% to 15.0%. This mixture of air and nitrogen is termed vitiated air. The NOx reduction with vitiated air is given in figure 5.

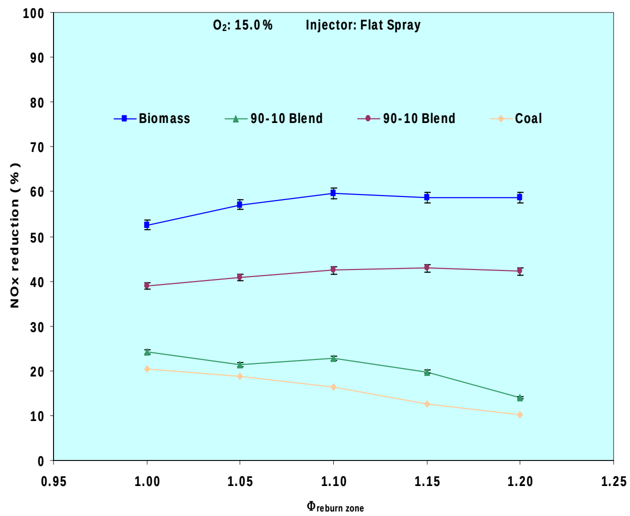

Figure 5: NOx reduction with different fuels carried by vitiated air through flat spray injector

The trends of NOx reduction with vitiated air in terms of the different fuels were identical to that of air as carrier medium. But curves looked more flat with equivalence ratio. Again the FB exhibited the maximum reduction and coal showed the minimum. The reduction with blends lay between that of FB and coal. The coal exhibited decreased performance at higher equivalence ratios. The maximum reduction for FB occurred at lower equivalence ratios with vitiated air which will reduce the required over fire air. At higher equivalence ratios the use of vitiated air may have produced locally very fuel rich zones.

Summary

The following is a summary of results from the experiments on coal and FB reburning.

1. The size analysis of coal and biomass indicate that biomass is coarser than coal. In coal, 70 % of the sample was below 100 μm in size, whereas in biomass only 50 % of the sample was below 100 μm in size.
2. Biomass is a better reburn fuel than coal at all conditions of equivalence ratio at the reburn zone.
3. Maximum NOx reduction of 62 % was obtained with biomass as the reburn fuel which was about five times higher than that achieved with coal.
4. The NOx reduction ability of blends lay between that of coal and biomass.
5. NOx reduction increased with the decrease in the O_2 concentration of the supply air at lower equivalence ratios but decreased at higher equivalence ratios.
6. Maximum NOx reduction of 62 % was obtained with biomass injected with vitiated air.

Acknowledgements

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