LIVESTOCK WASTE STREAMS: ENERGY AND ENVIRONMENT

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COMBUSTION OF FEEDLOT MANURE FOR ENERGY RECOVERY

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ABSTRACT

Power plants spend nearly 50 billion dollars a year on fuel cost and coal accounts for over 75% of the electricity generated in the U.S.A. The fuel cost could be reduced by supplementing coal fuels with alternatives such as the byproducts of industries located in the near vicinity of the power plants. The supplemental fuel for utilities located near feedlots in Northwest Texas happens to be feedlot manure, a bio-solid waste. Feedlot manure is attractive because it is nearly 2.5 times cheaper than coal, on a BTU basis, and is relatively inexpensive to transport. Feedlot manure presents water and air pollution concerns if not disposed of properly. As such, the feedlot operators are eager to find methods of safely disposing of the feedlot manure. Since manure contains high moisture and low heat value, coal:manure blend technology is proposed to solve the waste problem. In order to determine the performance, Texas A&M has developed a research facility for firing a coal:manure blend and measuring the combustion efficiency and pollutants emission. The goals are i) to demonstrate the viability of blending coal with manure and firing in existing boiler burners, and ii) to help the feedlot operators in the Texas Panhandle area in reducing their clean-up and utility costs. A small scale boiler burner facility has been constructed. Experiments were conducted with coal only and then for 80:20 coal:manure blends. Data were taken during warm up, gasification and combustion. Performance characteristics and emission data were taken for each case. A summary of the findings is as follows:

1) Manure contains up to 80% volatile matter on DAF basis which is twice the VM of conventional coal. Thus combustion efficiency is higher with blend than with coal.

2) Emissions of NOx and SO2 increased as the burned mass fraction increased.

3) NOx emission increased from 420 at 80% burned fraction (f) to 550 ppm at 95% burned fraction for coal while corresponding numbers for coal:manure blend are 620 ppm to 550 ppm.

4) SOx increased from 30 ppm to 180 ppm for coal while for the blend it is almost zero up to 90% burned fraction, but increased to 10 ppm at 95% burned fraction. The reduced SO emission is possibly due to the capture of SOx by the alkaline ash of the feedlot manure.

5) When the fuel blend is fully burned, the NOx emissions with the blend firing was comparable to firing of coal alone, even though N of manure is twice as high compared to coal.

INTRODUCTION

Coal has become the dominant fuel for the production of electricity in the United States. As such, the attendant pollutant emissions has also increased. Significant among these pollutants are sulfur dioxide (SO2) and nitrogen dioxide (NO2) 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 emission of these pollutants have become particularly demanding. The cost associated with the new source performance standards (NSPS), NOx and SOx emission of 0.6 lb per million BTU, has dramatically risen in recent years.

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Fuel costs could be reduced if cheaper supplemental fuel sources were explored. One such alternate source exists in feedlot manure, which is nearly limitless (112 million tons in cattle and poultry manure per year). The quantity of waste that could be sold as fertilizer is negligible compared to the accumulation. These wastes, if stored over the land, pose severe problems in drinking water supply to the rural areas (Sweeten 1992) and releases CH₄, NH₃, H₂S, amines, volatile organic acids, mercaptans, esters and other chemicals. The methane accounts for the second largest emission from the land. In addition it creates air pollution and the waste management is a perennial problem for the feedlot operators. [Sweeten’s Testimony to Congress, 1989], and waste management is a perennial problem for the feedlot operators. Hence newer technologies are required to provide solutions to the feedlots. Various technologies have been attempted in the past on using feedlot waste as an energy source [Sweeten et al, 1986 and Annamalai et al, 1987]. They include on-site anaerobic digestion to methane in stirred tank and plug flow reactors and covered lagoons, gasification, fluidized beds [Annamalai et al, 1987] and circulating fluidized beds, etc. A few of the technologies failed since attempts were made to use them as sole source fuel. Anaerobic digestion is a slow process and further all the solids may not be converted into gas.

We had proposed to experiment with the co-firing of feedlot manure with coal. Since feedlot waste has higher moisture, higher nitrogen, chlorine and ash and lower heating values, a blend technology is essential where the blending with higher quality coal reduces the flame stability problems due to higher moisture in manure and as well as minimizes the corrosion effects due to higher Cl content of manure. Further the co-firing approach has the potential for immediate commercialization. Blend technology has been used before for RDF (Refuse Derived Fuel) using special binder densified RDF with coal [US DOE, 1993] with RDF quantities up to 20%. However, the characteristics of coal and feedlot manure differ. Feedlot manure contains 25%-75% volatile matter (as-received) as opposed to coal which contains volatile matter in the range of 20% - 40%. The heating value of feedlot manure, on average, is 15,000 kJ/kg (5,000 Btu/lb) versus coal which is 35,000 kJ/kg (14,000 Btu/lb). Since the characteristics of the two fuels are different, flame stability, combustion behavior and, most importantly, emission characteristics must be studied. In order to determine the performance, a blend of coal and manure was fired through a specially constructed boiler burner.

This technology, if successful, provides a method of safe disposal of animal waste, develops a strategy to market the waste as a fuel, increases the financial resources for the feedlot operators, reduces water and air pollution problems of storage of waste, reduces fossil fuel consumption, reduces SOx emission from coal fired facilities and at the same time provides a cheaper fuel for utilities, which annually spends almost 50 billion dollars on fuel alone.

**EXPERIMENTAL SETUP**

A schematic of the experimental setup is shown in Fig. 1. The boiler burner (1) 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 (2) 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) (3) before it enters the boiler through a swirlor. (4). The fuel feed system consists of a feed hopper (5) with a capacity of 14 kg (30.8 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 (6) runs through the conical section of the feed hopper and is driven by an adjustable DC motor (5 hp, 1725 rpm) (7). The auger can deliver up to 200 g/min (0.41 lbs/min) of coal into the boiler burner. The primary air (8) 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 suspension is then fired through the quarl (9) of the boiler burner. 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 (11) are injected into the boiler to catch the particulate 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 (10). The diagnostic system consists of an orifice plate for
measuring the secondary air flow rate, sheathed "type K" and "type S" thermocouple, 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 which
uses Electro Chemical Cells as sensors. The system can accurately measure six gases including, SO$_2$, NO, NO$_2$,
CO$_2$, and O$_2$. The probe also contains a "type K" thermocouple mounted at the tip for temperature
measurements. The sampling probe for each measurement was located at the centerline of the boiler far enough
downstream to ensure complete combustion.

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.

**FUEL CHARACTERISTICS**

The ultimate and proximate analysis are shown in Table 1, while the ash analyses are shown in Table 2. The
low S coal was supplied by Southwest Public Utilities and later pulverized to 70% passing through 200 mesh
(75 ppm). The manure samples were air dried at 80°F, ground to 8 mesh (2mm) particle, dried again and then
pulverized to 60 mesh (200 µm). ASTM D-5 test procedure was adopted in obtaining proximate analyses.
Manure like coal consists of fixed carbon, volatile matter, moisture and ash with the difference being higher
with manure having twice the VM of coal on dry ash free basis and larger % moisture. The heat values on a
dry ash-free basis for raw manure (RM), partially composted (PC), composting-decomposition of manure in air
producing CO$_2$ and water over a long period of time and finished composted (FC) are almost the same as the
heat value of rations fed to the cattle.

**PROCEDURE**

The experimental procedure for firing was as follows: the boiler burner was preheated to the desired
temperature (~ 800 K) using two propane torches. The secondary air was preheated to a minimum of 475 K
using a circulation heater. Once the appropriate temperatures were reached in the boiler, coal or blend was
injected and the experimental data were recorded. The feed air:fuel ratio is kept constant (near stoichiometric
conditions). As the reactor continues to warm up and burn more fuel, 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 furthest
from the burner just prior to water quenching. These transient measurements were made in order to understand
the relative rates of gasification, NO$_x$ and SO$_2$ release from coal and as well as the blend. Combustion
experiments are generally over a period of 30 minutes. The first data were taken with coal firing followed by
coal:raw manure (RM) blend, coal:partially composted (PC; composting-decomposition of manure in air
producing CO$_2$ and H$_2$O over a longer period of time with reduction in heat value on as-received basis) and
ccoal:finished composted (FC) manure blends.

**RESULTS AND DISCUSSION**

Boiler performance will be discussed in terms of the burned mass fraction, and most importantly emission
measurements. The temperature distributions with and without manure blend were not significantly affected.
Note that the probe is located just above water injection ports and hence the probe temperature will be lowered
within the reactor. This suggests that the addition of feedlot manure has not adversely affected flame stability.
The maximum axial temperature at 28 cm (11 in.) 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 suggest an RZ length of 22 cm
for the swirl number and swirl dimensions chosen.
As with the firing of coal, the maximum axial temperature 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. Again, the radial temperature distribution is relatively flat downstream of RZ varying by less than 50 K.

The fraction of fuel burned will depend on the residence time for combustion and also the reactor temperature. In the past both exhaust gas analysis and ash tracer methods have been used to determine the extent of coal gasification. Since fine particles are not captured in the ash tracer method, the ash tracer method gave a higher gasification compared to exhaust gas technique [Uphayak et al., 1976]. Further certain inaccuracies in the ash tracer method exist due to devolatilization of ash at high temperatures, and due to the dissolving of ash in the quench water. There the ash analysis is expected to yield a lower combustion efficiency than the actual value. The average combustion efficiency using the ash tracer method is about 67% while the exhaust gas analysis indicated 97%. The low combustion efficiency is due to collection of ash mass over a longer time period during which there may be fluctuations in flow. Due to the transient nature of combustion, the exhaust gas analysis technique is found to be more accurate and hence is used in determining the burned fraction. Knowing the exhaust gas O₂% and the ultimate analysis of fuel fired, one can determine the burned fraction. Typically the feed rate is selected around 100 g/min. As a check the vacuum bag collection indicated 92 g/min while the exhaust gas analyses indicated 82 g/min.

As the fuel enters a relatively cool reactor (≈ 250°C), a large percentage of the fuel will be unburned. As the fuel is burned, the reactor and the probe temperature slowly increases, accompanied by an increase in the burned mass fraction. As the amount of fuel burned increases, the oxygen content in the flue gas will decrease and the probe temperature increases. Fig. 2 shows the O₂ concentration versus probe temperature with coal firing. The rate of decrease of O₂ is an indication of rate of burning of coal. Therefore, there exists an important relationship between the burned fuel fraction, oxygen content, and reactor temperature. By knowing the oxygen percentage in the flue gases and the chemical composition of the blend, the burned fractions were computed; details were given in Frazzitta, 1993.

The CO emission is of the order of 4000 ppm and is ignored in (f) the burned fraction calculations. Figs. 3 to 5 plot the variation of burned mass fraction of fuel with the probe temperature for both coal and various coal:manure blends. At the maximum probe temperature of 1100 K (not the flame zone temperature), a burned fraction of 97% was recorded when firing coal alone. Alternatively at a maximum probe temperature of 1090 K, a burned mass fraction of 97% was recorded when firing the coal:raw manure blend. The similarity in the trend of burned mass fraction versus probe temperature in both cases suggests again that flame stability was maintained with the addition of 20% feedlot manure.

All emission measurements have been normalized with 3% O₂ in the products as prescribed by EPA guidelines. The sampling probe for each measurement was located at the centerline of the boiler far enough downstream to ensure complete combustion. The NOₓ production increases rapidly with burned fraction due to increased fuel N contribution from fuel (Fig. 6). However, as more fuel is burned, the O₂% decreases, and therefore, the rate of production of NOₓ begins to slow down. Maximum NOₓ emission (540 ppm) occurs at f = 0.97 (Fig. 6). Note that typical pulverized coal-fired boilers release 375-550 ppm for tangential-fired burners and 500-825 ppm for wall-fired boilers while stoker-fired boilers emit 250-400 ppm.

Fig. 6 compares the emission of NOₓ when firing coal alone and coal and raw feedlot manure. The error bars indicate fluctuations when experiments were repeated 3-4 times. As expected the emission of NOₓ has generally increased throughout the range of burned mass fraction. Since raw feedlot manure has nearly twice as much fuel nitrogen as Wyoming coal, the production of NOₓ is higher even at lower burned fractions (Fig. 6). Feedlot manure devolatilizes more readily than coal and hence N is released much earlier, even at low temperatures. Thus, even at low burned mass fraction or low temperature, the N released is readily oxidized. It is well known that the conversion of fuel N to NO is weakly dependent upon temperature but the strong function of local stoichiometry. Fuel N will readily form NO in an oxidizing atmosphere while it can be converted into molecular N₂ in reducing the atmosphere. In coal literature it has been reported that the increasing fuel:air ratio
and temperature will convert more NO into \( \text{N}_2 \). Thus, the rate of growth of NO is slowed down [Song, 1982]. It is clear that N to NO conversion is lower for blends. Look at the burned mass fraction of 70%. Wyoming coal produces 370 ppm NO\(_x\) while the blend produces approximately 490 ppm. Thus, 194 ppm (490 - 0.8 x 370) is due to the combustion of 20% manure, thereby indicating that the manure is burning. Thus, if one neglects the synergism effect, the manure alone will contribute to 970 ppm (= 194/0.2).

Typical boilers operate with an efficiency above 95%. At this point, since only 80% coal is used, the contribution of coal N to NO\(_x\) is 432 ppm (0.8 x 540). The manure (20%) releases approximately 55 ppm. Thus, if manure alone burns, it will contribute 275 ppm which is a significant decrease compared to emissions at lower temperatures.

Fig. 7 shows the fraction of N converted to NO\(_x\) when firing coal alone and various coal:manure blends. Both curves show the fraction of N converted to NO\(_x\) to be decreasing for all ranges of burned mass fraction. This trend would seem to indicate that the formation of NO\(_x\) is more oxygen dependent than temperature dependent. Emission measurements were repeated for coal:partially composed (PC) and coal:finished composted (FC) blends. Detailed results for coal:RM, coal:PC and Coal:FC blends are presented elsewhere [Frazzitta, 1993].

Fig. 8 shows the comparison of the results for SO\(_x\) emission for coal and various coal:manure blends. As more fuel is burned, the temperature rises, therefore more sulfur in fuel is converted into SO\(_2\), hence SO\(_x\) emissions increase. This indicates that SO\(_x\) emission is a strong function of burned fraction and weakly dependent upon \( \text{O}_2 \) concentration. Maximum emission of SO\(_2\) (198 ppm) occurred at \( T = 0.97 \). The surprising finding is that the SO\(_x\) emissions with the blend were less than the emissions when firing coal alone. It has been shown in earlier literature that coal ash captures up to 33 % SO\(_x\), from Low S coals in fluidized beds [Hoyt and Gill, 1987] and 5 and 50 % for bituminous and lignite coals [Lawn and Godridge, 1987]. Hence, ash analyses were performed on manure and coal ash (Table 2), which shows the composition of minerals in manure vs coal. The volatile ash is 17% for coal while blend contains 20%. Apparently, the manure ash captures the SO\(_x\) emitted by coal.

**ECONOMIC ANALYSIS**

Approximately, the manure fuel is about five times cheaper in comparison to coal on mass basis and about 2.5 times cheaper for the same thermal energy. Assuming coal to cost about $25 per short ton (at power plant), a 2200 MW (thermal) plant consumes almost 11,200 tons/day accounting for $102 million in fuel costs per year. The blending of coal with 20% manure for the same thermal power requires 2,500 tons of manure and 10,000 tons of coal per day which reduces the fuel cost to $95 million per year with a potential savings of $7 million per year for a 2200 MW coal fired utilities. On the other hand, a 50,000 head feedlot uses 50,000 mcf (1.4x10\(^{10}\) m\(^3\)) of natural gas and 3.9 million kWh of electricity at a total cost of $470,000 each year. About 210 metric tons (230 tons) of collectable manure are produced daily by a 50,000 head feedlot. If this waste is sold as a fuel at $3.00/ton (cost excluding transportation) which would overcome the cost of collection and temporary storage, then the feedlot recovers $250,000 which is more than half of the utility costs. It should be noted that manure is a renewable biomass fuel as opposed to fossil fuels and as such the supply of feedlot waste is assured, as long as the eating habits of the USA remains "American."

**SUMMARY**

A small scale boiler burner facility was constructed and instrumented for measuring temperature distribution, pollution emissions, and composition of flue gases. For the 80:20 blend of coal and manure the firing of coal blends did not change the temperature distribution or size of the recirculation zone, indicating that the flame stability was maintained. The formation of NO\(_x\) generally increased with burned mass fraction; however, the contribution of NO\(_x\) from the 20% feedlot manure decreased with burned fraction. 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. The most surprising finding is that the SO\(_x\) emission is lower for blended fuel than for pure coal firing probably due to capture by the alkaline ash of the feedlot manure. Using blend technology, one can
produce thermal energy and replace a part of the fossil fuels; at the same time the emissions from the storage of manure are reduced along with a reduction in emissions from coal-fired power plants.

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Sweeten, J., Testimony to Congress, House Committee on Agriculture, Stephenville, Texas, June 30, 1989.

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Table 1: Coal and Raw Feedlot Manure Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Coal</th>
<th>Raw Manure</th>
<th>Coal/Manure (80:20)</th>
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<tr>
<td>Moisture</td>
<td>10.8</td>
<td>36.61</td>
<td>15.96</td>
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<tr>
<td>Ash</td>
<td>5.68</td>
<td>25.25</td>
<td>9.6</td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>30.72</td>
<td>31.57</td>
<td>48.55</td>
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<tr>
<td>Fixed Carbon</td>
<td>52.80</td>
<td>6.57</td>
<td>25.89</td>
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<tr>
<td>Heat Value(DAF), kJ/kg</td>
<td>26535</td>
<td>7865</td>
<td>22801</td>
</tr>
<tr>
<td>Carbon</td>
<td>54.9</td>
<td>19.24</td>
<td>47.77</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>4.33</td>
<td>2.22</td>
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<tr>
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<td>23.32</td>
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<tr>
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<td>1.47</td>
<td>0.902</td>
</tr>
<tr>
<td>Sulfur</td>
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<td>0.53</td>
<td>0.378</td>
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Table 2: Ash Constituents of Coal and Manure

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<thead>
<tr>
<th>Element</th>
<th>Moisture Coal</th>
<th>Steam Distilled Manure</th>
<th>Coal/Manure (80:20)</th>
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<tr>
<td>Silica (SiO₂)</td>
<td>29.69</td>
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<td>Alumina (Al₂O₃)</td>
<td>13.63</td>
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<td>Iron (Fe₂O₃)</td>
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<td>1.71</td>
<td>1.27</td>
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<td>Calcium (CaO)</td>
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<td>13.88</td>
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<td>Magnesium (MgO)</td>
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<td>Sodium (Na₂O)</td>
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<td>Potassium (K₂O)</td>
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<tr>
<td>Phosphorus (P₂O₅)</td>
<td>0.89</td>
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<td>Sulfur (SO₂)</td>
<td>10.84</td>
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<tr>
<td>Chlorine (Cl)</td>
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<td>3.84</td>
<td>3.60</td>
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<tr>
<td>Titania ( TiO₂)</td>
<td>1.11</td>
<td>0.33</td>
<td>0.41</td>
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Fig. 1. Texas A&M Boiler Burner Facility

Fig. 2. Oxygen % in Flue Gases vs Probe Temperature

Fig. 3. Comparison of Burnt Mass Fractions
Coal and Coal: RM Blend

Fig. 4. Comparison of Burnt Mass Fractions
Coal and Coal: PC Blend