Co-firing Coal: Feedlot and Litter Biomass Fuels

Quarterly Progress Report # 7

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PROGRESS REPORT # 7

A. Proposed activities for quarter 7 (12/15/01-3/14/2002)

1. Incorporation of moisture model into PCGC2 code. Parametric study of moisture effects on flame structure and pollutants emissions in cofiring of coal and Liter Biomass (LB) (Task 4).
2. Use the ash tracer method to determine the combustion efficiency and comparison it to results from gas analysis (Task 2)
3. Effect of swirl on combustion performance (Task 2)
4. Completion of the proposed modifications to the gasifier setup (Task 3)
5. Calibration of the Gas Chromatograph (GC) used for measuring the product gas species (Task 3).
6. To obtain temperature profiles for different fuels under different operating conditions in the fixed bed gasifier (Task 3).
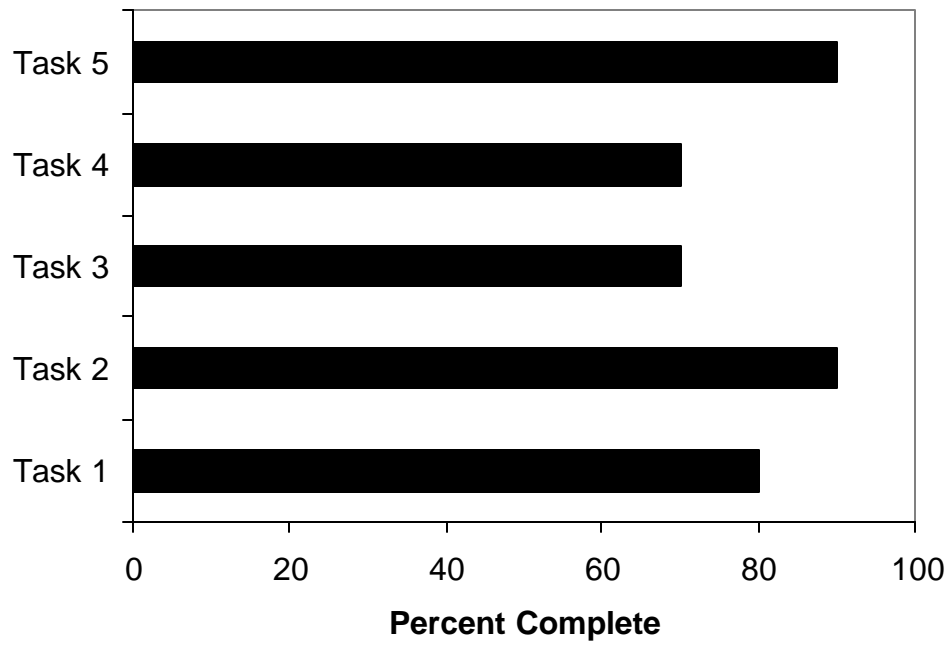
B. Achieved During Quarter 7 (12/15/01-3/14/2002)

1. 1.Moisture model is now incorporated in the PCGC2 code. Conducted a parametric study of moisture effects to flame structure and pollutants emissions in cofiring of coal and LB (Appendix A).
2. The results show that combustion efficiencies based on the ash tracer analysis are near 1, and the results are presented in Appendix B. The Sulfur capture in ash are found to be 4 to 8 % for coal while for feedlot biomass (FB) and LB the capture ranges from 8 to 18 %
3. Completed the proposed modifications to the setup (Appendix C-1).
4. Calibration of the GC has been performed (Table-Appendix C-1).
5. Obtained temperature profiles for different operating conditions for Coal and Feedlot biomass (Appendix C-2). Stoichiometric A:F calculations were performed for the batch mode gasification of FB (Appendix C-3).
6. LB sample analyses have been performed (Task 1b, Appendix D)
7. In addition a paper entitled, 'Co-firing of coal and broiler litter (BL) fuels for power generation: BL fuel quality and characteristics.' is being prepared to be presented at the American Society of Agricultural Engineers Annual International meeting at Chicago in July 2002.

See the attached milestone log for a summary of the progress.

C. Proposed activities for quarter 8 (3/15/01-6/14/2002)

1. Continue the parametric study of cofiring of pulverized coal and LB according to the following factors: combustion behavior, flame structure, and emissions of NO, CO, CO_2, PO_2 and P_4O_{10}, etc. The air-fuel ratio, swirl number of the secondary air stream and moisture effects will also be investigated.
2. Measuring the temperature profile for chicken litter biomass under different operating conditions.
3. Measuring the product gas species for different operating conditions for different fuels.
4. Determining the bed ash composition for different fuels.
5. Determining the gasification efficiency for different operating conditions.

Milestone Log- **DE-FG26-00NT40810-Annamalai-**Quarter # 7; **Report Period**:   12/15/01-

3/14/2002

Percent Complete bar chart showing Task 1 at 80, Task 2 at 90, Task 3 at 70, Task 4 at 70, and Task 5 at 90.
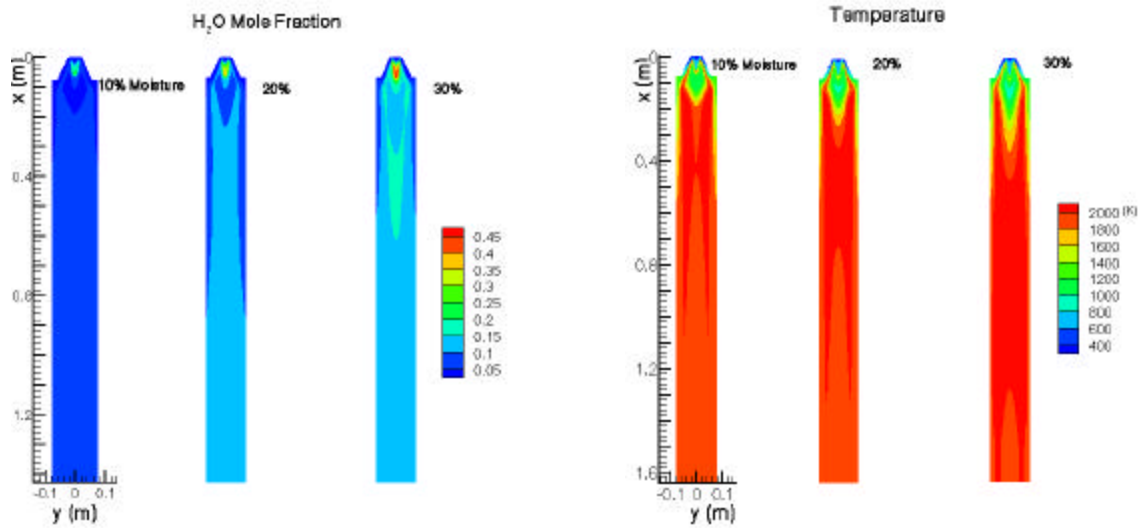
APPENDIX A: Simulation Studies (Task 4)

The PCGC2 code was modified with the three mixture fractions tracking primary air, fuel offgas, and moisture. A moisture vaporization model was added into the PCGC2 code. The particle vaporization model is as follows: as the vaporization proceeds a dry outer layer is formed and there exists an inner wet core. The dry layer enlarges while the wet layer shrinks during vaporization. The moisture evaporation rate equation (Annamalai et al, 1987) is used.

Parametric studies were conducted for cofiring of coal and LB with coal in a mass ratio of 9:1. Corresponding to experiments with 10% excess air, the primary airflow rate is 109 SCFH (0.001012 kg/s) at 298K, and the second airflow rate is 1113 SCFH (0.008205 kg/s) at 373.15K. Swirl number is zero for primary air stream and 0.7 for secondary air stream. Three cases were studied with moisture content in both coal and LB of 10%, 20% and 30% respectively. The air pressure at both primary and secondary air stream inlets is assumed to be one atmosphere.

Figure 1 shows the calculated temperature, H_2O, CO_2, CO, H_2, and NO distributions. The axial distance from burner inlet to roughly the highest temperature is called the flame standoff distance. It is seen that the flame standoff distance increases with increasing moisture content. This is because evaporation from fuel with higher moisture takes a longer time and thus delays fuel pyrolysis and fuel offgas release. It is also seen that the H_2O mole fraction is higher for higher moisture contents as expected. As moisture content increases, CO model fraction decreases while CO_2 and H_2 decreases in the upper part of the furnace due to the reaction $H_2O + CO \rightarrow CO_2 + H_2$. The effect of moisture content to NO, however, looks insignificant.
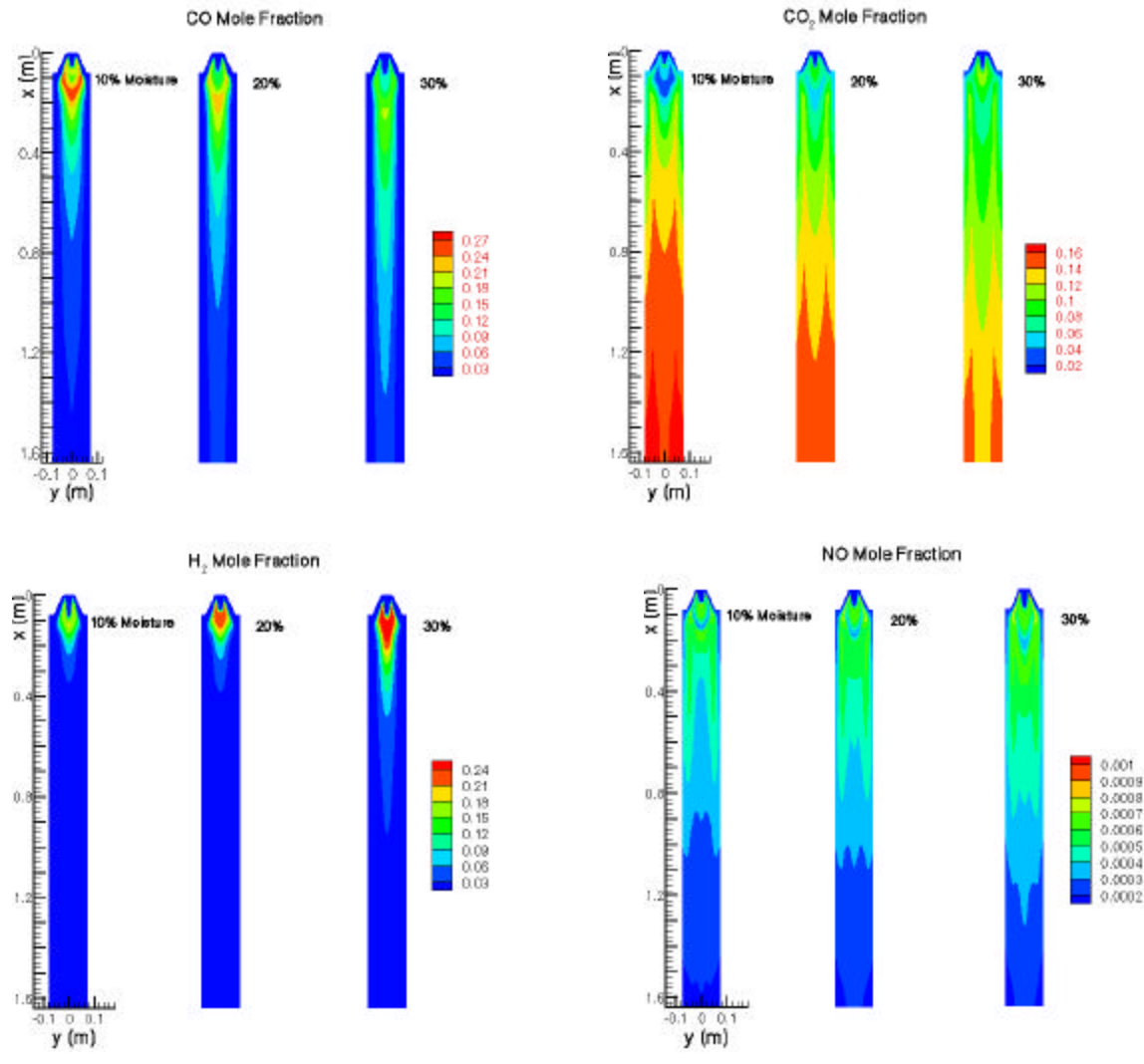
Figure 1. Calculated distributions of temperature and species mole fractions.

References

Annamalai, K. A., Caton, J. A., Roth, J., Ryan, W. and Schmidt, J., 1987, "Performance and emissions of coal-fueled engines using combustion theory", Contract No. DE-AC21-86, Interim Report 1986-1987, Department of Mechanical Engineering, Texas A&M University, College Station, Texas.

Appendix B: Ash Tracer Analysis

Ash collected from the experiments was analyzed to determine the burnt mass fraction and the fraction of sulfur captured in the ash. The analysis was conducted by Huffman labs who dried and then analyzed the samples for ash and total sulfur content. The results were then reported on a dry basis. The results of the burnt mass fraction analysis (figure 1) shows that the burnt mass fraction for all of the fuels was in the range of 0.95-.99 or very close to one. The values are higher than the burnt mass fraction calculated from the gas analysis, which were in the range of 0.85 to 0.95. Like the burnt mass fraction gas analysis, it shows that the burnt mass fraction will be similar for both the coal, and the blended biomass fuels. The fraction of sulfur capture is shown in figure 2. Here the sulfur capture fractions are all less than 0.2, as is expected in coal combustion. The results indicate that the biomass ash captured a slightly greater fraction of sulfur than the coal ash. The results here do not indicate a high level of sulfur absorption as predicted by the gas analysis. The difference could be due to errors in measuring the sulfur absorption based on the gas analysis, or sulfur could be absorbed by the walls for the furnace, which is partially composed of CaO.
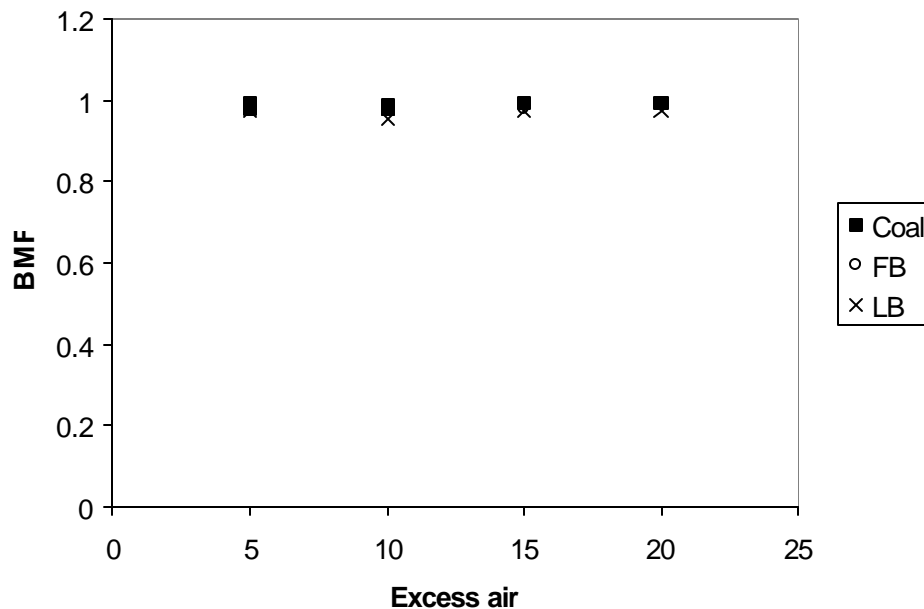

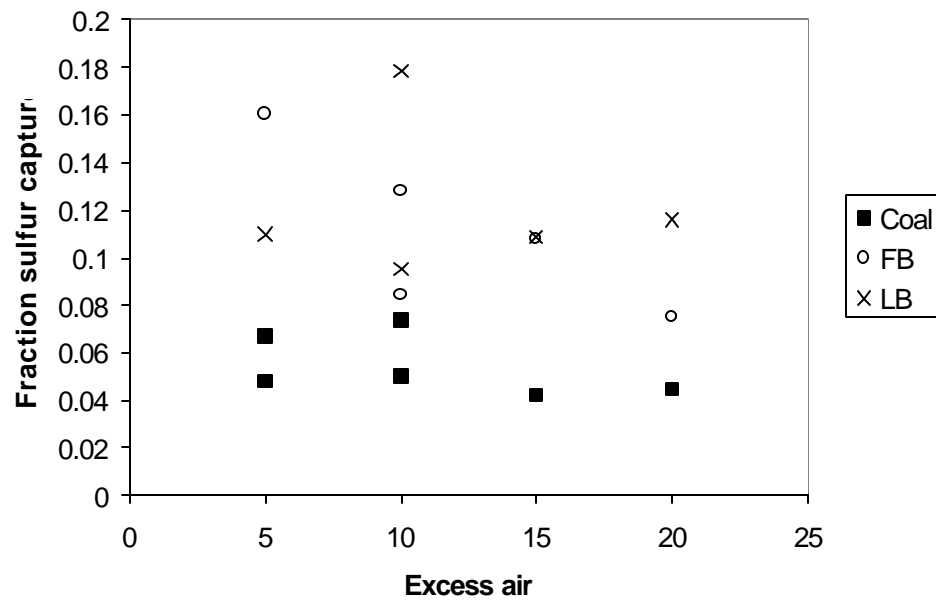Figure 1: Burnt mass fraction based on the ash analysis.

Figure 2: Fraction Sulfur absorbed based on the ash analysis.

Appendix C: Fixed Bed Gasification (Task 3)

In this quarter, there has been a modification to the setup and the temperature profiles for the different fuels have been obtained. The gas chromatograph (GC) has been calibrated for the expected gases and the gas sampling system has been designed.

C-1 Modifications:

The gas sampling method has been modified. The presence of excess tar excess CO (up to 25% by vol.) forbids the usage of the gas analyzer (Enerac 3000E) used in the laboratory. So, it was decided to measure the gas species using a gas chromatograph. Since an online system is not possible in the laboratory, the gas samples have to be collected using syringes and stored in gas tight containers (vials) before being taken to the TCD (thermal conductivity detector) for analysis. Before collecting the gas samples the samples are conditioned, by passing them through a hydrophobic filter followed by cooling in a heat exchanger then passing them through a moisture filter (using nafion tubes, which allow most gases to pass through excepting NH_3) and then passing them through another hydrophobic filter. There is an additional hydrophobic filter (0.2*m*m) at the syringe inlet. This enables the samples gases to be clean enough to avoid impurities inside the TCD. A sample pump is used to draw the sample gases from the gasifier at different locations along the length. The gas sample is drawn at a constant rate of 2.5 SCFH by the pump, and a flow regulator helps to ensure the required flow rate. The gas samples are stored in 4ml capacity vials with Teflon lined septums. The gases are going to be analyzed by a HP 6890 TCD using a 60/80 Carboxen packed column. The measured gas species are H_2, N_2, CO, CH_4, CO_2, C_2H_4, and C_2H_6. The GC takes a total elution time of 20 minutes per sample. The Gas Chromatograph was calibrated and the correction factors for different gases were calculated (Table 1).

Element	Calibration Gas				Correction factor
	Actual readings		Theoretical readings		
	Mole frctn	% Vol.	Mole frctn	% Vol.	
H2	0.039355	3.935528	0.1	10	2.540955307
N2	0.219384	21.93837	0.2	20	0.911644637
CO	0.433216	43.32156	0.4027	40.27	0.929560352
CH4	0.073814	7.381442	0.05	5	0.677374375
CO2	0.117252	11.72523	0.147	14.7	1.253706458
C2H4	0.056632	5.66315	0.05	5	0.882900797
C2H6	0.060347	6.034719	0.0503	5.03	0.833510274

Table 1: Correction factor for measured gas species

In order to calculate the gasification efficiency it necessary to measure the product gas flow rate. However, the presence of condensable tar makes it difficult to measure the flow rate. Therefore, the product gas is water scrubbed and then the cleaner product gas flows through a rotameter to measure the flow rate.

Previously the fuel in the gasifier was ignited using charcoal mixed along with fuel, this lead to a lot of ignition trouble as the incoming air was at 25°C, which took a lot of time to ignite. In the new system, the reactor is heated to around 250°C, by using two propane torches, which heat the incoming cold air. Then a small amount of fuel is added to the grate and the heating continues until the fuel burns, at this point the external heating is stopped, and more fuel is added slowly to get the bed height to the required height above the grate. The advantage of this method is a quicker ignition and the ash composition does not change, as charcoal is not added to the fuel.

C-2 Temperature Profiles:

The temperature profiles along the fuel bed were measured for coal and feedlot biomass under airflow rate of 45 SCFH. The temperature along the bed was measured at six locations and during the experiments; the bed height was kept constant at 6.75"~ 0.5". The runs are conducted over a stretch of three hours for each operating condition. It takes about one hour for the bed to stabilize at the required height. Then the temperature readings are taken over a period of two hours. Since there is a problem of ash disposal from the bed the experiment cannot be run for a longer time, as ash accumulation above the grate pushes the oxidation zone further into bed and a actual representative temperature profile is difficult to obtain.

For feedlot biomass there is flaming pyrolysis of the fuel due to higher volatile content. Due to which the fuel feed rate is higher to maintain the same bed height. A comparison of the temperature profiles between coal and feedlot biomass for 45 SCFH primary airflow rate shows (fig. 1) that there is a distinct temperature peak for feedlot biomass. This is because it has lower fixed carbon, which burns quickly, and the temperature just above the grate drops as there is only ash, where as for coal since it has a higher fixed carbon content (refer to Table 2), the particles above the grate are still burning so the peak temperature occurs at the grate itself. Due to flaming pyrolysis for feedlot biomass, the freeboard temperature much higher as the volatile matter might be burning in the freeboard region, which is not true for coal (refer appendix C-3 for stoichiometric air calculations). As the measuring thermocouples are ungrounded and sheathed, the temperature in the bed is the average temperature of the gas and solid phase.

Proximate Analysis			Ultimate Analysis		
	Feedlot	Coal	Element	Feedlot	Coal
Dry loss	10.875	21.225	Carbon	37.205	56.345
Volatile Matter	56.965	32.58	Hydrogen	5.65	5.905
Fixed Carbon	17.33	41.92	Oxygen by difference	38.26	32.35
Ash	14.83	4.275	Nitrogen	3.405	0.85
Phosphorus	0.955	NA	Sulfur	0.65	0.275
HHV (BTU/Lb)	6441.5	9376	Ash	14.83	4.275

Table 2: Comparative Proximate and Ultimate Analysis for coal and feedlot.

Future work:

The temperature profiles for chicken litter biomass are to be obtained for different operating conditions. The measurement of gas species shall be done for all the cases.
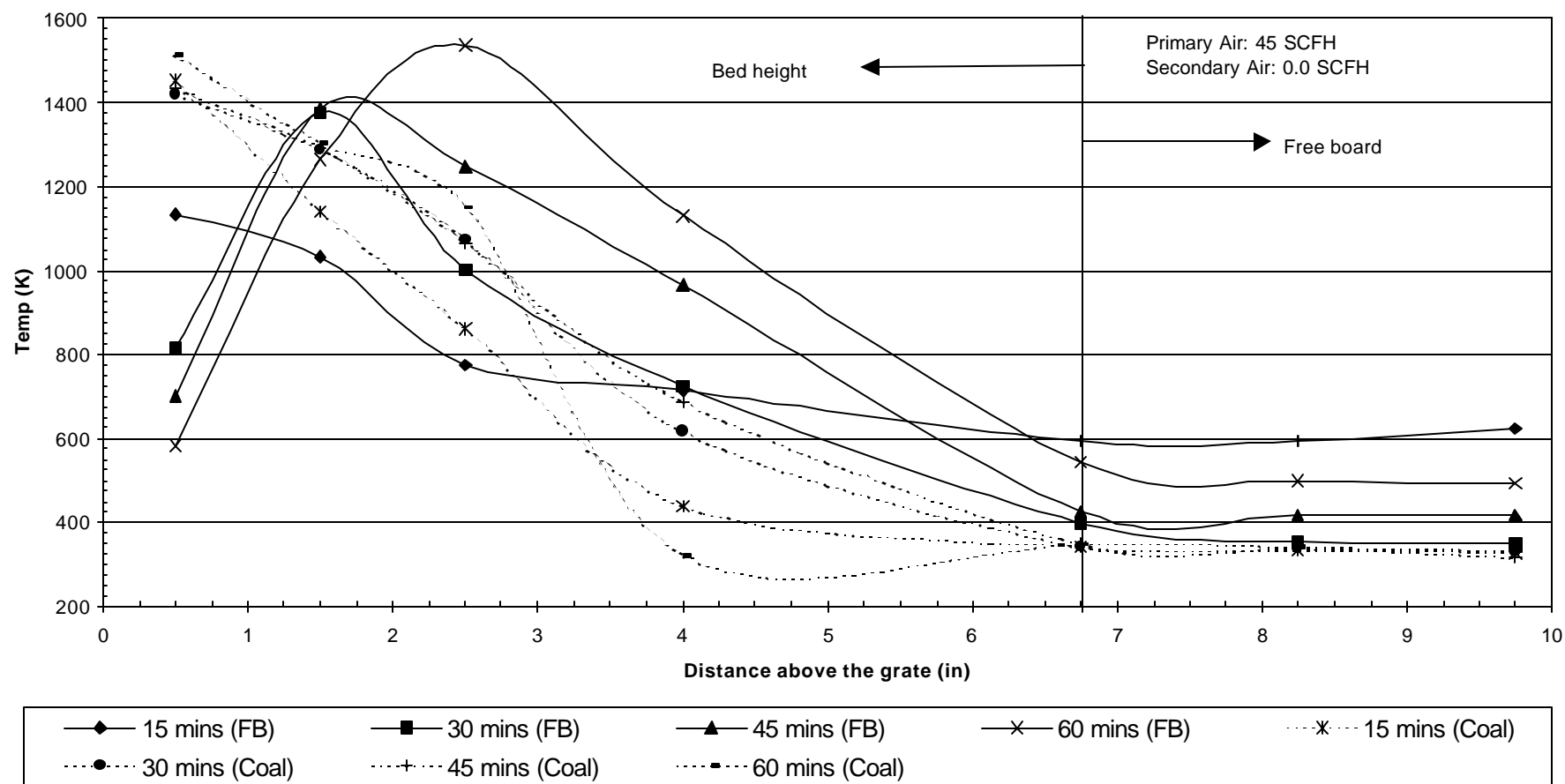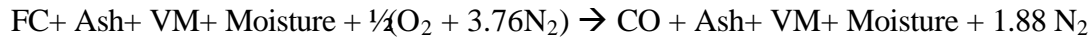
Figure 1: Comparison of temperature profiles at different time intervals for Coal and feedlot biomass.

C-3 Stoichiometric Air calculation

1. **Assuming all the FC oxidizes to CO**:

FC+ Ash+ VM+ Moisture + ½(O_2 + 3.76N_2) → CO + Ash+ VM+ Moisture + 1.88 N_2

Coal:

FC = 41.92 % (assume to be Carbon)
Stoichiometric A/F ratio (mass basis) = 5.72
A/F ratio actual (mass basis)
Coal consumed per hour: 1.2665 kg/hr
FC consumed per hour: 0.4192*1.2665 = 0.5309 kg/hr
Air supplied per hour: 45 SCFH = 1.2857 m^3/hr
⇨ 1.4914 kg/hr
A/F ratio actual (mass basis) = 2.809

SR = 0.4911

Feedlot biomass:

FC = 17.33 % (assume to be Carbon)
Stoichiometric A/F ratio (mass basis) = 5.72
A/F ratio actual (mass basis)
Feedlot biomass consumed per hour: 1.71428 kg/hr
FC consumed per hour: 0.1733*1.71428 = 0.2971 kg/hr
Air supplied per hour: 45 SCFH = 1.2857 m^3/hr
⇨ 1.4914 kg/hr
A/F ratio actual (mass basis) = 5.02

SR = 0.8776

2. Stoichiometric ratio of DAF fuel calculation assuming products as CO and H_2

$Fuel_{DAF} + air \rightarrow CO + H_2 + other\ products$

Coal:

DAF fuel formula: $CH_{0.747868}O_{0.179475}N_{0.0122875}S_{0.00183}$

Stoichiometric air calculation:
$CH_{0.747868}O_{0.179475}N_{0.0122875}S_{0.00183} + 0.41023\ (O_2 + 3.76N_2) \rightarrow CO + 0.373934\ H_2 + 1.549025\ N_2 + 0.00183\ S$

A/F ratio (DAF mass basis): 3.549663

Actual A/F ratio calculation:

Coal consumed per hour: 1.2665 kg/hr
DAF fuel consumed per hour: 0.745*1.2665 = 0.9435 kg/hr
Air supplied per hour: 45 SCFH = 1.2857 m^3/hr
$\Rightarrow$ 1.4914 kg/hr
A/F ratio actual (mass basis) = 1.5806

SR = 0.4453

Feedlot biomass:
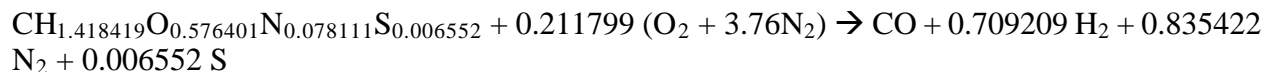
DAF fuel formula: $CH_{1.418419}O_{0.576401}N_{0.078111}S_{0.006552}$

Stoichiometric air calculation:
$CH_{1.418419}O_{0.576401}N_{0.078111}S_{0.006552} + 0.211799\ (O_2 + 3.76N_2) \rightarrow CO + 0.709209\ H_2 + 0.835422\ N_2 + 0.006552\ S$

A/F ratio (DAF mass basis): 1.213368

Actual A/F ratio calculation:

Feedlot biomass consumed per hour: 1.71428 kg/hr
DAF fuel consumed per hour: 0.74295*1.71428 = 1.27362 kg/hr
Air supplied per hour: 45 SCFH = 1.2857 m^3/hr
$\Rightarrow$ 1.4914 kg/hr
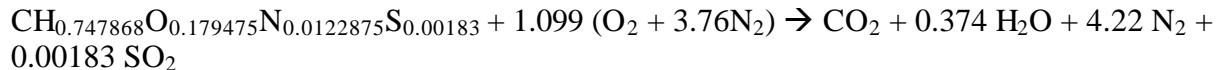A/F ratio actual (mass basis) = 1.170988

SR = 0.96507

3. Stoichiometric ratio of DAF fuel calculation assuming products as CO_2 and H_2O, complete combustion

$Fuel_{DAF}$ + air $\rightarrow$ CO_2 + H_2O+ other products

Coal:

DAF fuel formula: $CH_{0.747868}O_{0.179475}N_{0.0122875}S_{0.00183}$

Stoichiometric air calculation:
$CH_{0.747868}O_{0.179475}N_{0.0122875}S_{0.00183} + 1.099 (O_2 + 3.76N_2) \rightarrow CO_2 + 0.374\ H_2O + 4.22\ N_2 + 0.00183\ SO_2$

A/F ratio (DAF mass basis): 9.508

Actual A/F ratio calculation:

Coal consumed per hour: 1.2665 kg/hr
DAF fuel consumed per hour: 0.745*1.2665 = 0.9435 kg/hr
Air supplied per hour: 45 SCFH = 1.2857 m^3/hr
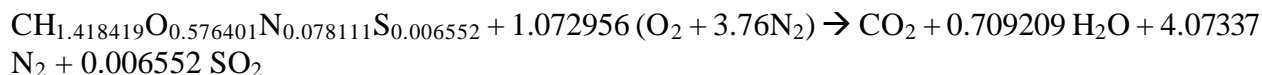$\Rightarrow$ 1.4914 kg/hr
A/F ratio actual (mass basis) = 1.5806

SR = 0.16624

Feedlot biomass:

DAF fuel formula: $CH_{1.418419}O_{0.576401}N_{0.078111}S_{0.006552}$

Stoichiometric air calculation:
$CH_{1.418419}O_{0.576401}N_{0.078111}S_{0.006552} + 1.072956 (O_2 + 3.76N_2) \rightarrow CO_2 + 0.709209\ H_2O + 4.07337\ N_2 + 0.006552\ SO_2$

A/F ratio (DAF mass basis): 6.14680

Actual A/F ratio calculation:

Feedlot biomass consumed per hour: 1.71428 kg/hr
DAF fuel consumed per hour: 0.74295*1.71428 = 1.27362 kg/hr
Air supplied per hour: 45 SCFH = 1.2857 m^3/hr
$\Rightarrow$ 1.4914 kg/hr
A/F ratio actual (mass basis) = 1.170988

SR = 0.19050
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Appendix D:

Sample Analyses of LB (Task 1b)

Currently, excreta during the complete life cycle of a broiler (about 29 days) is being collected for ultimate, proximate analyses and heating values. To accomplish this task, excreta from broilers raised at the Texas A&M University Poultry Research Center is being collected based collected at 3, 5, and 7 week intervals corresponding to the change in feed composition. This sampling scheme provides a more representative assessment of broiler excreta contents. Earlier, litter biomass (a mixture of excreta and bedding material such as pine wood shavings) samples were analyzed for the above mentioned parameters. Excreta analyses will shed light on differences between excreta and bedding material versus excreta only and provide information on sources and availability of chemicals such as phosphorous, calcium and total carbon.

Broiler Operations (Task 1b)

Task 5b was concluded by providing broiler litter production information from operations in the 8 county Brazos valley area in specific, and from operations in Texas and the USA in general.

In addition a paper entitled, 'Co-firing of coal and broiler litter (BL) fuels for power generation: BL fuel quality and characteristics.' is being prepared to be presented at the American Society of Agricultural Engineers Annual International meeting at Chicago in July 2002.