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TECHNICAL REPORT
March 1 through May 31, 1995

Project Title: **COMBUSTION OF CHAR-COAL WASTE PELLETS FOR HIGH EFFICIENCY AND LOW NO_x**

DOE Cooperative Agreement Number: DE-FC22-92PC92521 (Year 3)
ICCI Project Number: 94-1/5.2A-1M
Principal Investigator: S. Rajan, Southern Illinois University at Carbondale
Project Manager: Frank Honea, Illinois Clean Coal Institute

ABSTRACT

To maintain market share, new uses must be found for Illinois coals in the largest end use area, namely power generation. To this end, the suitability of Illinois coal for high efficiency power plants like combined cycles must be investigated. This approach involves partial gasification of the coal to produce fuel gas for the topping cycle gas turbines, while the residual char is burnt in the gas turbine exhaust to produce steam for the Rankine bottoming cycle. This project seeks to improve the combustion characteristics of the residual char by pelletizing it with waste coal in order to improve its combustor residence time and carbon conversion efficiency. At the same time, attempts are made to reduce pollutant emissions.

During this quarter, the residual char produced by Foster Wheeler Development Corporation in their pyrolyzer has been pelletized with Illinois gob coal in various proportions. Combustion tests have been performed in a laboratory scale circulating fluidized bed combustor. Preliminary results show that the pellets are much easier to burn and exhibit high carbon conversion efficiencies. Further combustion tests are in progress.

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EXECUTIVE SUMMARY

The research being conducted is aimed at providing a favorable position for Illinois coals for use in new power generation technologies. Advanced combined cycle power generation schemes involve producing a fuel gas in a pyrolyzer to provide the heat input for the gas turbine topping cycle, while the residual char is burnt in a pressurized fluidized bed to raise steam for the bottoming cycle. Since this residual char is light and essentially has no volatiles, its combustion characteristics can be improved by pelletizing with other fuels. In the work being conducted in this project, the pyrolyzer char is pelletized with waste coal using cornstarch as a binder. This enables the pyrolyzer char to be fed easily and improves its residence time in the combustor, making it easier to achieve high carbon conversion efficiencies. At the same time, it is expected that the sulfur dioxide and oxides of nitrogen emissions will be reduced.

Thus, the research objectives are:

1. to pelletize the low volatile pyrolyzer char from Illinois coals obtained from FWDC with coal wastes using cornstarch or lignin as binder.
2. to conduct combustion experiments with the char pellets in a bench scale circulating fluidized bed combustor and measure carbon conversion efficiencies and SO_2, NO_x, HCl, and other emissions.
3. to compare with data from similar experiments with the char alone.
4. to demonstrate the increased carbon conversion efficiency and lower SO_2, NO_x and other emissions obtainable from the char-waste coal pellets.

During the last quarter, extensive laboratory tests were performed investigating the various proportions of char and gob coal that needed to be blended together. Also, the amount of cornstarch binder to be used was studied. The mechanical strength of the pellets made were measured.

During this quarter, pyrolyzer char obtained from Foster Wheeler Development Corporation was pelletized with Illinois waste coal using cornstarch as binder on a larger scale. The pellets were manufactured at the California Pellet Mill Company in Crawfordsville, Indiana. The pellets were then dried. Combustion tests in the laboratory scale fluidized bed combustor have been performed and emissions of CO_2, O_2, NO_x and SO_2 have been measured.

Preliminary results show that the pellets are much easier to burn than the char alone. High combustion efficiencies on the order of 98% are attainable in the circulating fluidized bed combustor. Because of the different combustion history of the pellets, emissions of NO_x and SO_2 appear to be controlled by different temperature regimes than the combustion of the char itself or the coal. This is being investigated with further testing.

OBJECTIVES

The objectives of the research are:

1. to pelletize the low volatile pyrolyzer char from Illinois coals obtained from FWDC with coal wastes using cornstarch or lignin as binder.
2. to conduct combustion experiments with the char pellets in a bench scale circulating fluidized bed combustor and measure carbon conversion efficiencies and SO_2, NO_x, N_2O, HCl, and other emissions.
3. to conduct similar experiments with the char alone.
4. to demonstrate the increased carbon conversion efficiency and lower SO_2, NO_x and other emissions obtainable from the char-waste coal pellets.
5. to investigate the effects of cornstarch and lignin as binders.
6. to analyze the ash and spent limestone residues with a view to proposing waste disposal strategies.

INTRODUCTION

Illinois coals have good potential for use in advanced High Efficiency Power Plants (HIPPs) because of their good gasification properties and high reactivity. Companies such as Foster Wheeler Development Corporation and others are currently involved in developing such High Efficiency Power Plants. The approach here is to partially gasify the coal in a pyrolyzer producing a fuel gas that will power the topping cycle gas turbine. The residual char will then be burnt to raise steam for the Rankine cycle bottoming plant.

Because the char is low in volatiles and its density is lower than the original coal, it tends to elutriate from the bed during fluidized bed combustion and carbon conversion efficiencies are reduced. The work proposed here seeks to improve the char carbon conversion efficiency while also finding an end-use for waste coals from gob piles. This is accomplished by pelletizing the char with the gob pile wastes using cornstarch or wood lignin as binder. Additional limestone may be added to the pellets as necessary. The char pellets will be burnt in a 4-in. internal diameter circulating fluidized bed combustor to investigate carbon conversion efficiencies, SO_2, NO_x and HCl emissions. The results will be correlated with other literature data. The use of char from Foster Wheeler Development Corporation, a leading boiler manufacturing contractor to DOE on these IGCC projects, provides a direct link to near term commercialization of this technology. The successful utilization of Illinois high sulfur coals in these high efficiency power plants will provide near term economic benefits to the coal industry by overcoming the roadblocks currently placed upon it by the current stringent Environmental Protection Agency (EPA) emissions requirements. The high volatility and good reactivity of Illinois coals make it a viable coal for IGCC applications, with good opportunities for success. The enhanced char-pellet combustion, emissions and reactivity data obtained from the research in the bench scale experiments will make Illinois coals more attractive for these IGCC applications. The research will extend the database and permit high efficiency IGCC plants to be designed and fired with Illinois high sulfur, high chlorine coals.

In particular, the research will

(a) reduce the difficulties in burning the low volatility char
(b) ensure overall high plant efficiency which is not possible without the char utilization
(c) promote lower emissions of SO_2, NO_x, N_2O from char combustion

EXPERIMENTAL PROCEDURES

I. Equipment and Instrumentation

The experiments are being conducted in the 4-inch internal diameter circulating fluidized bed combustor shown schematically in Figure 1. The combustor is lined with a castable refractory to reduce heat losses. As shown in Figure 1, a blower supplies fluidizing air that is split into two streams. The main stream enters the fast fluidized bed section of the combustor through a distributor plate specially designed to provide even fluidization. This section of the air duct also houses a propane-fired preheat system, which is utilized to bring the bed solids up to temperatures required to ignite the main fuel. Unburnt fuel, limestone and ash entrained by the gases in the main bed column pass through a refractory-lined hot cyclone, which traps the larger particles and deposits them into an auxiliary bubbling bed attached to the bottom end of the hot cyclone. The second smaller air stream enters this bubbling bed into which the carry-over solids from the fast fluidized bed trapped by the hot cyclone are deposited. A non-mechanical seal ensures that this unburnt fuel and bed solids flow from the bubbling bed into the fast fluidized bed and not vice-versa. Both air streams are metered with ASME nozzles and incorporate control valves for adjusting the flow velocities in the fast fluidizing and bubbling bed sections of the combustor.

Crushed and sieved coal is fed from a pressurized hopper via a screw feeder pneumatically into the dense portion of the fast fluidized bed, using metered high pressure air. Sized limestone, stored in a separate hopper, is fed simultaneously into the air stream, conveying the coal into the bed. Both coal and limestone feed systems have been calibrated individually.

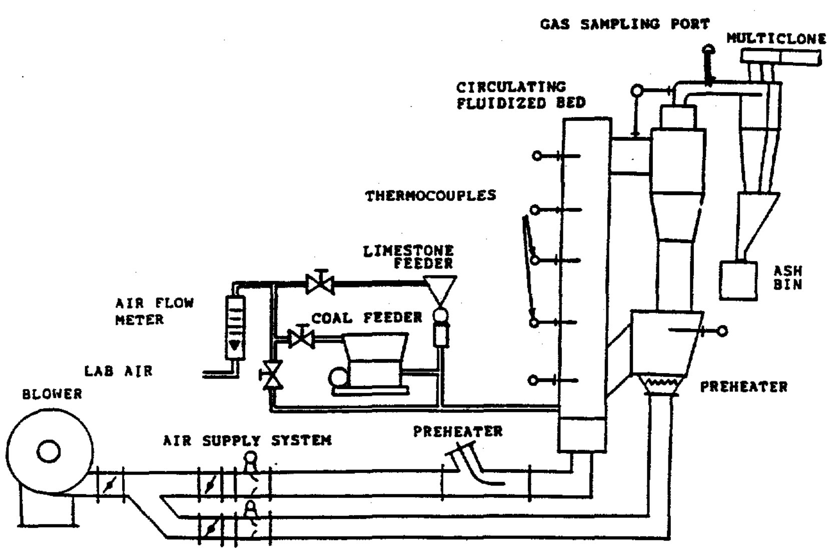

Figure 1. Schematic of 4-Inch Internal Diameter Circulating Fluidized Bed Combustor

Two quartz, glass-lined observation ports, one located in the dense bed at the bottom and the other located near the top in the dilute phase or transport section of the bed, serve for visual monitoring of the combustion process. The circulating fluidized bed combustor is instrumented with chromel-alumel thermocouples at various positions for measuring temperature. The thermocouples are connected to a selector switch and, thence, to a digital readout meter.

Solids too small to be captured by the hot cyclone are trapped in a multiclone, mounted at the hot cyclone exit. In the present system, these multiclone solids are not reinjected into the bed. The multiclone solids are later analyzed for heat content, using an adiabatic calorimeter. Combustion gases are drawn off from a point at the exit of the multiclone, filtered through 2-5 micron particulate filters, and conveyed via heated lines to an instrument panel for determining gas composition. Carbon monoxide and carbon dioxide are measured with Beckman NDIR analyzers, oxygen with a Beckman 755 paramagnetic analyzer, oxides of nitrogen, NO_x, with a Thermoelectron 10 AR chemiluminescent analyzer and sulfur dioxide with a Beckman IR analyzer. HCl is measured with a Thermoelectron gas filter correlation hydrogen chloride analyzer.

II. Test Procedures

CFBC Combustion and Emissions Tests

The combustion testing of the pellets involves the following steps:

* The CO, CO_2, O_2, NO_x and SO_2 analyzers are calibrated at the beginning and at several times during a test burn.
* The CFBC combustor is filled with the proper amount of bed material (sand or limestone).
* The propane preheat system is fired the bed material and unit is brought up to about 1100-1200°F. This step takes several hours.
* Coal and limestone hoppers are filled with prepared standard coal and limestone sorbent, respectively.
* The coal feed is initiated and the CFBC unit is brought up to operating temperatures of around 1500°F on the standard coal. The operation of all sampling and control systems are checked.
* For tests with the standard coals and the char-coal waste pellets, typical values of operating variables are as follows:

fluidization velocity 9 ft/sec
Ca/s ratio 1-4
bed temperature≈1450-1650°F

These parameters are kept constant with all the fuels, so that comparison of the combustion and emissions parameters can be made under identical conditions of operation.

* No additional limestone sorbent will be injected during initial tests. If SO_2 emissions are higher than EPA limits, further tests will be conducted with limestone injection.
* Six to ten test runs are planned to be made. Each test run is made after the combustor has reached steady state conditions. Combustor steady state conditions are usually achieved after 30-48 hours of operation. Where test fuel supplies are limited, the procedure adopted is to first bring the combustor to steady state operation on the standard coal or another Illinois coal, and then change the fuel feed to the test coal, only for the duration of the steady state data acquisition period.
* The variables measured during a test include:

- fuel and air mass flows
- air superficial velocity
- bed temperature
- other temperatures at various combustor locations
- combustion gas analysis comprised of CO, CO_2, O_2, NO_x, HCl and SO_2 emissions
- test duration time
- quantity of ash collected in cyclones during test period

Combustion generated ash and spent limestone from the experiments are analyzed. The heat content of the elutriated unburnt carbon is determined from calorimetry tests. Spent limestone and ash are prepared on metal stubs and subjected to energy dispersive x-ray (EDX) analysis to determine the elements present in the samples.

Sample Analysis

(a) Proximate and Ultimate Analyses

Proximate and ultimate analyses of the parent coals and chars are obtained using standard ASTM procedures at the Coal Technology Laboratory at Carterville, Illinois.

(b) Particle Size Analysis

Particle size analysis in the range below 125 microns is measured utilizing a Leeds and Northrop Microtrak Model 7995-10 particle size analyzer. A schematic of the instrument is shown in Figure 2. In this version of the instrument, a laser beam is projected through a transparent cell that contains a stream of moving particles suspended in a liquid. Light rays that strike particles are scattered through angles that are inversely proportional to their sizes. The rotating optical filter transmits light at a number of predetermined angles and directs it to a photodetector. Electrical signals proportional to the transmitted light flux values are processed by a microcomputer system to form a multichannel histogram of the particle size distribution.

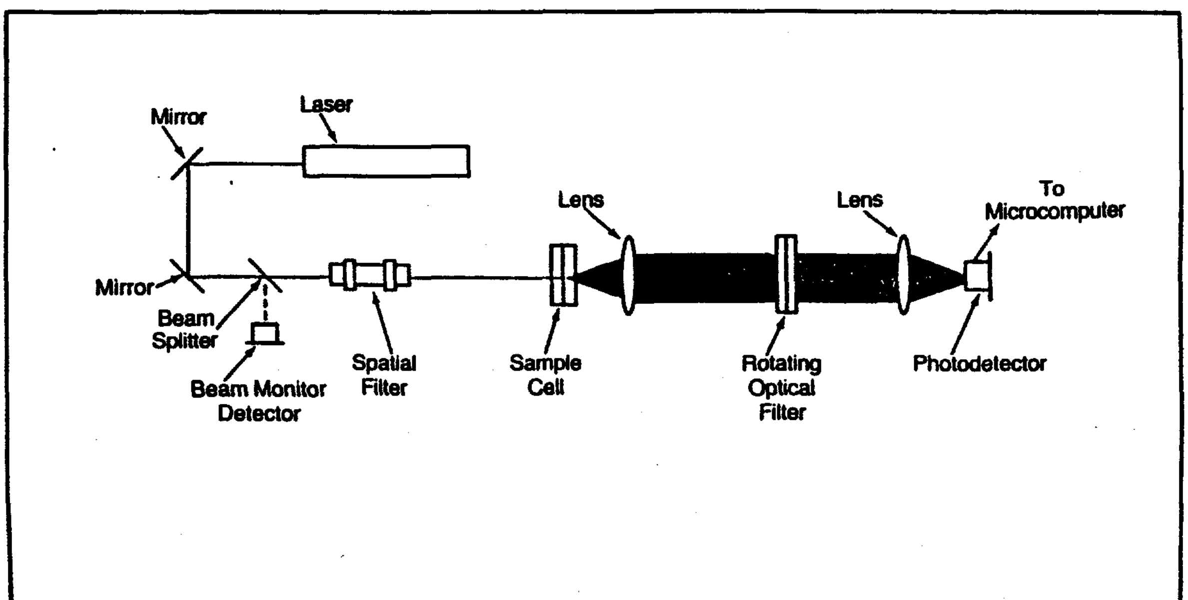

Figure 2. Schematic of Microtrak Particle Size Measurement System

(c) Mineral Matter Analysis

The mineral matter analysis of the coal in the pellet fuels and the reference Illinois No. 6 coal is conducted with a Hitachi H-600 analytical electron microscope operating both in the transmission and the scanning-transmission electron microscopy (STEM) modes. With STEM, a Tracor-Northern energy dispersive x-ray (EDX) Model 5500 analysis system was employed. The specimen samples were mounted on adhesive copper grids and examined at 100 kV in the electron microscope. The samples were uncoated.

Data Analysis

From the measured data the following parameters will be computed:

* excess-air ratios
* Ca/s mole ratios
* carbon conversion efficiency
* sulfur capture efficiency %
* SO_2 emissions levels in lb/10^6 Btu
* NO_x emissions levels in lbs/10^6 Btu
* HCl emissions levels in lbs/10^6 Btu
* carbon balances

RESULTS AND DISCUSSION

1. Pyrolyzer Char-Gob Coal Pellet Manufacture

Following the laboratory evaluation of the various proportions of char, gob coal and binder to be used, that was reported last quarter, larger quantities of pellets were made this quarter for combustion testing. The char, gob coal and cornstarch binder were transported to the California Pellet Mill Company in Crawfordsville, Indiana, and the pellets were made using their pellet mill. First, the gob coal and char were weighed out in proper proportions and thoroughly mixed using mechanical mixing equipment. Although the gob coal contained about 22% moisture, additional water was often added to aid the pellet extrusion process. Cornstarch binder was also weighed out and mixed in with the char and gob coal. The size of the pellets made were about 0.125 inches diameter and 0.375 inches long.

The pellets were then transported back to Southern Illinois University at Carbondale. They were dried to reduce the moisture content of the pellets and to let them harden. The pellets made had the following composition.

(1) 60% char 40% gob coal--no limestone added

(2) 70% char 30% gob coal--no limestone added

(3) 80% char 20% gob coal--no limestone added

(4) 80% char 20% gob coal--additional limestone used

The first three pellet compositions did not have any additional limestone added. Since the char has calcium sulfide mixed in with it from the pyrolyzer, the effectiveness of sulfur dioxide retention from this calcium sulfide alone will be investigated. In addition, limestone can be fed separately during combustion to evaluate the effect of limestone addition.

The fourth pellet composition does have limestone incorporated into the pellet. For this mixture, it was assumed that no calcium was present in the char-gob coal mixture and limestone was added to provide a 2:1 Ca/S ratio. This will enable the effectiveness of limestone impregnation to be evaluated.

Circulating Fluidized Bed Combustor Experiments

Combustion evaluation of the carbon conversion efficiency and emissions levels from pellet combustion are in progress. The dried pellets are fed with an Accurate screw feeder which is calibrated for the pellets being fed. Although the pellets are fed with a screw feeder, care has been taken to select the proper size of pellets and screw feeder so that the pellets are not damaged in the feeding process.

The pellets with the 60% char and 40% gob coal were fed into the bench scale circulating fluidized bed combustor and burnt in the temperature range of 1420-1680°F. It was found that the pellets burnt much more easily in the CFBC than the char alone as compared to the tests conducted with the char during the previous year's experiments. Bed temperatures could be maintained quite easily even as low as 1400°F.

Figure 3 shows preliminary data of the SO_2 emissions measured. The measurements appear to indicate that SO_2 emissions levels from the char-gob coal pellets are influenced by temperature, and that the SO_2 capture efficiency decreases as the temperature increases. This is similar to that observed in general with calcium sorbents. Further tests are continuing.

CONCLUSIONS

During this quarter, the char-gob coal pellets have been manufactured. Preliminary combustion testing indicates that the SO_2 emissions characteristics of the pellets, which contains calcium sulfide, is similar to that which commonly occurs with coal and limestone combustion. Further investigation is in progress.

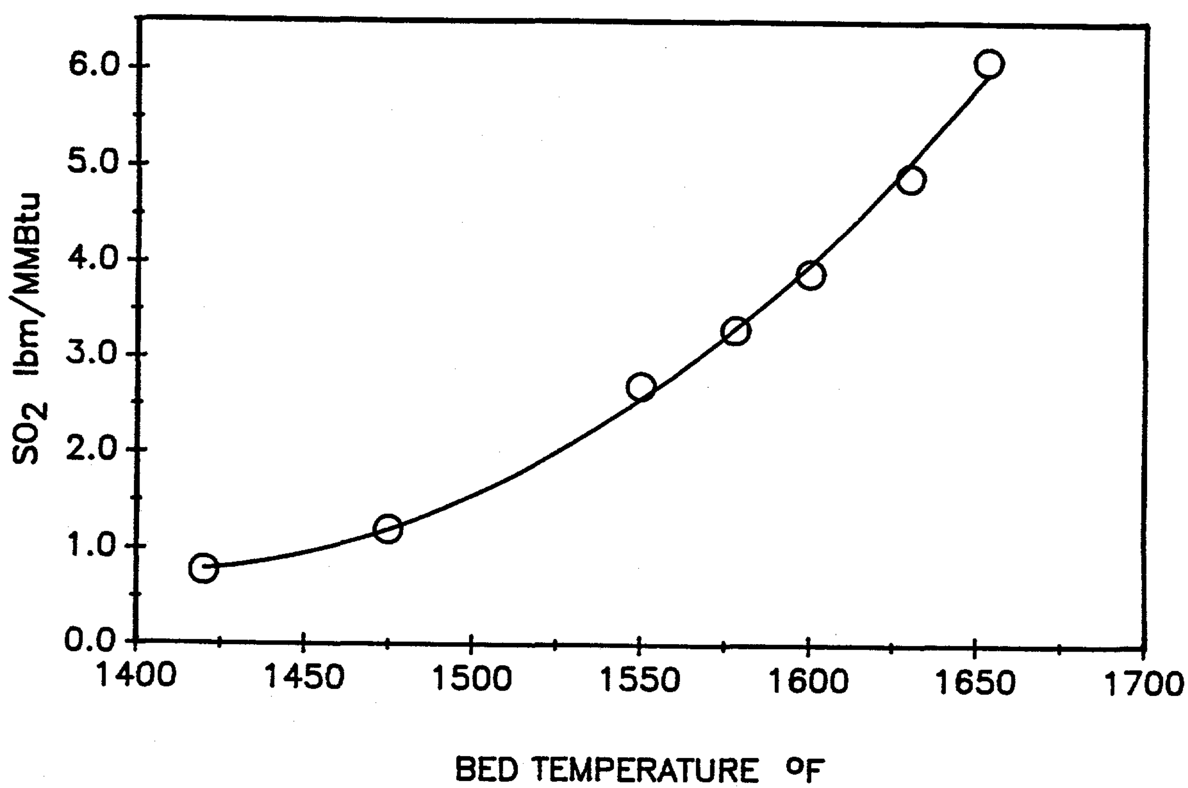

Figure 3. Variation of SO_2 Emissions from Char-Gob Coal Waste Pellets (60% Char, 40% Coal).

PROJECT MANAGEMENT REPORT
March 1 through May 31, 1995

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Principal Investigator:	S. Rajan, Southern Illinois University at Carbondale
Project Manager:	Frank Honea, Illinois Clean Coal Institute

EXPENDITURES - EXHIBIT B

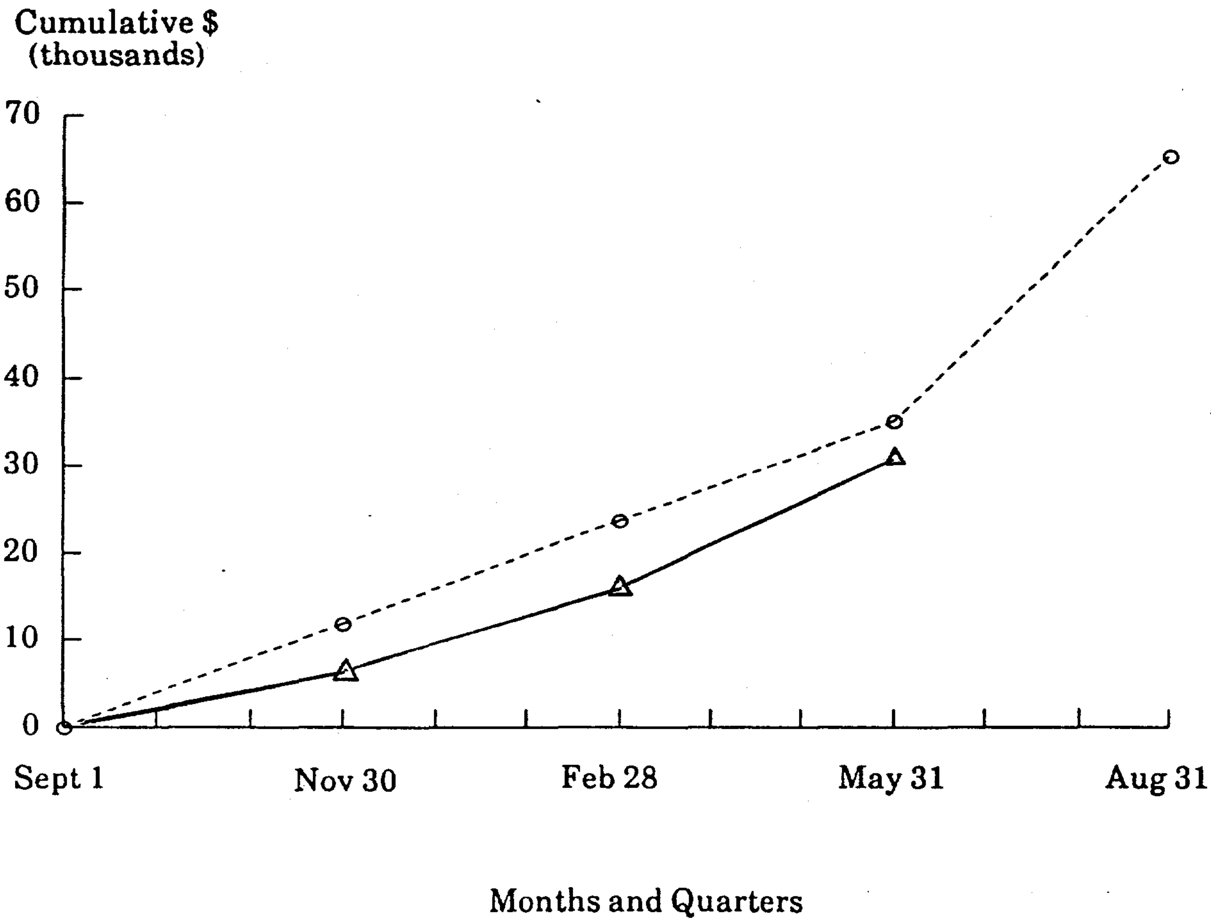
CUMULATIVE PROJECTED AND ESTIMATED EXPENDITURES BY QUARTER

Quarter*	Types of Cost	Direct Labor	Fringe Benefits	Materials and Supplies	Travel	Major Equipment	Other Direct Costs	Indirect Costs	Total
Sept 1, 1994	Projected	7,466	923	1,125	0	0	1,250	1,076	11,840
to Nov 30, 1994	Estimated	3,500	100	500	0	0	600	400	5,100
Sept 1, 1994	Projected	14,931	1,846	2,250	0	0	2,500	2,153	23,680
to Feb 28, 1995	Estimated	8,500	500	1,500	0	0	1,800	1,500	13,800
Sept 1, 1994	Projected	22,397	2,769	3,375	0	0	3,750	3,229	35,520
to May 31, 1995	Estimated	20,000	2,000	3,400	0	0	3,500	3,000	31,900
Sept 1, 1994	Projected	43,962	6,140	4,500	500	0	5,000	6,010	66,112
to Aug 31, 1995	Estimated								

*Cumulative by Quarter

CUMULATIVE COSTS BY QUARTER - EXHIBIT C

Combustion of Char-Coal Waste Pellets for High Efficiency and Low NO_x



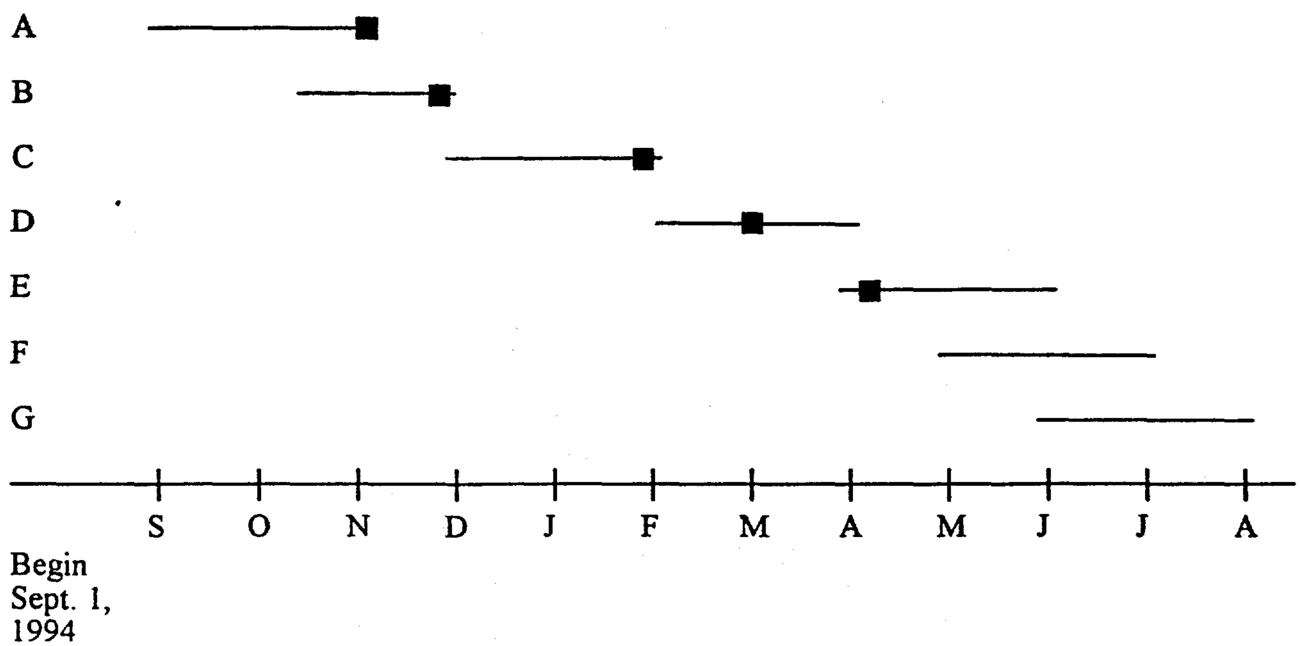
O = Projected Expenditures --------------

Δ = Actual Expenditures _______

Total ICCI Award $66,112

The schedule for this one year project is shown below.

PROJECT SCHEDULE



A. Fuels Procurement

B. Fuels Analysis

C. Char-Coal Pellets Manufacture

D. CFBC Combustion Tests

E. Combustion Residues Analysis

F. Data Analysis

G. Final Report