PERFORMANCE OF A SMALL SCALE BOILER BURNER IN THE FIRING OF COAL AND RAW FEEDLOT MANURE

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ABSTRACT

Since feedlot manure exists in large quantities in some regions, and is nearly 10 times cheaper than coal, the possibility of using feedlot manure as an alternate fuel is being explored in this work. The characteristics of coal and feedlot manure differ in some respects, particularly ash content, heating value, moisture content, and sulfur content. Therefore, tests need to be performed to determine the effects of these differences and ultimately, to determine the viability of feedlot manure as a supplemental fuel. To accomplish the above mentioned goals, it will first be necessary to establish base line data by performing tests with the firing of coal/feedlot manure blends. Preliminary results with an 80% coal and 20% manure blend indicated that the emissions of NO_x increased as the burnt mass fraction of fuel increased. However, the fraction of N converted to NO_x decreased at the same time. It was also noticed that when the burnt mass fraction of fuel is in the typical utility boiler operational range (>90%), the NO_x for the blend was lower than for coal alone.

INTRODUCTION

Coal has become the dominant fuel for the production of electricity in the United States. Figure 1 shows that the use of coal in the production of electricity for the year 1991 was dominant, producing over 75% of the electricity generated from fossil fuels. Consequently the attendant pollutant emissions have also increased. Most important among these pollutants are sulfur dioxide (SO_2) and nitrogen dioxide (NO_x), which cause acid rain and ozone depletion. At least for the foreseeable future, coal will continue to be the dominant fuel used for the production of electricity. Therefore, additional techniques and/or methods must be undertaken in an effort to reduce gaseous emissions. Federal regulations regarding the emissions of these pollutants have become particularly demanding. The current *New Source Performance Standards (NSPS)* for SO_2 and NO_x are equal to or less than 2.6×10^{-4} kg/MJ (0.6 lbs/million Btu) thermal input.

Due to *NSPS*, the cost of low sulfur Wyoming coal has risen to nearly $20 per ton delivered. The increase in cost has motivated utilities to explore fuel alternatives. One such alternate source exists in feedlot manure, which is a renewable resource. For instance, in the state of Texas there exists 2.3 million head of cattle in feedlots producing nearly 7.5 million kg (8,300 tons) of dry manure per day. The characteristics of coal and feedlot manure differ. Feedlot manure contains 25%-75% volatile matter (dry basis) and has a mean heating value typically ranging from 11,000 to 20,000 kJ/kg (Sweeten et al, 1985). Coal has a heating value of 35,000 kJ/kg (14,000 Btu/lb). Since the characteristics of the two fuels are different, flame stability and combustion behavior must be studied.

Swirl burners are an effective device for flame stabilization which will satisfy all three elements of combustion. In typical boilers air is split into the primary stream (<25%) carrying the fuel and the secondary air stream (>75%) which is imparted a swirl by the swirler vanes. Typically for a swirl number greater than 0.6, a recirculation zone will be created (Beer and Chigier, 1972). Extensive studies on swirl burners have been conducted by the International Flame Research Foundation, and these studies have produced the following recommendations: (i) the velocity of the primary air-coal flow should be kept above 15 m s^{-1} to prevent settling of coal on the burner tube, and the secondary air velocity was generally 30-45 ms^{-1}, (ii) the swirl number is very flexible but should be maintained above 0.6, and (iii) the axial location of the fuel nozzle should generally be at the quarl entrance. Usage of these recommendations should generally enhance flame stability.

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OBJECTIVES

The primary objectives of this research project was to gather data in the area of emissions and fame stability criteria when firing coal alone and secondly when firing coal and raw feedlot manure blends (80%-20%), respectively. The experiments were designed to determine:

(i) operational parameters such as burnt mass fraction,
(ii) burner rating and boiler temperature distribution,
(iii) pollutants production and measurement, and
(iv) fraction of N in fuel converted to NO_x.

PROCEDURE

Experimental Setup

A small scale boiler burner facility has been designed and constructed for the purpose of firing low sulfur Wyoming coal and feedlot manure blends. Tests were initially conducted firing low sulfur Wyoming coal and later firing coal and raw feedlot manure in 80:20 blends.

A schematic of the experimental setup is shown in Figure 2. The boiler burner is 0.152 m (6 in.) in diameter and 1.575 m (62 in.) in height. The entire boiler is constructed from stainless steel. The boiler contains three viewing ports mounted 5.1 cm (2 in.) apart, and located underneath the quarl. The windows are fused quartz housed in a stainless steel 316 body. Three sampling ports serve as locations to perform emission sampling. The combustion air is supplied by a secondary air blower driven by an adjustable speed DC motor. The secondary air is preheated to a minimum of 200°C with the use of a circulation heater (3 kW) before it enters the boiler. The fuel feed system consists of a feed hopper with a capacity of 14 kg (309.8 lbs). Compressed air is supplied through the top of the feed hopper in order to maintain a positive pressure higher than the boiler burner. An auger screw runs through the conical section of the feed hoper and is driven by an adjustable DC motor (½ hp, 1725 rpm). The auger can deliver up to 200 g/min (0.41 lbs/min) of coal into the boiler burner. The primary air is supplied by the laboratory and can deliver up to 432 g/min. The purpose of the primary air is to carry the fuel and to a lesser extent provide a fraction of the combustion air. The boiler burner walls are insulated on the outside using a fibrous alumina-silica blanket rated to operate at a maximum temperature of 1300°C (2372°F). Dual water jets are injected into the boiler to catch the particulates and ash, which empty into a 113.6 L (30 gallon) polyethylene tank. The products of combustion are exhausted with an induced draft fan, capable of providing a vacuum of 0.5 inches water gauge inside the boiler burner. The entire facility can be operated from a central control panel. The diagnostic system consists of an orifice plate for measuring the secondary air flow rate, sheathed type K and type S thermocouples both in the boiler, the secondary air stream and in the exhaust. Rotometers are employed to measure the primary as well as hopper air flow rates. Emission measurements are performed using a Lancom 6500 emission measuring system. The system can accurately measure six gases including, SO_2, NO, NO_2, CO, CO_2, and O_2.

Burner Characteristics

The burner is a concentric type swirl burner with downward firing. Further details of the burner arrangement may be found in Frazzitta and Annamalai (1994). The primary air/fuel nozzle is 1.905 cm (¾ inches) in diameter. The secondary air duct is 3.175 cm (1¼ inches) in diameter. The entire burner is constructed from stainless steel. An impeller plate at the primary air/fuel exit serves to split the thick stream of coal into thin streams and also to direct the coal into the hot recirculation zone. Radially attached swirlers provide the necessary swirl to create a recirculation zone. A swirl number greater than 0.6 is necessary to create a recirculation zone (Beer and Chigier, 1972). The swirl number is a function of the burner geometry and swirl angle. For the burner in this experiment the swirl angle is 60°, and the swirl number is 1.4.

The quarl is constructed from ceramic fiber boards rated for 1300°C continuous service temperature. The quarl has an L/D ratio of 1.8. The quarl half angle is 24°, which is nearly optimum as determined by Fricker and Leuckel (1976). The burner is fitted with a propane torch which serves to preheat the boiler and initiate combustion. The torch rating is approximately 1% of the total burner rating, this to ensure that the contribution of the propane torch is negligible in emission measurements as well as performance of the boiler burner.

Experimental Procedure

The experimental procedure for firing was as follows:

The boiler burner was preheated to the desired temperature using two propane torches. The secondary air was preheated to a minimum of 200°C using a circulation heater. Once the appropriate temperatures were reached in the boiler, coal or the blend was injected and the experimental data were recorded. Data were taken for: the temperature along the centerline of the boiler at various locations, air flow rates, and the composition of the flue gases. The flue gas temperature was also recorded using the emission monitoring probe mounted in the sampling port farthest from the burner.

RESULTS

Boiler performance will be discussed in terms of the burnt mass fraction, temperature distribution, and most important emission measurements. Figure 3 shows the axial temperature distribution in the boiler when firing coal alone, measured from the burner nozzle exit. The maximum axial temperature (1240°K) is indicated to be approximately 28 cm (11 inches) from the burner nozzle exit. The radial temperature distribution is relatively flat downstream of the recirculation zone (RZ), varying by less than 50°K. The maximum axial temperature usually occurs in the recirculation zone boundary. This would indicate the recirculation zone is approximately 28 cm (11 in.) in length. Syred and Beer (1974) suggested a RZ length of 22 cm for the swirl number and quarl dimensions chosen.

Figure 4 shows the axial temperature distribution in the boiler when firing coal and raw feedlot manure blend. As with the firing of coal, the maximum axial temperature (1262.5 K) occurs approximately 28 cm (11 in) from the burner nozzle exit. This suggests that the addition of feedlot manure has not adversely affected flame stability. It should be noted that the maximum temperature obtained occurred when firing the blend. This can be explained by feedlot manure's low pyrolysis temperature (200°C) and high volatile matter content.

The fraction of fuel burned will depend on the residence time for combustion and also the reactor temperature. The burnt mass fraction of fuel versus probe temperature both for coal and coal/mannure blend is shown in Figure 5. A maximum probe temperature of 1099°K at a burnt fraction of 97% was recorded when firing coal also. Alternatively, a maximum probe temperature of 1090°K at a burnt mass fraction of 96.7% was recorded when firing the blend. The similarity in the trend of burnt mass fraction versus probe temperature in both cases suggests again that flame stability was maintained with the addition of 20% feedlot manure. Initially, as fuel enters a relatively cool reactor a large percentage of the fuel will be unburned. As the fuel is burned, the reactor and the probe temperature slowly increase, accompanied by an increase in the burnt mass fraction. It is also important to realize that as the amount of fuel burned increases the oxygen content in the flue gas will decrease. Therefore, there exists an important relationship between burnt mass fraction, oxygen content, and reactor temperature.

Emission measurements were taken for different burnt mass fractions and temperatures in each case. All emission measurements have been normalized with 3% O_2 in the products as prescribed by EPA guidelines. The sampling probe for each measurement was located at the centerline of the boiler far enough down stream to ensure complete combustion. Since raw feedlot manure has nearly twice as much fuel nitrogen as Wyoming coal, the production of NO_x will also be greater.

Figure 6 compares the emissions of NO_x when firing coal alone and coal and raw feedlot manure. As expected, the emissions of NO_x generally increased throughout the range of burnt mass fraction. At a burnt mass fraction of 71%, Wyoming coal produced 370 ppm NO_x while the blend produced approximately 490 ppm. Thus, 194 ppm (490-0.8x370) was due to the 20% manure, thus indicating that the manure was burning. Feedlot manure devolatilizes more readily than coal and hence N is released much earlier, even at low temperatures. Thus, even at burnt mass fraction or low temperature, the N released is readily oxidized. Typical boilers operate with an efficiency above 95%. At this point, since only 80% coal is used, the contribution of coal N to NO_x emissions was 432 ppm (0.8x540). The manure (20%) released approximately 55 ppm.

Figure 7 compares the fraction of N converted to NO_x when firing coal alone and coal/raw feedlot manure. Both curves show the fraction of N converted to NO_x decreased for all ranges of burnt mass fraction. This trend would seem to indicate that the formation of NO_x was more oxygen dependent than burnt mass fraction dependent, since as burn mass fraction increased the oxygen content also decreased.

SUMMARY

A small scale boiler burner facility has been built and instrumented for measuring temperature distribution, pollution emissions, and composition of the flue gases.

The burnt mass fraction of fuel was a function of reactor temperature. The addition of raw feedlot manure with coal did not change the temperature distribution or size of the recirculation zone, indicating flame stability was maintained; rather it improved the burnt mass fraction. The formation of NO_x generally increased with burnt mass fraction; however, the contribution of NO_x from 20% feedlot manure decreased. In all cases the emissions were within the *NSPS* guidelines. The conversion of N to NO_x was seen to decrease as the oxygen content decreased.

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Table 1. Coal and Raw Feedlot Manure Characteristics

Parameter	Coal	Raw Manure	Coal/Manure (80:20)
Proximate Analysis			
Moisture	10.8	36.61	15.96
Ash	5.68	25.25	9.6
Volatile Matter	52.80	31.57	48.55
Fixed Carbon	30.72	6.57	25.89
Ultimate Analysis			
Carbon(3)	54.9	19.24	47.77
Hydrogen(3)	4.33	2.22	4.68
Oxygen(3)	23.32	14.68	29.28
Nitrogen(3)	0.76	1.47	0.902
Sulfur(3)	0.34	0.53	0.378
Empirical Formula(1) (DAF)	$CH_{0.94}O_{0.32N}N_{0.012}S_{0.0023}$	$CH_{0.37}O_{0.572}N_{0.065}S_{0.010}$	$CH_{0.97}O_{0.34}N_{0.016}S_{0.0030}$
Molecular Weight(2) (DAF)	18.32	23.8	18.75
Heating Value (DAF)	26,535kJ/kg or 11,410 Btu/lb	7,865 kJ/kg or 3,381 Btu/lb	22,801 kJ/kg or 9,804 Btu/lb
$A:F_{stoichiometric}$(2)	7.19	2.36	5.93
$A:F_{stoichiometric}$(2) (DAF)	8.18	6.18	7.96

(1) Determined from ultimate analysis; DAF = dry ash-free basis.

(2) Calculated from empirical formula

(3) Dry Basis

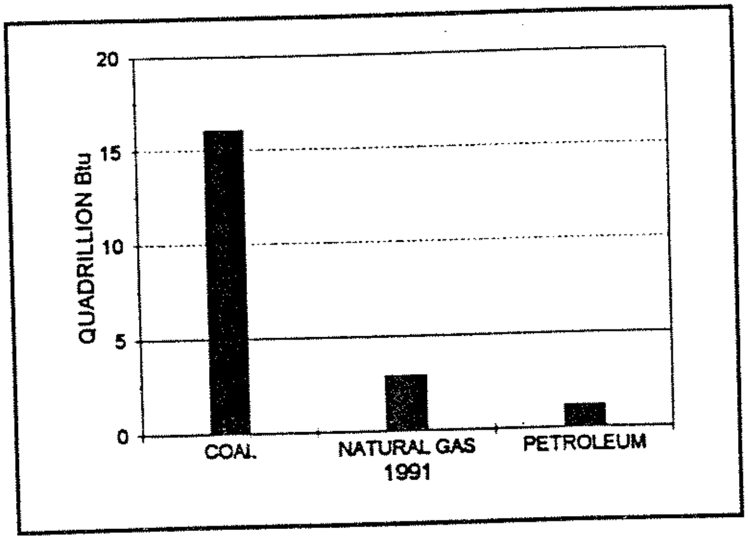

Figure 1. Electric Utility Consumption by Source
(Annual Energy Review 1991)

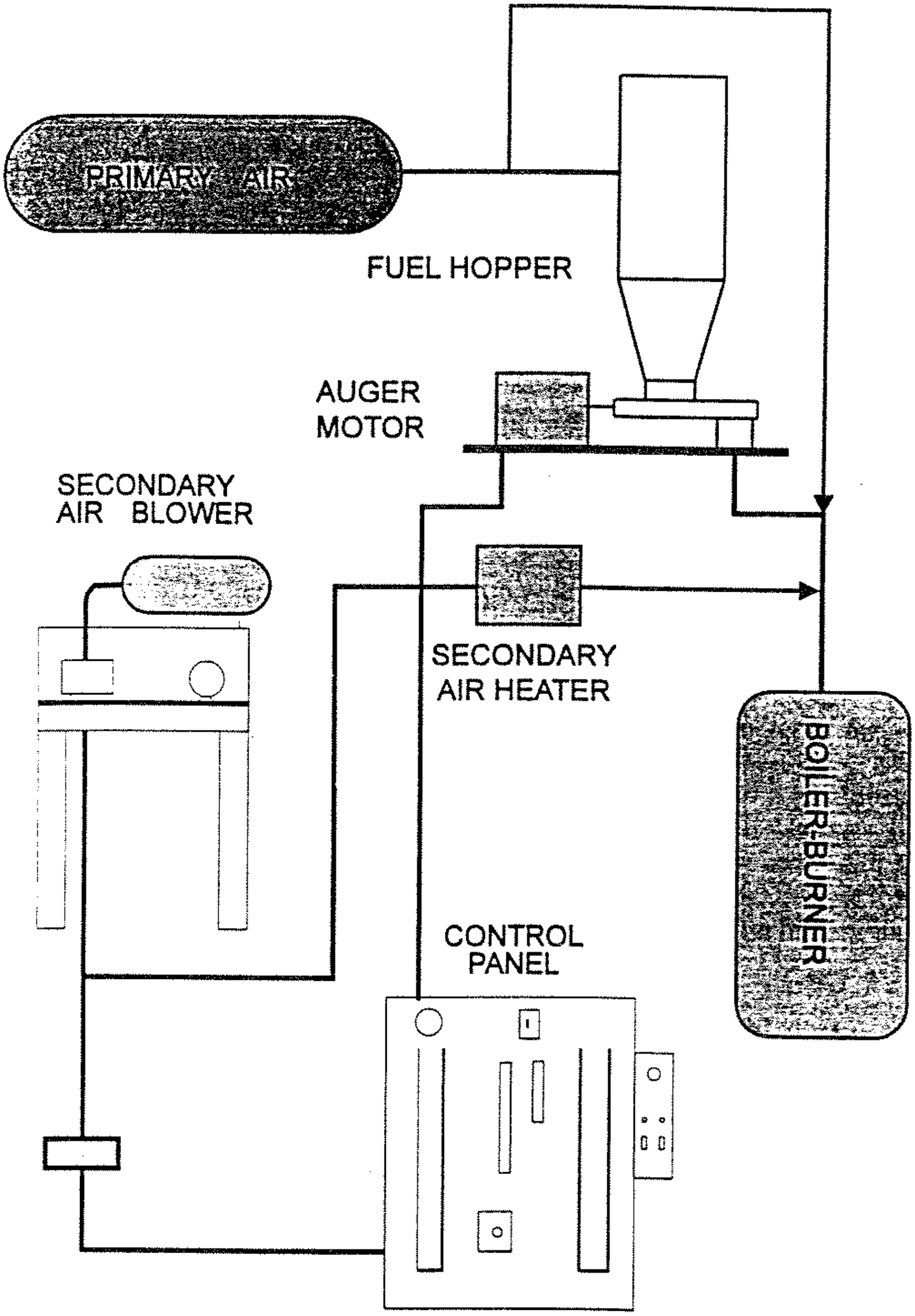

Figure 2. Laboratory Combustion Unit.

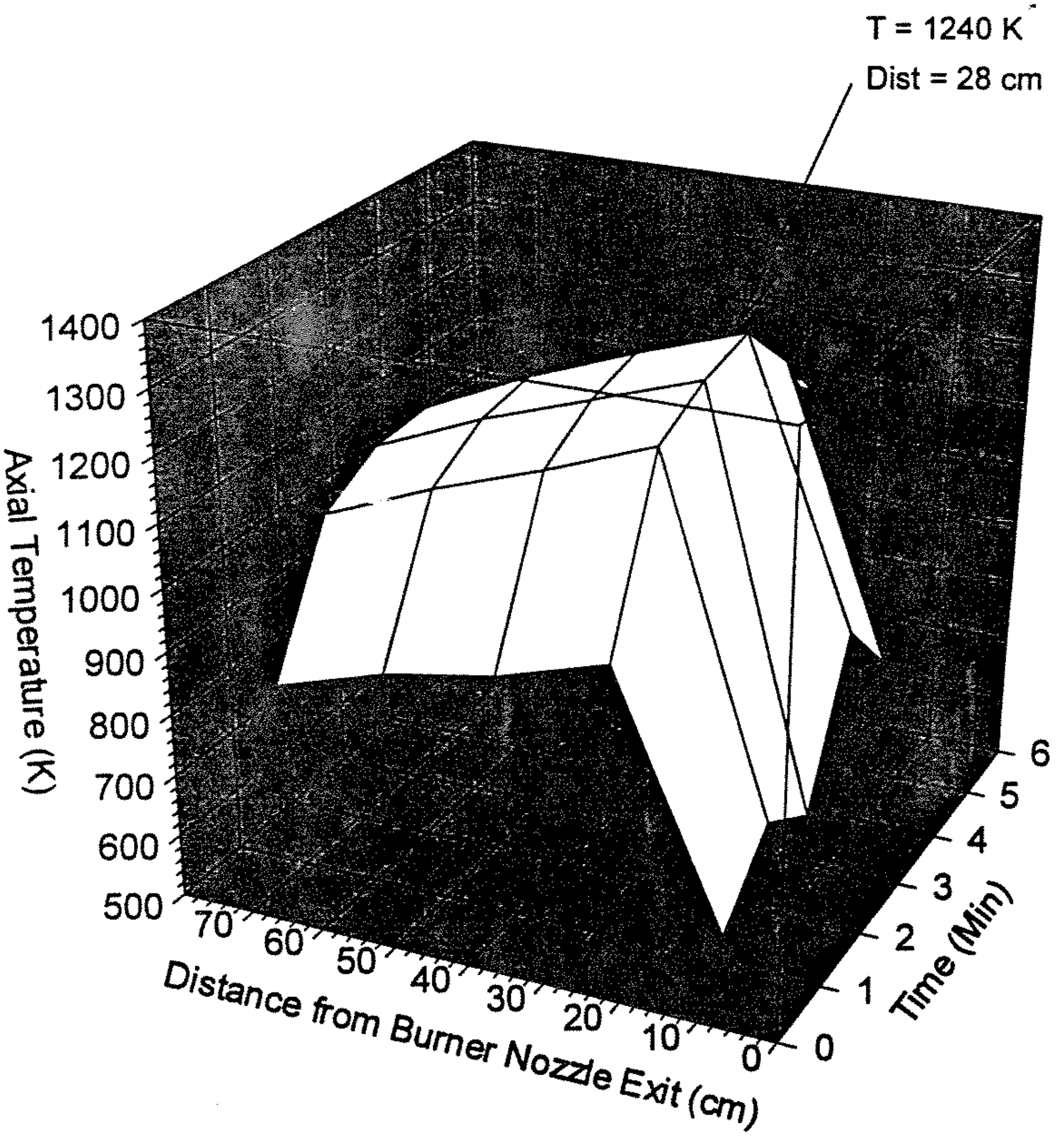

Figure 3. Axial Temperature Distribution in the Boiler When Firing Coal.

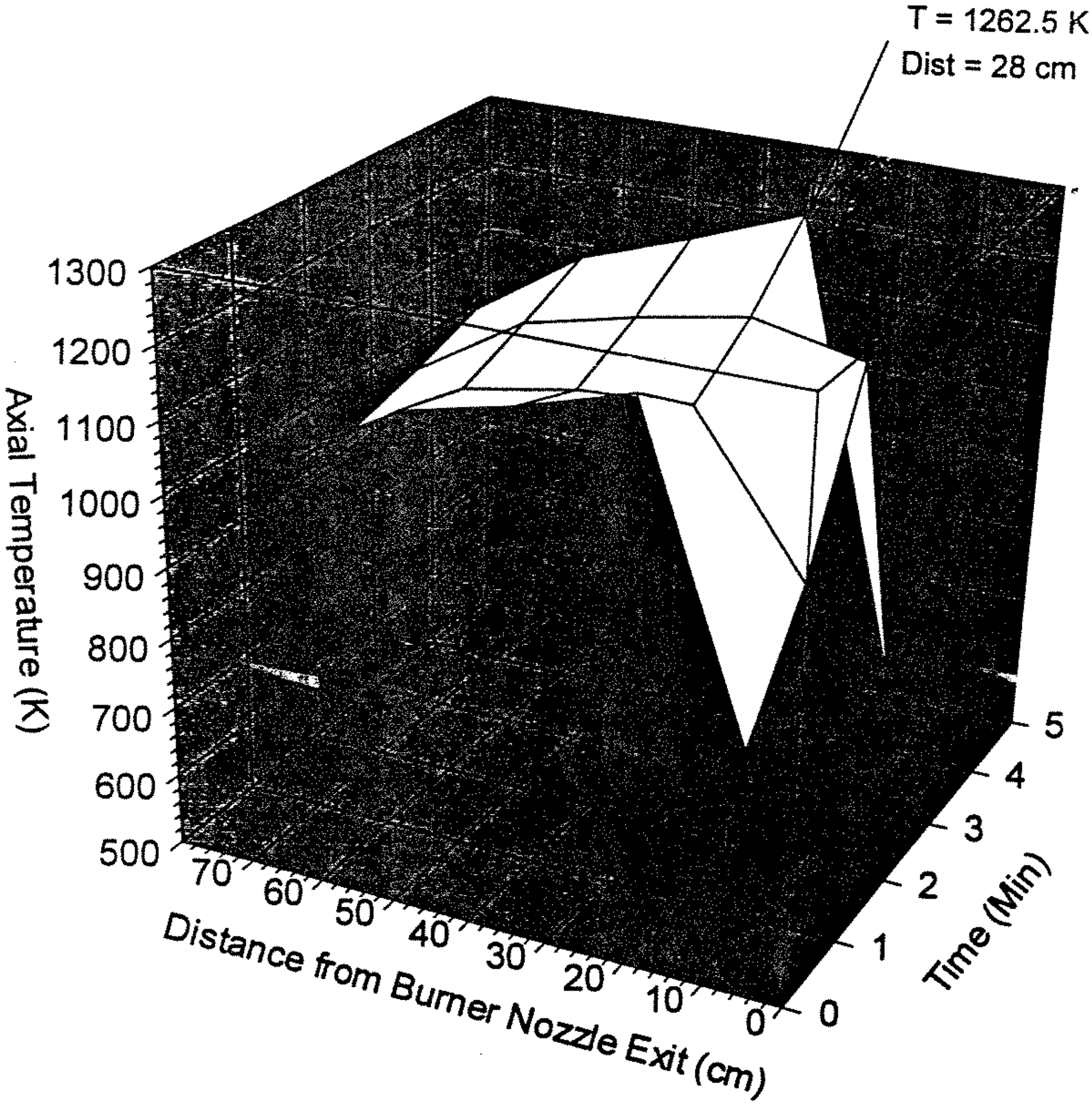

Figure 4. Axial Temperature Distribution in Boiler when Firing the Coal/Raw Feedlot Manure Blend.

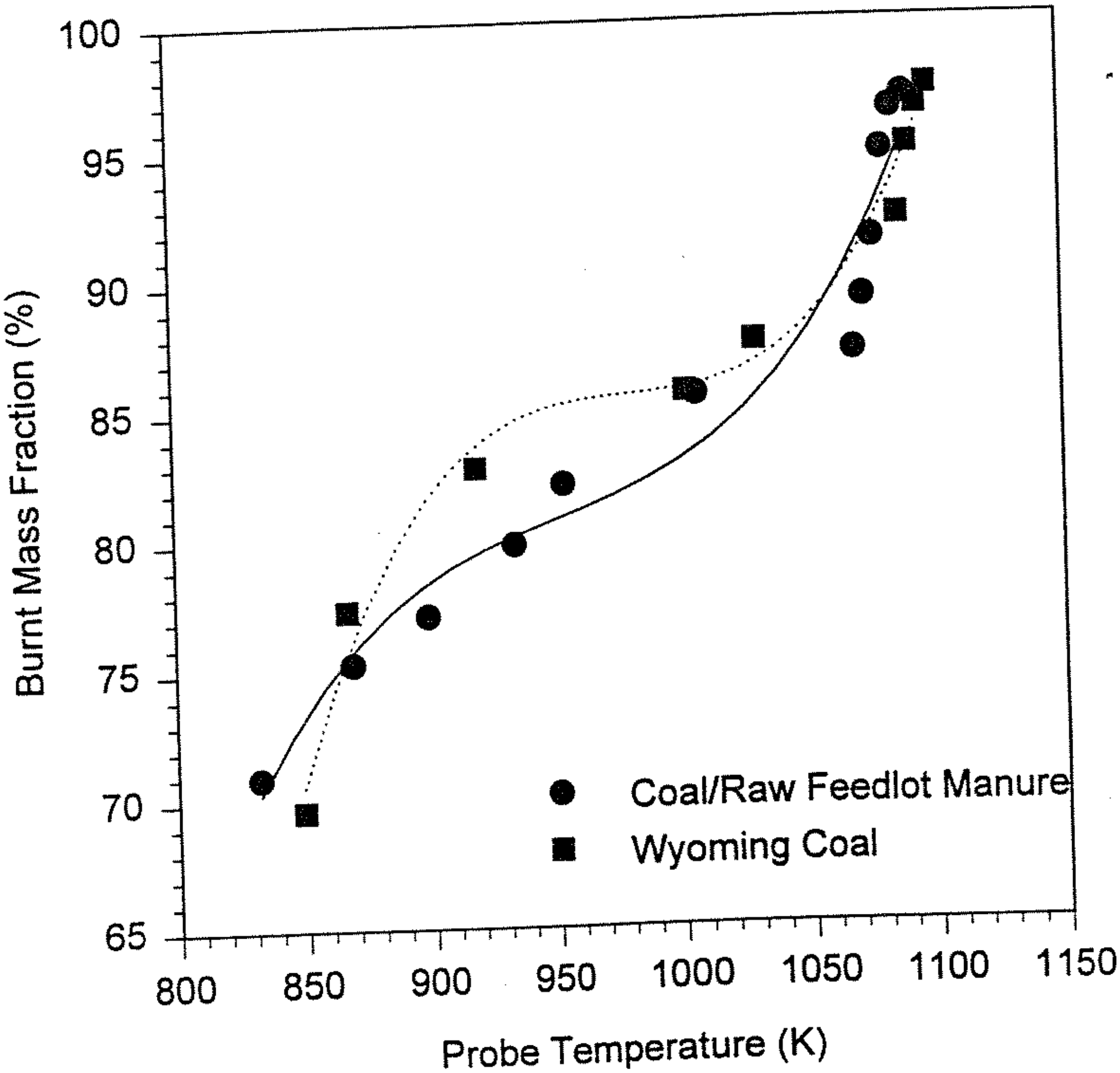

Figure 5. Comparison of the Burn Mass Fraction Verse Probe Temperature When Firing Coal and Coal/raw Feedlot Manure.

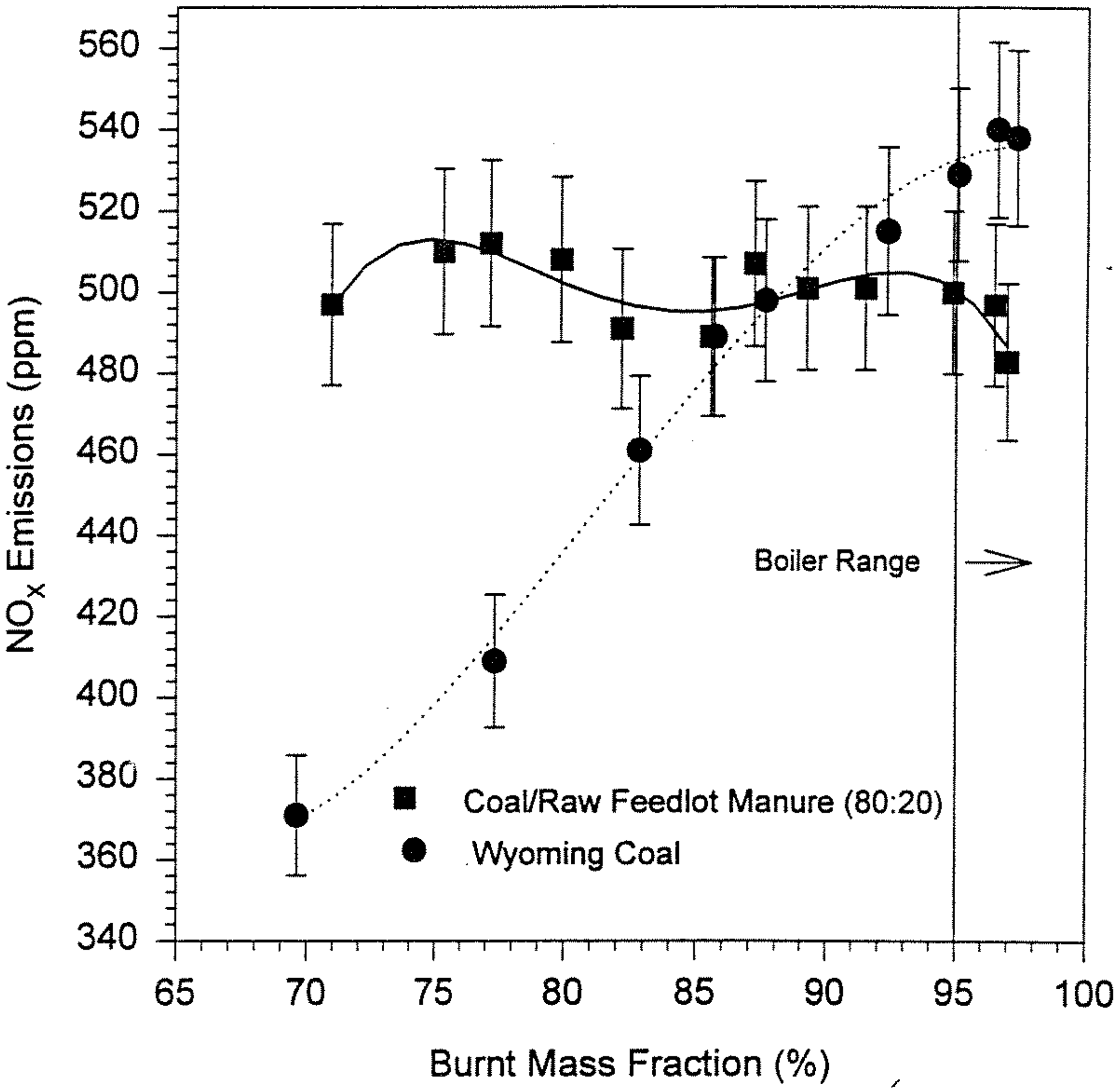

Figure 6. Comparison of NO_x Emissions When Firing Coal and Coal/Raw Feedlot Manure.

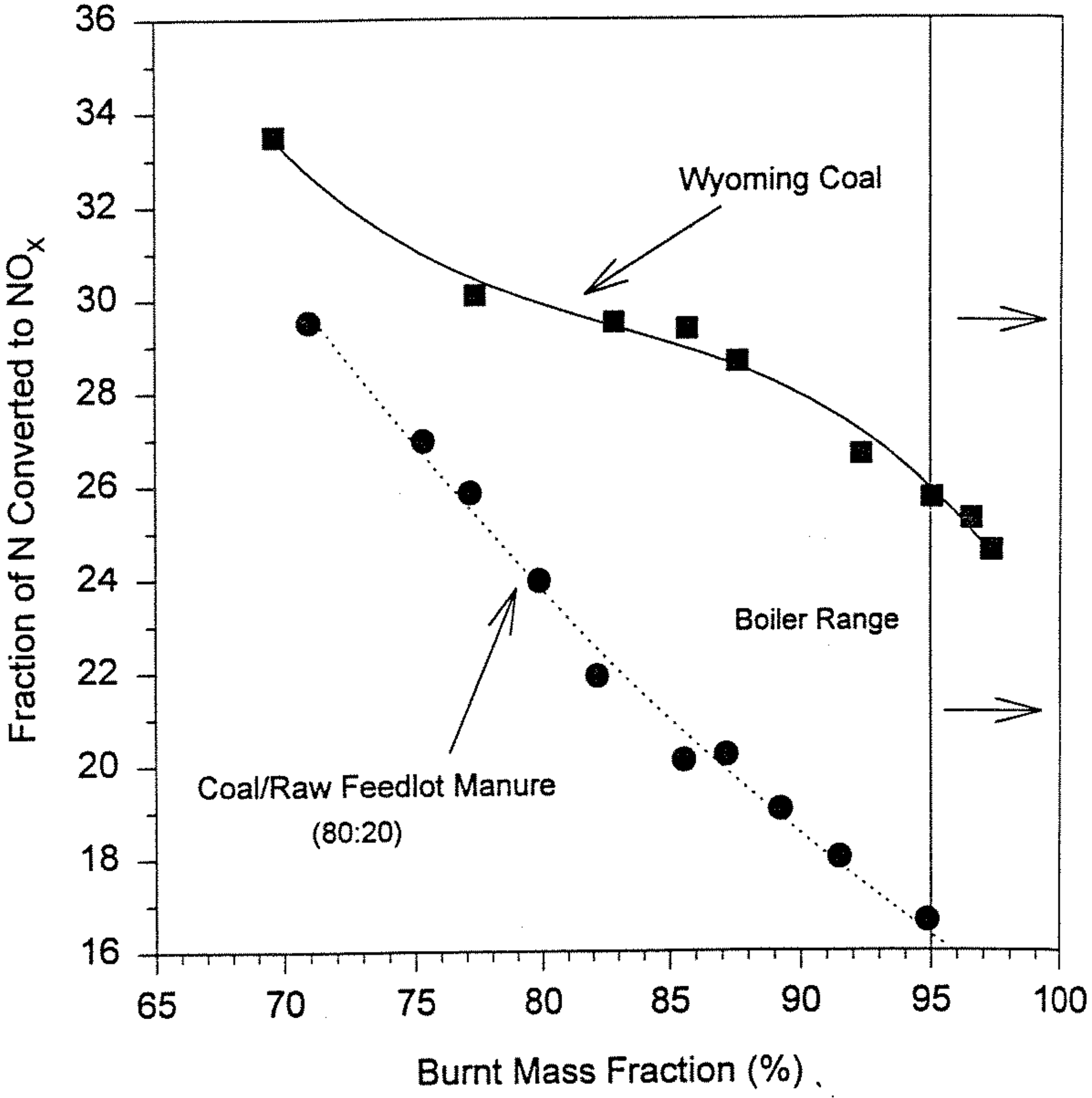

Figure 7. Comparison of the Fraction of N Converted to NO_x Between Coal and Coal/Raw Feedlot Manure.