Establishment of an Environmental Control Technology Laboratory with a Circulating Fluidized-Bed Combustion System

Quarterly Technical Progress Report

October 1 – December 31, 2004

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ABSTRACT

This report is to present the progress made on the project "Establishment of an Environmental Control Technology Laboratory (ECTL) with a Circulating Fluidized-Bed Combustion (CFBC) System" during the period October 1, 2004 through December 31, 2004. The following tasks have been completed. First, the renovation of the new Combustion Laboratory and the construction of the Circulating Fluidized-Bed (CFB) Combustor Building have proceeded well. Second, the detailed design of supporting and hanging structures for the CFBC was completed. Third, the laboratory-scale simulated fluidized-bed facility was modified after completing a series of pretests. The two problems identified during the pretest were solved. Fourth, the carbonization of chicken waste and coal was investigated in a tube furnace and a Thermogravimetric Analyzer (TGA). The experimental results from this study are presented in this report. Finally, the proposed work for the next quarter has been outlined in this report.

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1. EXECUTIVE SUMMARY

The following advancements have been achieved this quarter (October 1, 2004 through December 31, 2004). First, since the drill was damaged by hard rock during the digging of the foundation for the Circulating Fluidized-Bed (CFB) Combustor Building. As a result, the construction achieves on this building had to be delayed a couple of weeks. However, the renovation of the new Combustion Laboratory is on schedule. Second, the steel frame for supporting the CFB Combustor was integrated with the CFB combustor on the drawing. The support system required to eliminate horizontal displacement and twist of the CFB combustor riser was designed in detail. Third, the laboratory-scale simulated fluidized bed facility was modified to correct problems found during pretesting. Fourth, the carbonization of coal and chicken waste (CW) mixtures was conducted on a tube furnace, and the solid residues after carbonization were analyzed on a Thermogravimetric Analyzer (TGA). Finally, the work to be completed in the next quarter is briefly introduced, and the reasons for delays incurred in some of the tasks are discussed.

2. EXPERIMENTAL

2.1.Renovation of Combustion Laboratory and Construction of CFB Combustor Building

The renovation of the Combustion Laboratory is on schedule. However, the construction contractor's drill was damaged by hard rock during the digging of the foundation for the CFB Combustor Building. As a result, the construction of the CFB Combustor Building was delayed. The contractor expects to complete the CFB Combustor Building before June 1, 2005, according to the modified schedule.

2.2. Design and Manufacture of CFBC Facility

The supporting steel frame of the CFBC Facility was integrated with the CFB combustor on the drawing, as shown in Figure 1. Based on this drawing, the detailed structures of the CFBC

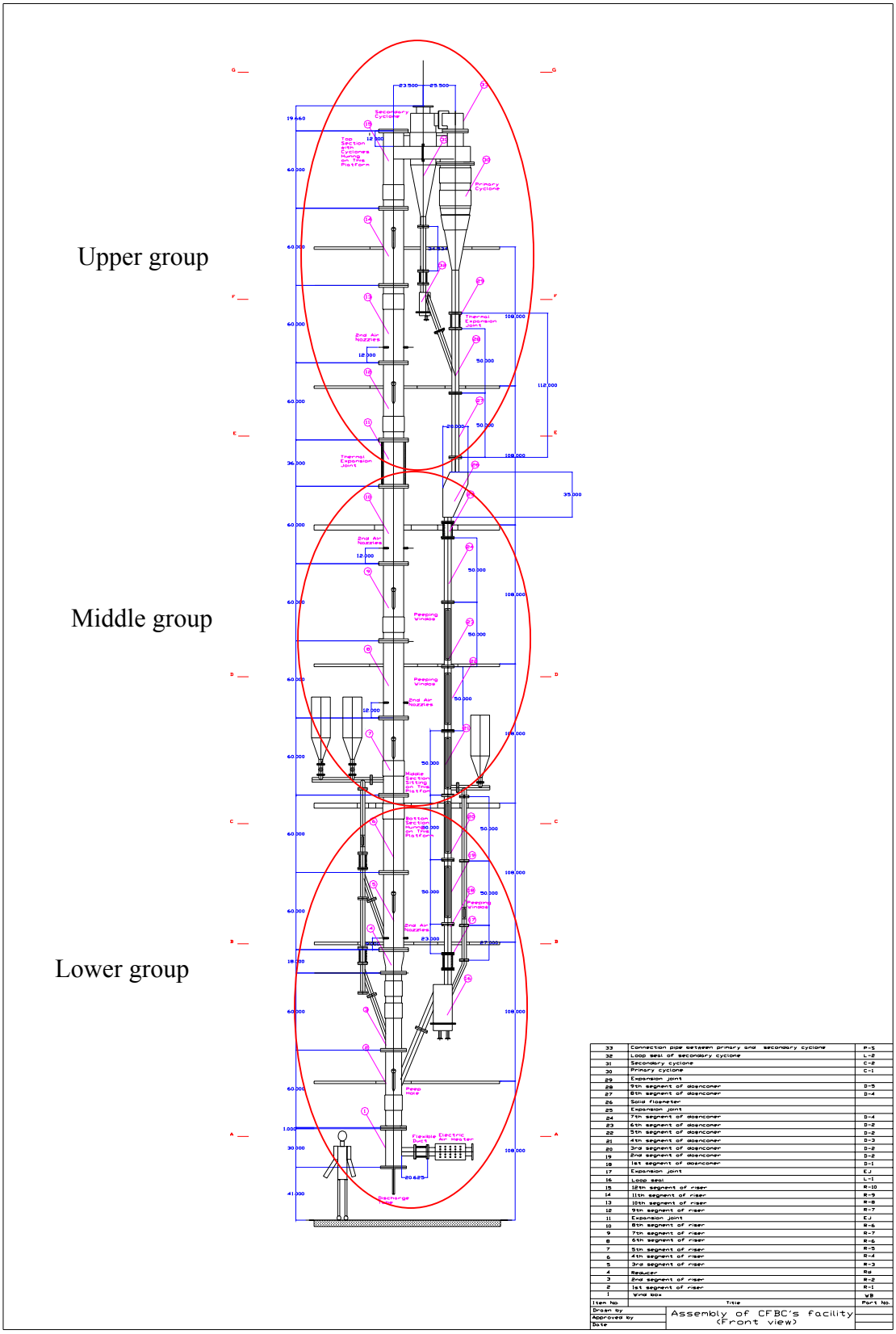

Figure 1. Integration of supporting steel frame with CFBC facility

FBC Facility support system were designed. The riser of the CFBC Facility was divided into three groups, i.e. upper, middle, and lower. The lower group, which consists of four pipe sections, a reducer, and a windbox, is hung from the fourth platform of the steel frame (the ground being the first platform). The middle group, which includes four pipe sections, sits on the fourth platform of the steel frame also. The upper group, which has four pipe sections, a primary cyclone, and a secondary cyclone, is hung from the top platform of the steel frame. Such supporting allows the lower and upper groups to move downward without limit while the middle group expands upward. A thermal expansion joint was designed specially to connect the middle group with the upper group. This joint can accommodate the thermal expansions of the upper and middle groups. To avoid possible displacement in the horizontal direction and twist of the CFBC riser, a structure was designed to eliminate such displacement and twist as shown in Figure 2.

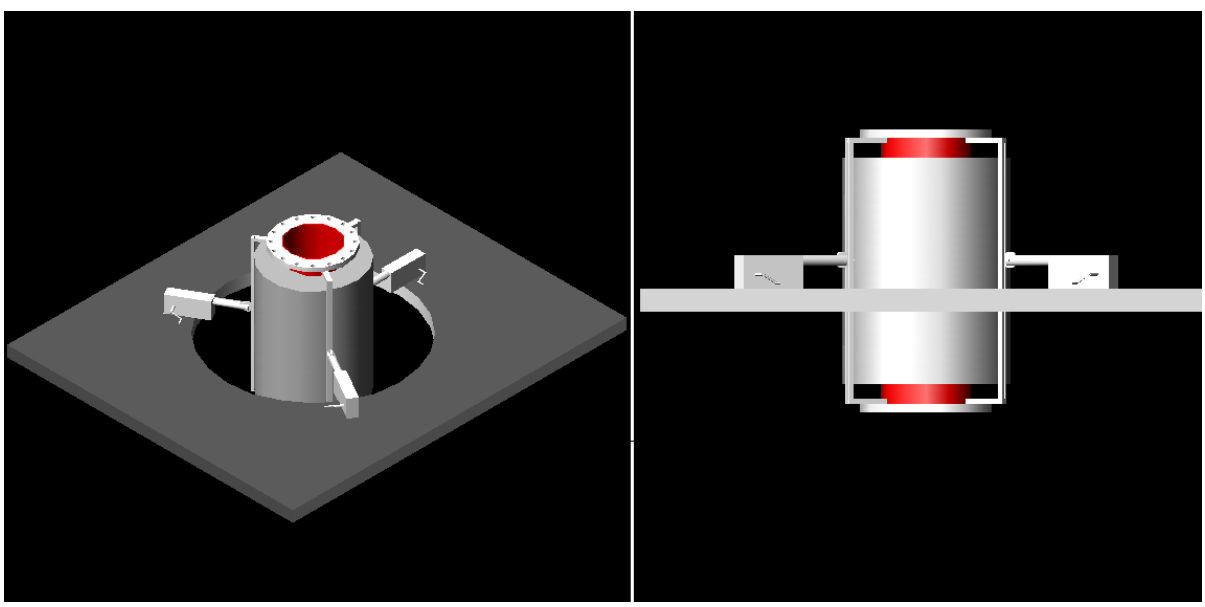

Figure 2. Structure for eliminating the horizontal displacement and twist of CFBC riser

This structure will be installed on the second, sixth, and seventh platforms of the steel frame. As shown in Figure 2, three wheels with adjustable support arms are fixed with uniform distribution annularly on each platform. Three tracks are attached to the riser pipe at the corresponding location of the three wheels. Each wheel can only move inside the corresponding track vertically; therefore, the horizontal displacement and twist of the CFBC riser will not be

possible. The movement of the CFBC riser in the vertical direction due to the thermal expansion is allowed since the wheels can slide inside the track vertically.

To date, potential manufacturers for the component parts of the CFBC Facility have been contacted. The relevant drawings have been sent to the potential manufacturers for review and quotation. The contract for fabricating the component parts of CFBC facility will be awarded soon.

2.3 Modification of Laboratory-Scale Simulated Fluidized Bed Combustor

After a screw-feeder with a rotation speed controller and a water-cooling section were installed, a pretest was conducted on the modified laboratory-scale simulated fluidized bed combustor. Two problems arose during the pretest. First, it was determined that the seal between the cover and the hopper of the screw feeder could allow the flue gas to go through the fuel falling tube installed on the top flange of the combustor and enter the hopper. This bypassed flue gas stream could hinder the coal particles from falling inside the fuel falling tube. The method used to solve this problem was to put some seal tapes between the cover and the hopper to stop the leakage. At the same time, adjustable belts were used to bond the cover and the hopper tightly. Second, the end of fuel falling tube was too far from the bed surface, which results in the upward flow of flue gas entraining some fine coal particles out of the combustor before they fell into the dense zone of the fluidized bed. Therefore, some very fine char particles were found in the gaseous sampling system deployed after the mini-cyclone. The means to avoid this phenomenon was to extend the end of the fuel falling tube close to the bed surface to reduce the entrainment of fine coal particles by the flue gas. To control the flowrate of the fluidizing air supplied into the bed accurately, a 250 SLPM mass flow controller was installed. The formal tests for co-combustion of coal and waste will be conducted in the next quarter.

2.4 Carbonization of Chicken Waste and Coal

Based on the experimental results obtained from the previous quarter for chicken waste pyrolysis and incineration on a TGA, mixtures of chicken waste and coal were carbonized on a tube furnace, and the solid residues from the carbonization process were tested on a TGA. The tube furnace employed in this study is shown in Figure 3.

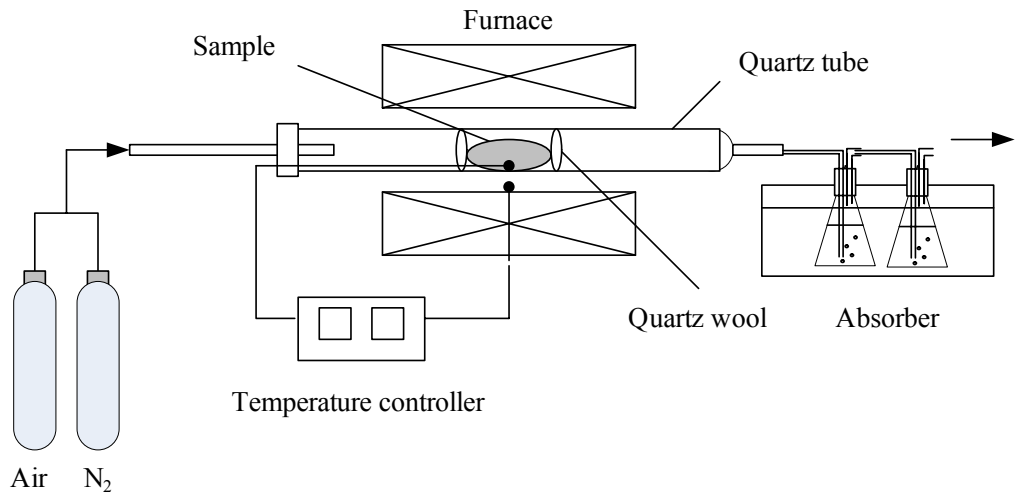

Figure 3. Schematic of experimental setup for chicken waste and coal carbonization

A 15" tube with a 13/16" inside diameter was inserted into an electric furnace. The weighed sample was put into this tube with quartz wool on both sides. The tube was heated to the desired temperature by the electric furnace via a temperature controller. For pre-oxidation experiments, the temperature inside the tube was set at about 204°C. Compressed air supplied by an air compressor flowed through the tube for about 60 minutes, then the air flow was switched to the nitrogen purge gas as the temperature was increased to about 427°C. After the sample sat in an 427°C nitrogen atmosphere for about 60 minutes, it was cooled down in a nitrogen stream. The solid residues were analyzed by TGA to study the properties of the char. For carbonization experiments, the weighed sample sat in an 427°C nitrogen atmosphere for about 60 minutes. Similarly, the solid residues were tested on a TGA. The char yield was evaluated in this study, and it can be estimated by the following equation:

$$\eta(\%) = \frac{m_{char}}{m_0} \times 100$$

where η is the char yield (%),and m_{char} and m_0 are char mass (g) and sample mass (g), respectively. The gaseous and liquid products were swept out of the reactor by the carrier gas and collected in a glass condenser immersed in a water bath. The condensable and gaseous fraction was not collected since the yields were very small.

3. RESULTS AND DISCUSSION

3.1 Proximate and Ultimate Analysis of Chicken Waste and Coal

The chicken waste and coal used in this study were analyzed for proximate and ultimate analysis, respectively. The analysis results are listed in Table 1.

Table 1. Summary of proximate and ultimate analysis of chicken waste and coal

Name	Moisture wt%	Ash wt %	Volatile Matter wt%	S wt %	Heat BTU/ lb	C wt%	H wt%	N wt%	O wt%	Cl ppm	Hg ppm
CW	10.60	26.6	54.7	0.8	5166	29.1	5.1	3.4	35	-	-
Coal	6.18	9.40	34.21	2.81	12118	67.18	5.36	1.46	13.78	107	0.10

Mixture samples with different blend ratios (20:80, 50:50 and 80:20 by weight) of coal to chicken waste were tested in this study. These samples are listed in Table 2.

Table 2. The list of tested samples with different blend ratios

Coal (below 0.08mm) (%)	Chicken Waste (milled) (%)	Sample Name			M %	A %	V %	Heat Btu /lb	C %	H %	O %	N %	S %
		Mixture	Carboni-zation	Carboni-zation with pre-oxidation									
100	0	EKPC coal	EKPC char	EKPC char (Pre-O)	6.2	9.4	34.2	12118	67.2	5.4	13.8	1.5	2.8
80	20	E8C2	E8C2 char	E8C2 char (Pre-O)	7.1	12.8	38.3	10727	59.6	5.3	18.0	1.9	2.4
50	50	E5C5	E5C5 char	E5C5 char (Pre-O)	8.4	18.0	44.5	8642	48.2	5.3	24.4	2.5	1.8
20	80	E2C8	E2C8 char	E2C8 char (Pre-O)	9.7	23.2	50.6	6556	36.7	5.2	30.8	3.0	1.2
0	100	CW	CW char	CW char (Pre-O)	10.6	26.6	54.7	5166	29.1	5.1	35.0	3.4	0.8

To evaluate the char properties, weight loss of the char samples in N_2 and air were measured on a Thermogravematric Analysis (TA 2950). The experimental conditions used for TGA are a sample weight of 20mg, a gas flow (N_2 or air) of 60ml/min, a heating rate of

20°C/min, and a final temperature of 1000°C for nitrogen and 800°C for air. The char samples prepared and used are also listed in Table 2.

3.2 Study Char Yield on Tube Furnace

3.2.1 Effect of coal/chicken waste ratios on char yield

Figure 4 shows the char yields from different coal/chicken waste ratios at 427°C for 60 minutes in a nitrogen stream. As shown by the black bars, chicken waste has a lower char yield than coal, and the carbon yield decreases with an increase of chicken waste in the blend sample. Obviously, this is because the carbon content in the mixture decreases with an increase of chicken waste content due to the low carbon content of chicken waste. The bars in red are the calculated results based on the ratios of coal and chicken waste in the blend sample. The calculated data are very close to the experimental results.

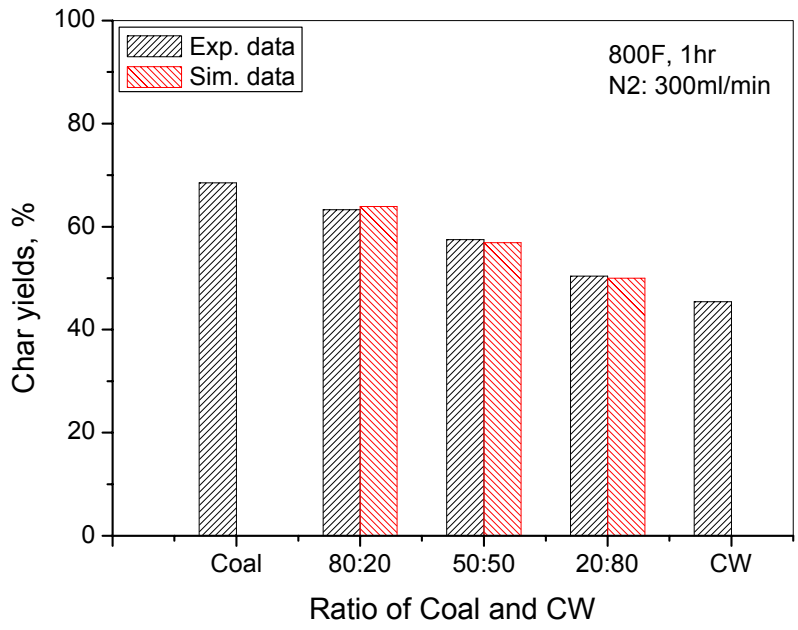

Figure 4. Char yield with different ratios of coal and chicken waste

3.2.2 Effect of pre-oxidization on char yields

The previous studies show that pre-oxidization can reduce the risk of coal particles coking during the carbonization process. The pre-oxidation before the carbonization process was conducted for the tested samples. Comparison of the results with/without pre-oxidation is shown in Figure 3. Experimental data indicate that the pre-oxidation process made the char yield decrease for coal, but increase for chicken waste. Tar caused the coking of coal particles could be discomposed for coal sample during the pre-oxidation process. However, the reason for the increase of chicken waste char yield is still under investigation. The char yields decreased with an increase of the coal content in the blend samples.

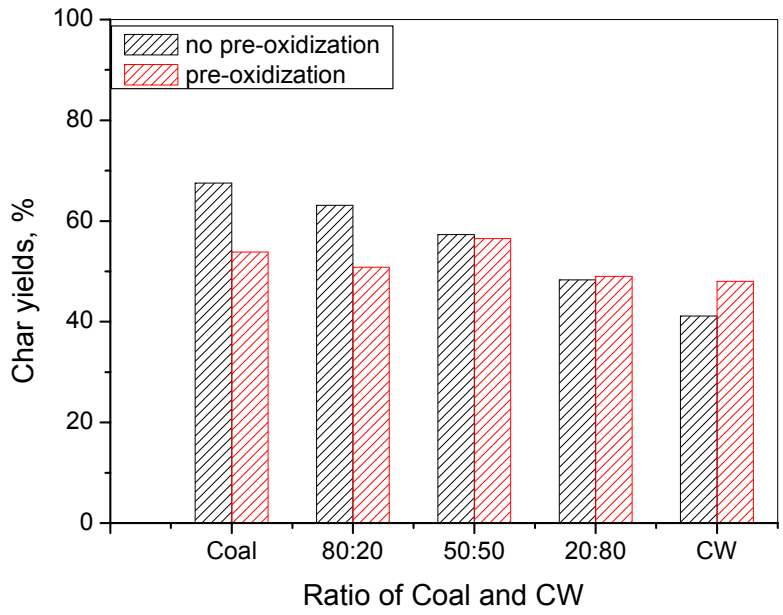

Figure 5. Effect of chicken waste/coal pre-oxidization on char yields

3.3 Pyrolysis and Co-combustion on TGA

3.3.1 Blend samples of chicken waste and coal

Figure 6 shows weight loss profiles and corresponding derivative curves for coal/chicken waste samples in a nitrogen atmosphere. The volatile releasing temperature is around 300°C for chicken waste and around 450°C for coal, at which point the devolatilization rate reaches its maximum. For blend samples, two peaks appear near 300°F and 450°C on the TGA curve.

Increasing the coal content in the blend sample caused the peak around 300°C to shrink, while the peak around 450°C increased in size.

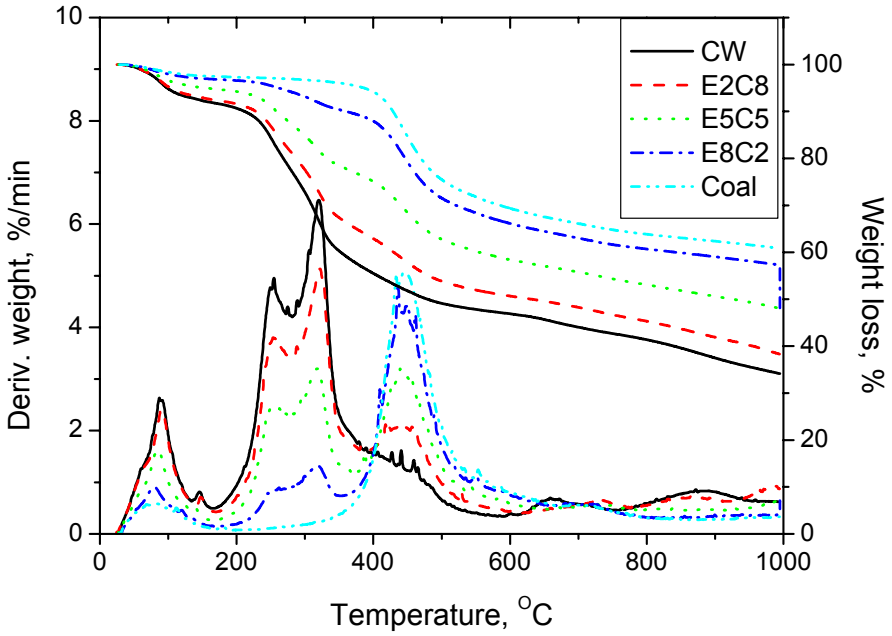

Figure 6. Pyrolysis of blend samples on TGA

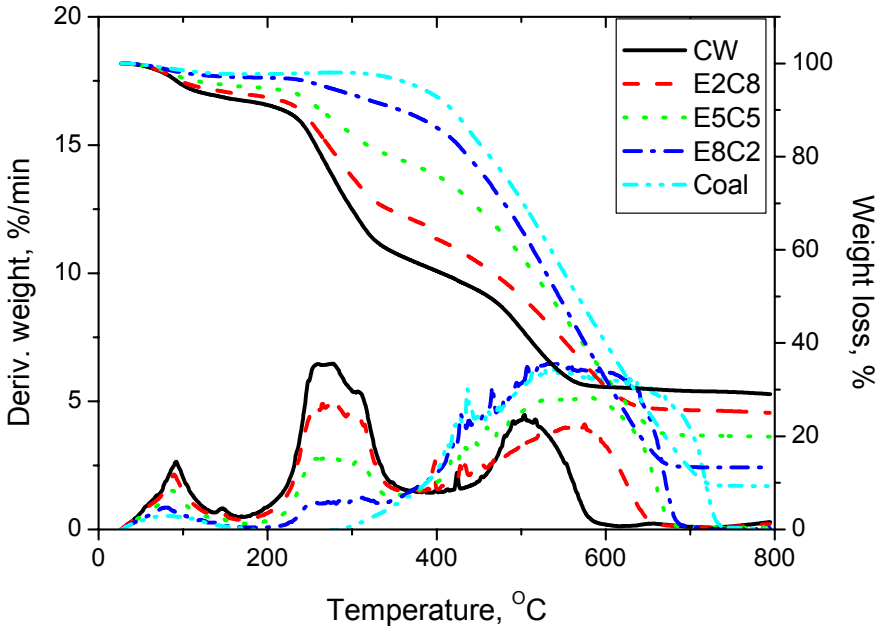

Figure 7. Co-combustion of blend samples on TGA

Figure 7 presents the weight loss profiles of the blend samples in air. For the coal sample, the main weight loss took place after 400°C, and only one big peak appeared on the Differential Thermogravimetric (DTG) curve after dehydration. This implies that volatile evolution overlaps with carbon combustion. In contrast, the chicken waste sample has two primary peaks at 300°C and 500°C, respectively. This suggests that the volatile evolution takes place prior to carbon combustion.

3.3.2 Char samples

To evaluate the thermal properties of char, char samples generated during the pyrolysis process were analyzed by using temperature-programmed TGA in nitrogen and air.

The weight loss profiles for CW/coal char samples with/without pre-oxidization before carbonization are presented in Figures 8 and 9. To evaluate the difference in the properties of the char with and without pre-oxidation, all curves shown in Figures 8 and 9 were

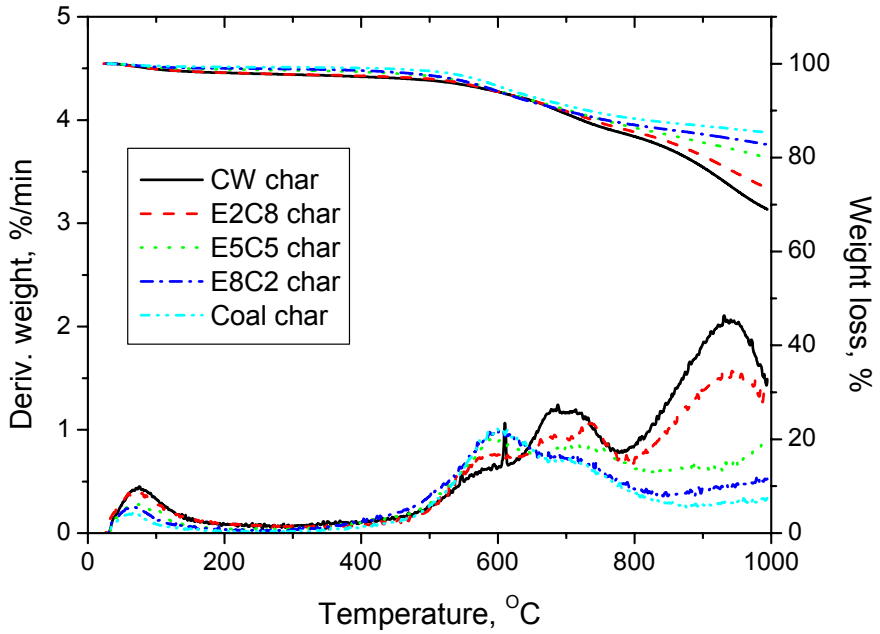

Figure 8. Thermal analysis for char samples without pre-oxidation in N_2 atmosphere

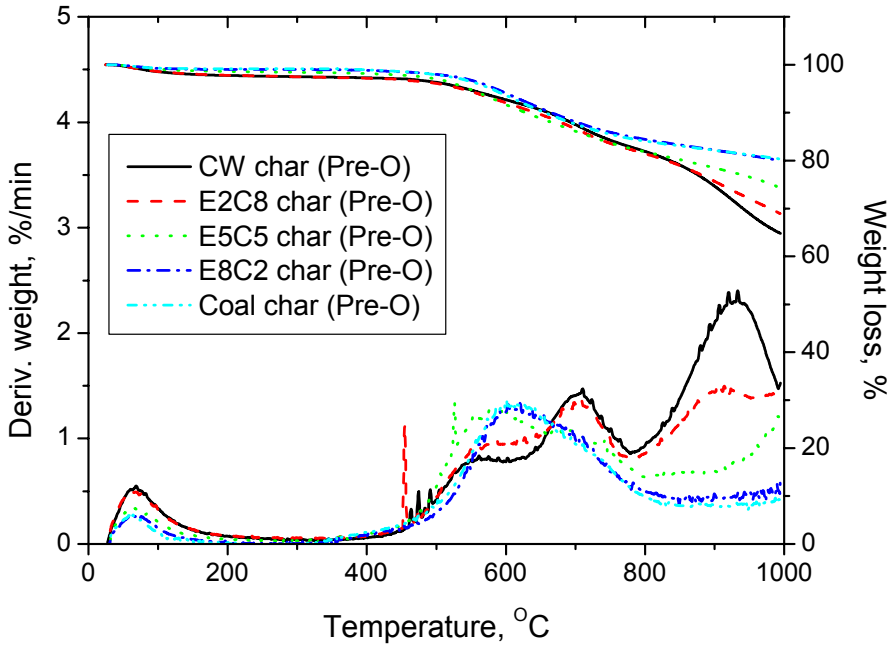

Figure 9. Thermal analysis for char samples with pre-oxidation in N_2 atmosphere

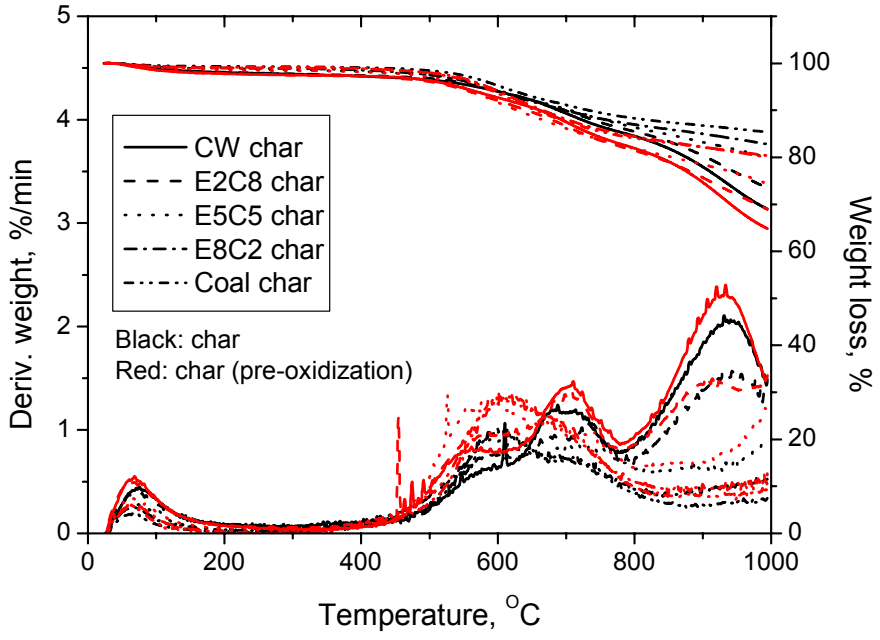

Figure 10. Comparison of thermal analysis for char samples with/without pre-oxidation in nitrogen atmosphere

combined to produce Figure 10. As shown, the chars with and without pre-oxidation have very similar variation tendencies. The weight loss rates for the char samples that underwent pre-oxidation were a little higher than those without the pre-oxidization, especially in the area around 600°C.

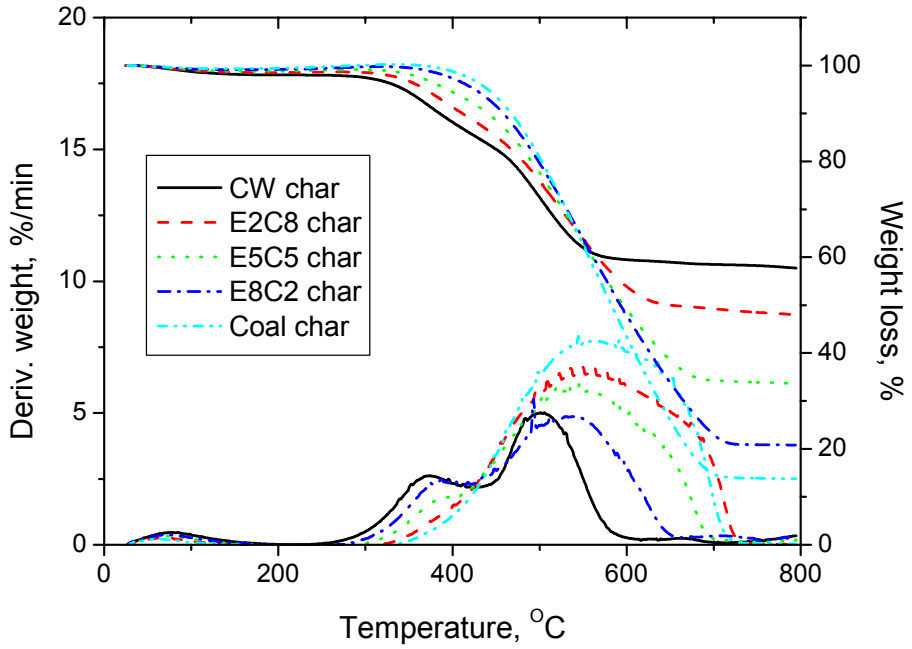

Figure 11. Thermal analysis for char samples without pre-oxidation in air atmosphere

The char samples with/without pre-oxidation before carbonization were tested in air as well. The weight loss profiles are shown in Figures 11 and 12. For the char samples without pre-oxidation, two peaks appear on the weight loss curve. This means that the char generated by chicken waste underwent a two-stage combustion. However, only one main peak could be seen on the weight loss curve for the char samples with pre-oxidation. It seems that the pre-oxidization reduced the weight loss around 350°C, which is not found in Figure 10 presenting thermal behavior of char samples in a nitrogen flow. This suggests that this fraction is stable in a N_2 atmosphere, but can react with O_2.

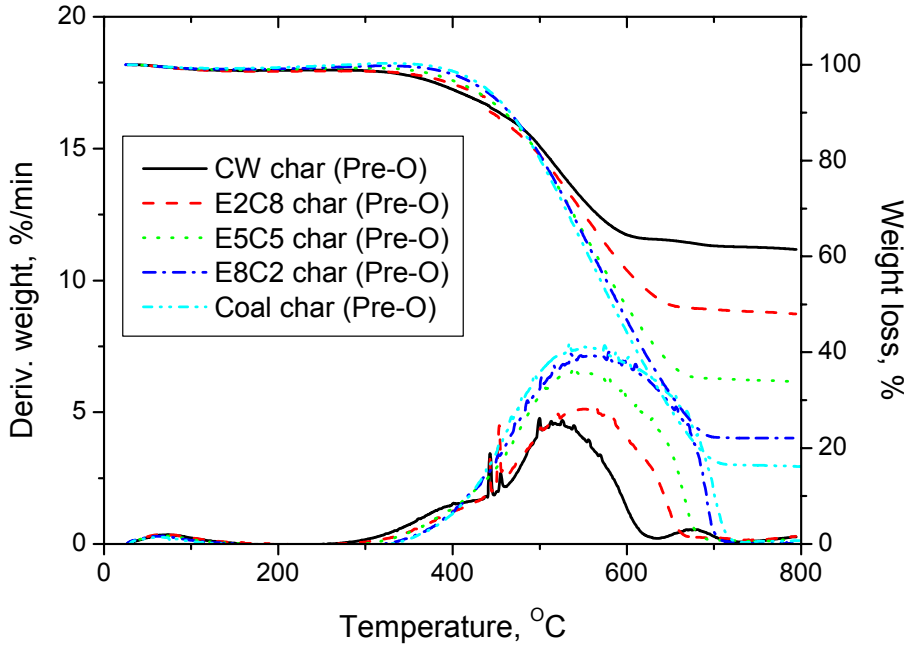

Figure 12. Thermal analysis for char samples with pre-oxidation in air atmosphere

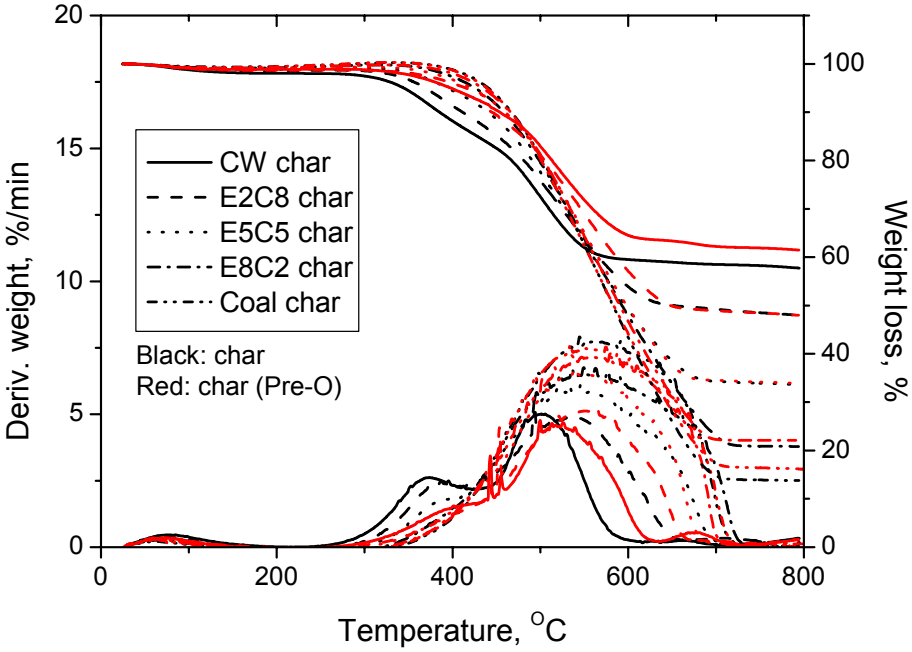

Figure 13. Comparison of thermal analysis for char samples with/without pre-oxidation in air atmosphere

4. CONCLUSIONS

During this quarter, the following progress has been attained:

- The renovation of the new Combustion Laboratory and the construction of the CFB Combustor Building progressed well. Since the contractor's drill was damaged during the digging of the foundation for the CFB Combustor Building. As a result, the construction of the CFBC Combustor Building was delayed several weeks.
- The steel frame for supporting the CFB Combustor was integrated with CFB combustor on the drawing. The support system for avoiding the horizontal displacement and twist of CFB combustor riser was designed in detail. The potential contractors for fabricating the component parts of the CFBC Facility were contacted for review and quotation.
- The laboratory-scale simulated FBC facility was tested after some modifications were made. Problems encountered during the pretest were resolved.
- The carbonization of coal and chicken waste (CW) mixtures was conducted on a tube furnace, and the solid residues after the carbonization process were analyzed on a Thermogravimetric Analyzer (TGA). The char yield was studied under different experimental conditions. The effect of pre-oxidation on the thermal properties of the char was discussed based on the experimental data.

5. FUTURE WORK AND UPDATED SCHEDULE

5.1 Future Work

During the next quarter, work efforts will concentrate on the following tasks:

- Award the contract to manufacturer for fabricating all parts of the CFBC Facility.
- Obtain initial quotations from individual suppliers for auxiliary devices, such as screw-feeders, air pre-heaters, coal crushing devices, blowers, induce fans, etc.
- Continue to work with architects and engineers on renovating the new Combustion Laboratory and constructing the CFB Combustor Building.

- Conduct experiments on the modified laboratory-scale simulated FBC Facility. The following experiments will be carried out on this laboratory-scale simulated FBC Facility in the next quarter:
  - Investigate conditions for co-firing of chicken waste and high sulfur coal.
  - Monitor pollutant emissions from co-firing of chicken waste and high sulfur coal.
  - Study pyrolysis of chicken waste.

5.2 Updated Schedule

Based on the current progress made on the project, the updated schedule for Fiscal Year 2005 is shown in Table 3.

Table 3. Updated Schedule for Fiscal Year 2005

Task	Updated Schedule
Initiate experiments for fundamental research on the laboratory-scale FBC Facility	January 1, 2005
Award the contract to the manufacturer for fabrication of all component parts of CFBC Facility	February 25, 2005
Complete renovation of the new Combustion Laboratory	March 30, 2005
Complete construction of the CFB Combustor Building	June 1, 2005
Complete fabrication of component parts of CFBC Facility	June 30, 2005
Initiate installation the bench-scale 0.6MW_{th} CFBC Facility.	July 15, 2005
Complete all experiments for fundamental research on the laboratory-scale FBC Facility	August 30, 2005
Grand opening of new Combustion Laboratory	October 1, 2005

ACRONYMS AND ABBREVIATIONS

A Ash content (wt%)

Btu	British Thermal Unit
C	Carbon content (wt%)
CFB	Circulating Fluidized-Bed
CFBC	Circulating Fluidized-Bed Combustion
Cl	Chlorine content (ppm)
CW	Chicken waste
DOE	U.S. Department of Energy
ECTL	Environmental Control Technology Laboratory
FBC	Fluidized-Bed Combustion
H	Hydrogen content (wt%)
Hg	Mercury content (ppm)
ID Fan	Induce fan
lb	pound
M	Moisture (wt%)
m_0	Sample mass (g)
m_{char}	Char mass (g)
N	Nitrogen content (wt%)
O	Oxygen content (wt%)
S	Sulfur (wt%)
SLPM	Standard liter per minute
TGA	Thermogravimetric Analyzer
V	Volatile matter (wt%)
W	Moisture content (%)
wt	Weight
η	Char yield (%)

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