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TECHNICAL REPORT
December 1, 1991, through February 29, 1992

Project Title: CFBC Evaluation of Fuels Processed from Illinois Coals

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Project Monitor: Dr. Ken Ho

ABSTRACT

The main thrust of this research project is the combustion testing and evaluation of two fuels processed from Illinois high sulfur coals. These fuels are (a) flotation slurry fuel beneficiated from coal fines containing 30% and 80% solids, and (b) coal-sorbent pellets made from coal fines using corn starch as a binder. Combustion data from these two fuels are to be compared with corresponding data obtained from a standard coal from the IBCSP coal bank. Parameters to be evaluated are SO_2, NO_x emissions, combustion efficiency and ash composition, insofar as its influences disposal techniques. During the last quarter, the equipment was serviced and brought on line, and combustion tests were initiated.

During the present quarter, the 4" internal diameter circulating fluidized bed facility was operated for more than 400 hours actual combustion time, not counting time required for coal and limestone preparation, and equipment maintenance. One of the results secured this quarter is the fabrication of equipment and the establishing of procedures for measuring solids recycle ratios. Typical recycle ratios under the condition of the present tests were found to be on the order of 15%. Tests were also conducted on standard IBCSP No. 3 coal to evaluate the influence of bed temperature. Results of the experiments are presented.

DISCLAIMER

This project is funded by the U. S. Department of Energy (METC) and by the Illinois Department of Energy and Natural Resources as part of their cost-shared program.

EXECUTIVE SUMMARY

To promote the widespread usage of coal and to improve the overall economics, CRSC is developing a variety of "clean" fuels. These include (a) slurry fuel beneficiated from coal fines containing various percentages of solids, and (b) coal-sorbent pellets processed from coal fines. Combustion testing and evaluation of these fuels, in terms of their burning characteristics and emissions levels is a necessary step in the process of developing and marketing these new fuel forms. Because of the experimental nature and small quantities of such fuels available, a laboratory scale combustion evaluation is a necessary first step in establishing feasibility. These "clean" fuels are being evaluated in this project by testing them in a bench scale circulating fluidized bed combustor to (a) demonstrate that the above-mentioned fuels have acceptable combustion properties and emissions levels of SO_2 and NO_x, and (b) provide feedback data to the researchers developing these fuels, so that the process techniques may be altered and improved as necessary.

In the previous quarter, the 3-inch internal diameter circulating fluidized bed facility was serviced and brought on line. A limestone feeder was installed and calibrated. Minor problems with the gas sampling equipment were remedied, and an electronic problem with the SO_2 analyzer was repaired. Samples of IBCSP No. 3 standard coal were acquired, ground and sieved to -14+18 mesh size for testing. Combustion tests were conducted on a run-of-mine coal to check out the operating systems.

During the present quarter, the main thrust of the experiments was to (a) measure the recycle ratios of the CFBC combustor, (b) conduct tests with the standard IBCSP No. 3 coal, and (3) prepare for testing of the beneficiated coal-water slurry fuels.

To measure the solids recycle rates, a special probe and associated accessories were designed and fabricated. Solids were collected at various locations in the combustor, from which the solids recycle rate could be calculated. Measurements show the solids recycle rate is a function of combustor operating conditions, such as superficial velocity, coal and limestone feed rate, bed temperature, etc. Under the conditions of the tests conducted in this quarter, the solids recycle rate varied from 0.4 to 0.6 lbs/hr.

A number of tests were conducted this quarter to obtain baseline data with standard coal, to be used for comparison purposes with the other test fuels. The emissions data measured included SO_2, NO_x, CO, CO_2 and O_2. Solids recycle rates were measured and ash samples to determine combustion efficiency and spent limestone characteristics were obtained. Analysis of these samples is in progress.

The shipment of coal-water slurry fuels prepared by ISGS researchers using preparation plant processed fuel at the Galatia plant of the Kerr-McGee Corporation was received in the third quarter of February. This fuel is being analyzed and prepared for combustion testing in the next quarter.

OBJECTIVES

The overall objectives for this one-year project are:

1. to demonstrate that new fuels derived from Illinois high sulfur coal, namely (a) coal-sorbent pellets and (b) coal-water slurry produced from froth flotation feed can be effectively utilized in a circulating fluidized bed combustor,

2. to compare the carbon conversion efficiencies, SO_2 and NO_x emission levels and Ca/S ratios needed to meet EPA regulations from the above fuels with those measured under similar operating conditions with a standard IBCSP coal, and

3. to analyze ash and spent limestone residues with a view to proposing waste disposal strategies for the combustion residues resulting from these new fuel forms.

The specific goals to be achieved as stated in the proposal are as follows:

1. determination of the carbon conversion efficiency of (a) the froth flotation coal water slurry fuel developed at the ISGS under CRSC sponsorship, and (b) the coal-sorbent pelletized fuel developed by ISGS under CRSC funding.

2. determination of the Ca/S mole ratio requirements for the coal-water slurry fuel to meet EPA SO_2 emissions requirements.

3. determination of the sulfur capture efficiency of the coal-sorbent pellet fuel

4. evaluation of the mineral matter elemental distribution in the combustion residues from the above fuels when burned in a laboratory scale 4-inch internal diameter circulating fluidized bed combustor

5. determination of the NO_x emission levels when burning the coal-water slurry and the pelletized fuel in a CFBC unit

6. comparison of the carbon conversion efficiency, carbon balances, SO_2 and NO_x emission levels and combustion waste analyses of the coal water slurry and pelletized fuel with equivalent values obtained from a standard IBCSP coal

The accomplishment of these goals involve the following tasks: (a) fuels procurement, (b) fuel testing and analysis, (c) fuels preparation, (d) installation of limestone feeder, (e) combustion testing in a three-inch internal diameter circulating fluidized bed combustor, (f) combustion residues analysis using EDX, and (g) data analysis and report preparation.

INTRODUCTION AND BACKGROUND

Increased utilization of Illinois coals can be promoted by developing clean burning coal-based fuels which are low in sulfur and high in heating value. One such project, funded by CRSC, is aimed at developing coal-sorbent pellets from coal fines. A second CRSC supported project recovers fine coal from plant waste employing various flotation techniques, producing a slurry with higher solids concentration and Btu content. The market potential of these fuels will depend on the combustion and emissions characteristics of the coal/sorbent pellets and the coal slurry. This can be established only by combustion testing under conditions simulating actual boiler firing. Because of the small quantities of the fuels being produced, laboratory-scale combustors are best suited to demonstrate their utility and emissions characteristics.

There is a need to evaluate the burning characteristics of the coal-sorbent pellets and the coal water slurry to determine whether they can be burned easily and with good carbon conversion efficiencies. In the case of the coal-sorbent pellets, it is necessary to quantitatively evaluate the sulfur capture efficiency of the pellets, in comparison with the case where the coal and sorbent are fed separately, to establish the merits of the coal-sorbent pelletization process. Additionally, it is necessary to investigate how the pelletization process, namely the mixing of the sorbent with the coal matrix influences the porosity and carbon burnout histories of the coal. The sorbent Ca/S ratios needed to meet EPA requirements with the coal water slurry and its carbon conversion efficiency needs to be evaluated in comparison with standard Illinois coals to demonstrate the usefulness of the separation process.

The research currently being performed in this project addresses the above needs to improve the usefulness of fuels produced from high sulfur coals.

EXPERIMENTAL PROCEDURES

The experiments are being conducted in the 4-inch internal diameter circulating fluidized bed combustor shown schematically in Figure 1. The combustion testing of the coal slurry and pellet fuels 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.

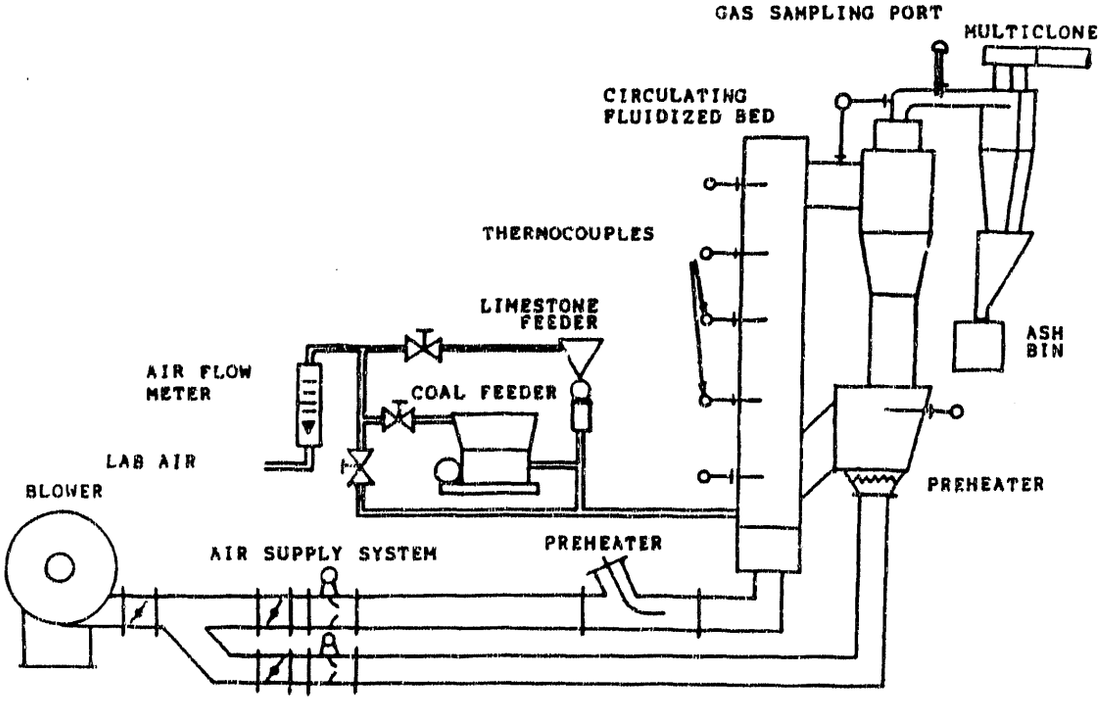

Figure 1. Schematic of 4" Diameter Circulating Fluidized Bed Facility Used for Fuels Testing

* For tests with standard coal and the slurry and pellet fuels, typical values of operating variables are as follows:

fluidization velocity 7-10 ft/sec
Ca/S ratio 1-3
Bed temperature ≈ 1500°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.

* During the coal-sorbent pellet tests, the pellets will be fed in the same manner as the standard coal. 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.

* With the coal-water slurry fuels, a special in-house fabricated pneumatic slurry injection system will be employed to inject the slurry fuel into the combustor.

* 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, slurry or pellet fuel 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 and SO_2 emissions
  - test duration time
  - quantity of ash collected in cyclones during test period

Combustion generated ash and spent limestone from the slurry fuel, pellets and standard coal tested will be analyzed. The heat content of the elutriated unburnt carbon will be determined from calorimetry tests. Spent limestone and ash will be prepared on metal stubs and subjected to energy dispersive x-ray (EDX) analysis to determine the elements present in the samples.

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
* carbon balances

RESULTS AND DISCUSSION

Measurement of Recycle Ratios

To measure the mass of solids recycled, a sampling system consisting of a probe, a filter holder and an air metering rotameter was set up as shown in Figure 2(a). The probe is installed at a height of approximately 1 ft from the top of the fast fluidizing section of the bed. When the CFBC is operating at its steady state, the probe is moved across the 4" diameter cross section of the fluidized bed, and timed samples of solids are collected on the filter. The sampling is performed isokinetically based on the prevailing superficial velocity at the location of the probe. At the end of the measurement, the filter is removed and weighed, along with the solids collected on it. The weight of the collected solids is determined by subtracting the weight of the filter.

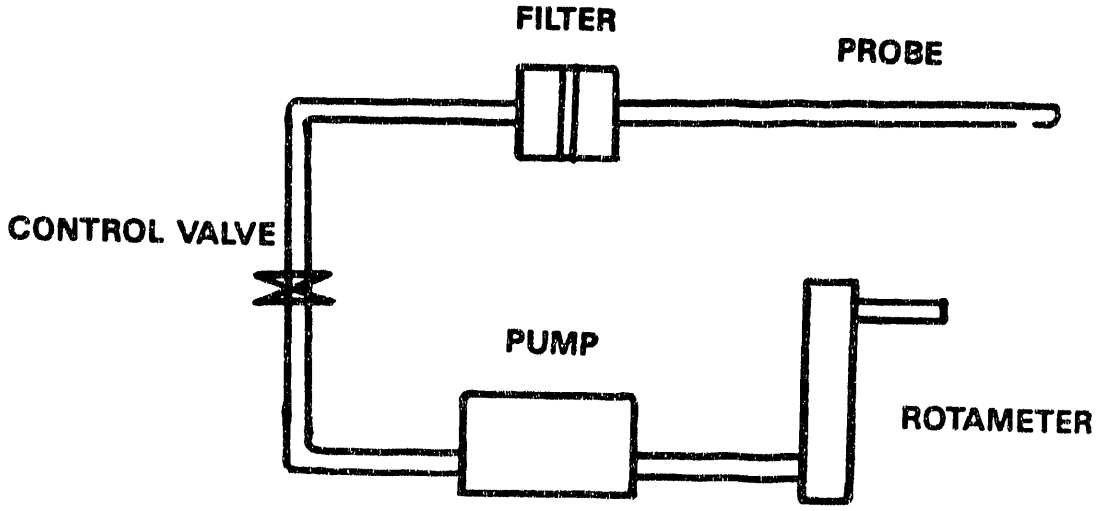

Figure 2(a). Schematic of Probe System for Measuring Solids Recycle Ratios

Figure 2(b) shows the rationale for determining the mass of recycled material.

Let A gms/min be the coal feed rate,
B gms/min the limestone feed rate,
C gms/min the mass collected on the filter (elutriated solids),
D gms/min the solids collected in the secondary cyclone, and
E gms/min the solids leaving the system through the exhaust gases.

For the purposes of these tests, the solid mass E leaving the system in the combustion gases is estimated as 2% of the solids entering the system i.e., $0.02 \times (A + B)$. The amount of solids recycled is calculated as $(C - D - E)$.

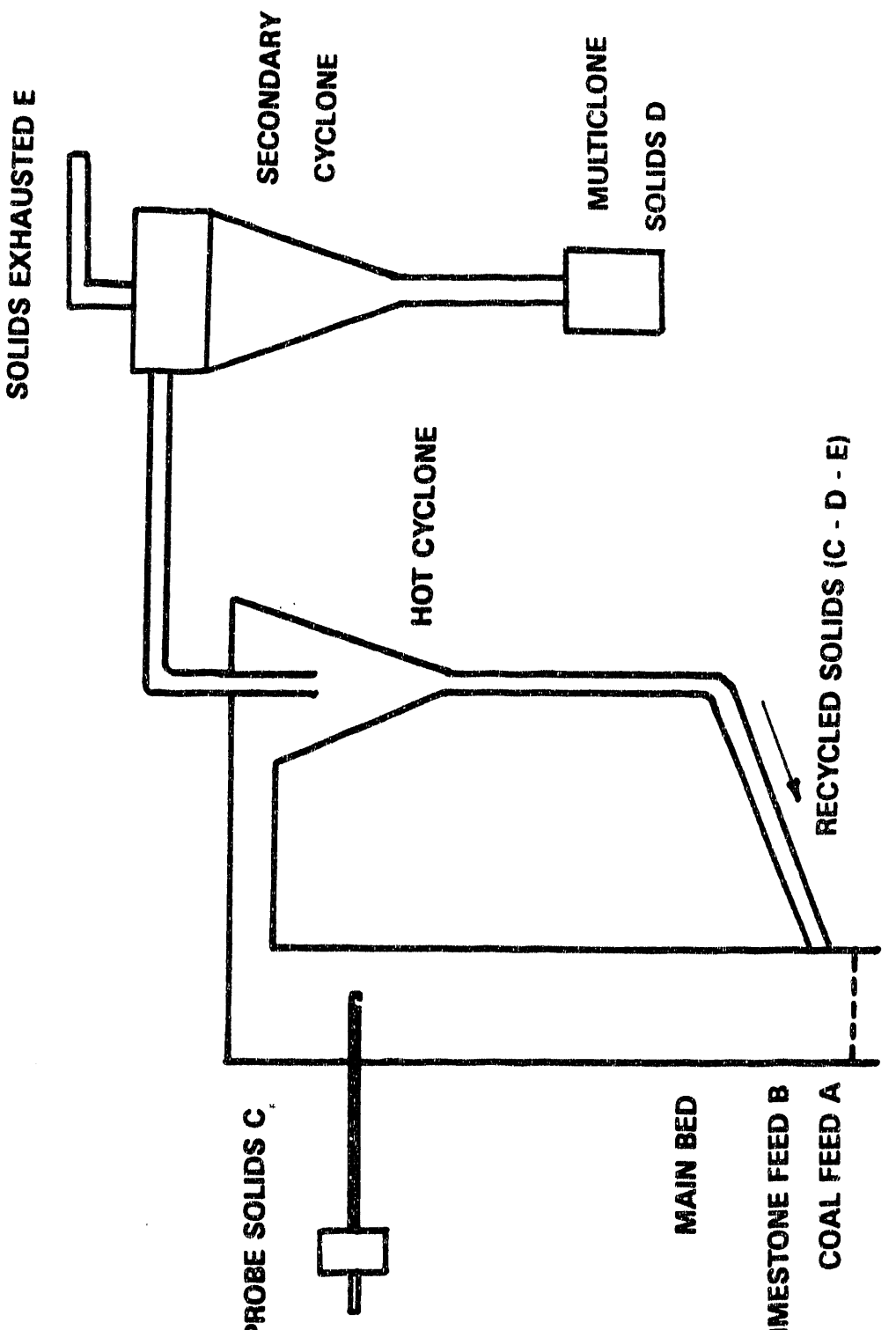

Figure 2(b). Schematic of CFBC Unit Showing Solids Flow Streams

$$\text{Ratio} \quad \frac{\text{Solids Recycled}}{\text{Solids fed in}} = \frac{(C - D - E)}{(A + B)} \times 100\%$$

Figure 3 shows the breakdown of the solids mass flow for a test. The superficial velocity was 8.9 ft/sec and the bed temperature was 1520°F. Of the solids fed in, about 37% were elutriated from the bed. Fifteen percent of input solids by mass were collected by the hot cyclone and recycled. This mass represents some of the larger particles that were elutriated. The major portion of the elutriated solids, (20% of input solids), being smaller in size, escaped the hot cyclone and were trapped by the three cyclone system comprising the multiclone particle trap shown in Figure 2(b). The composition of the elutriated solids is mostly unburnt char and limestone. For this test, a small limestone size +35 mesh was used. This limestone and combustion ash contribute to the 20% mass collected by the secondary cyclones.

Tests on Standard Coal

For the same test series with a superficial velocity of 8.9 ft/sec, the bed temperature was varied from 1465°F to 1650°F. The Ca/s ratio for the tests was 3.0. Figure 4 shows the measured CO, CO_2 and O_2 emissions measured as a function of bed temperature, while Figure 5 shows the NO_x emissions and Figure 6 the SO_2 emissions in ppm. The data shown in these figures are preliminary data. Further tests are to be conducted under similar conditions to confirm this data.

To obtain the data shown in the above figures, the fluidized bed combustor was operated for a period in excess of 400 hours. Not all of this period resulted in presentable data. Some of the test runs were made on run-of-mine coal used at the Southern Illinois University power plant. These tests were for the purpose of troubleshooting the equipment and establishing operating procedures. Some difficulty was experienced in feeding the coal. The coal feeder had to be calibrated on each coal used. In the last quarterly report, it was mentioned that the SO_2 analyzer could not be calibrated because of an electronic problem. This was fixed and the instrument could be calibrated. However, in the middle of the test period, when all other equipment was functioning properly, it was found that the SO_2 analyzer would sometimes behave erratically and drift from its calibration setting. This problem is being addressed at the present time, and the tests are planned to be repeated.

Additional tests are also planned to be conducted to investigate the influence of superficial velocity and other parameters. Particle size analysis, combustion efficiency calculations and carbon balances are planned for the coming quarter.

Three drums of coal-water slurry fuel were also received from ISGS on February 21, 1992. these samples are being prepared for moisture analysis, particle size analysis, proximate and ultimate analysis and EDX analysis. Ash and bed materials will also be subjected to similar analysis. Additional tests on the standard coal and the coal-water slurry fuels are planned for the next quarter.

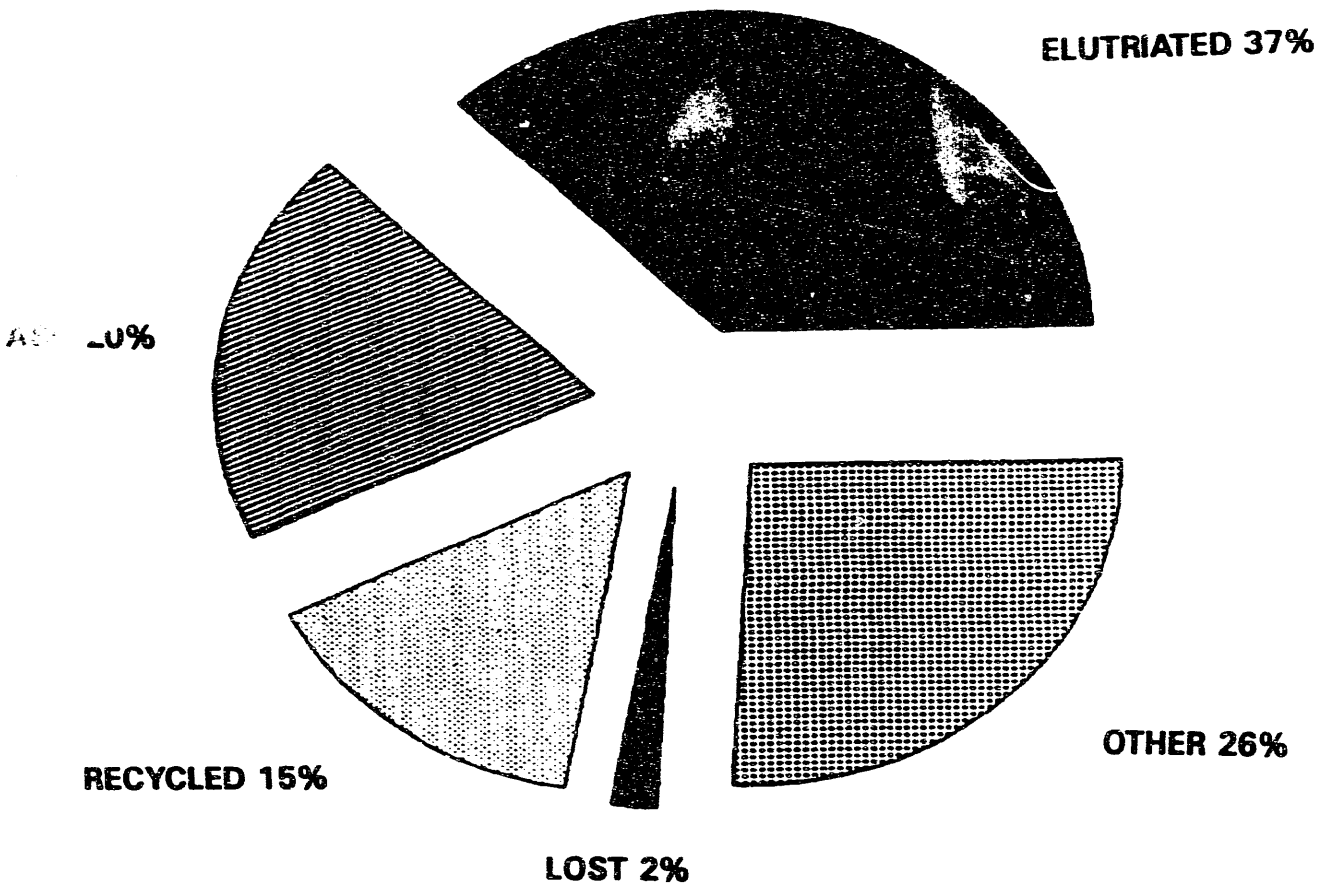

Figure 3. Solids Distribution in Combustor

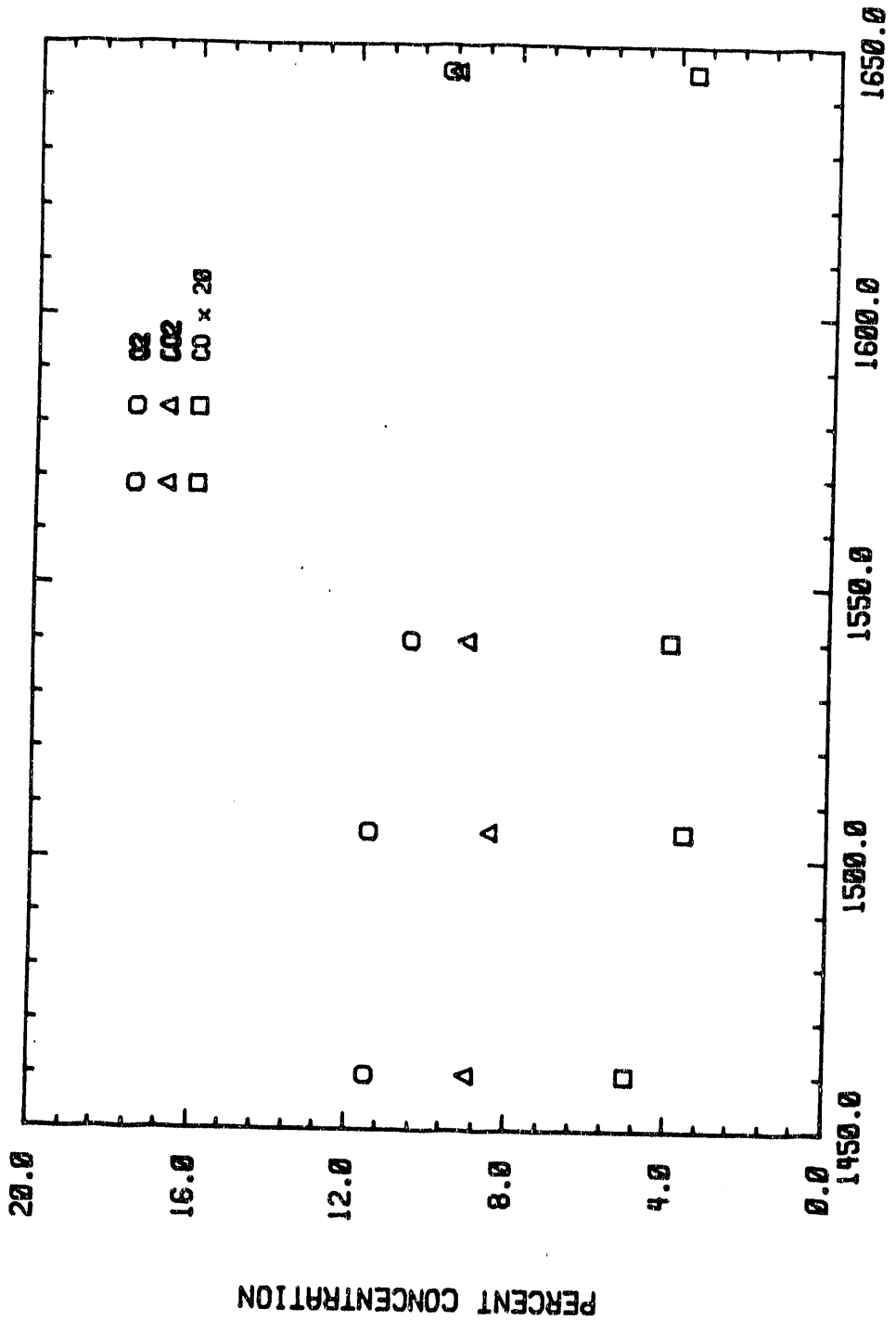

Figure 4. Variation of CO, CO_2 and O_2 with Bed Temperature

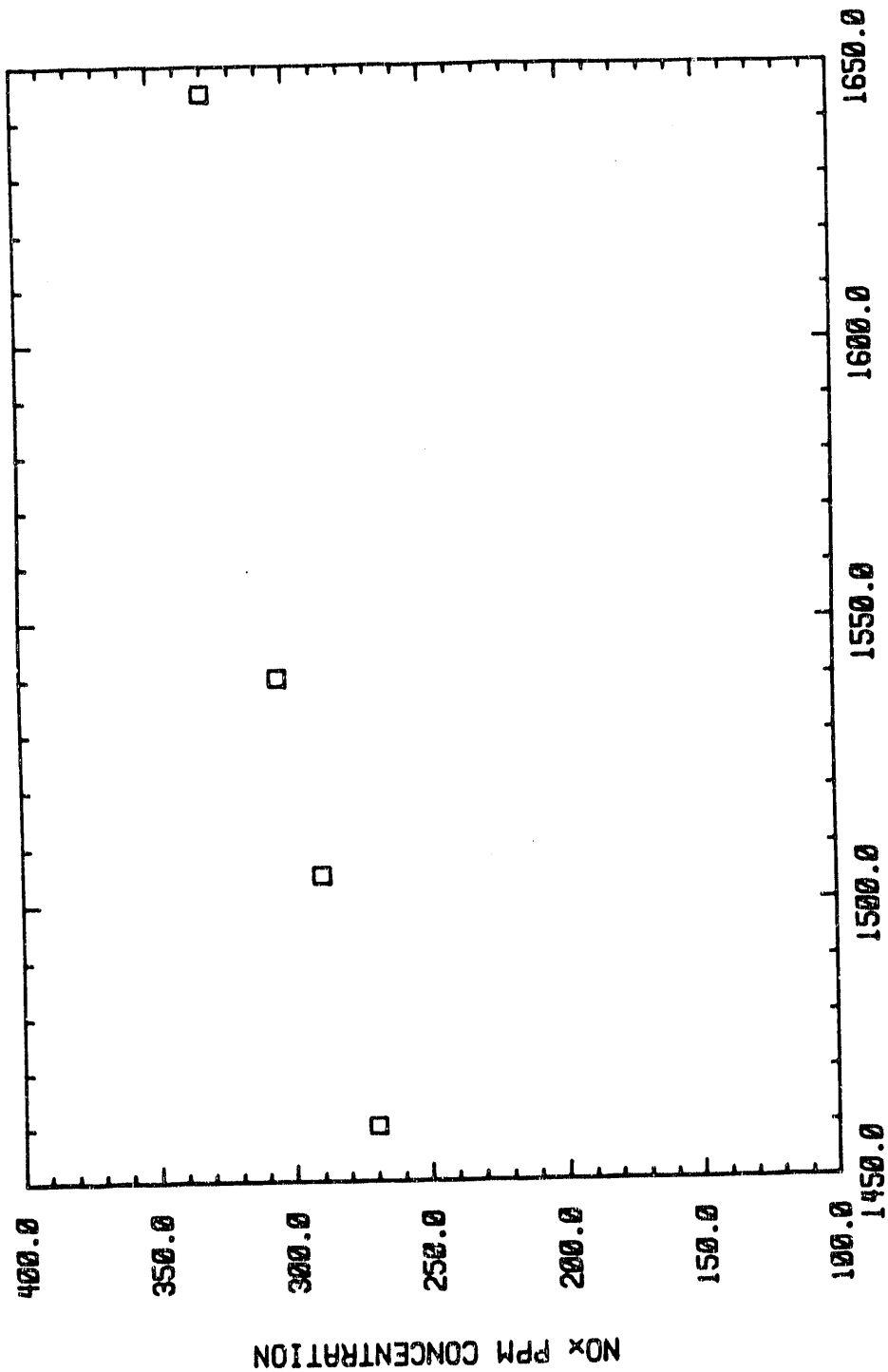

Figure 5. Influence of Bed Temperature on NO_x at Test Conditions

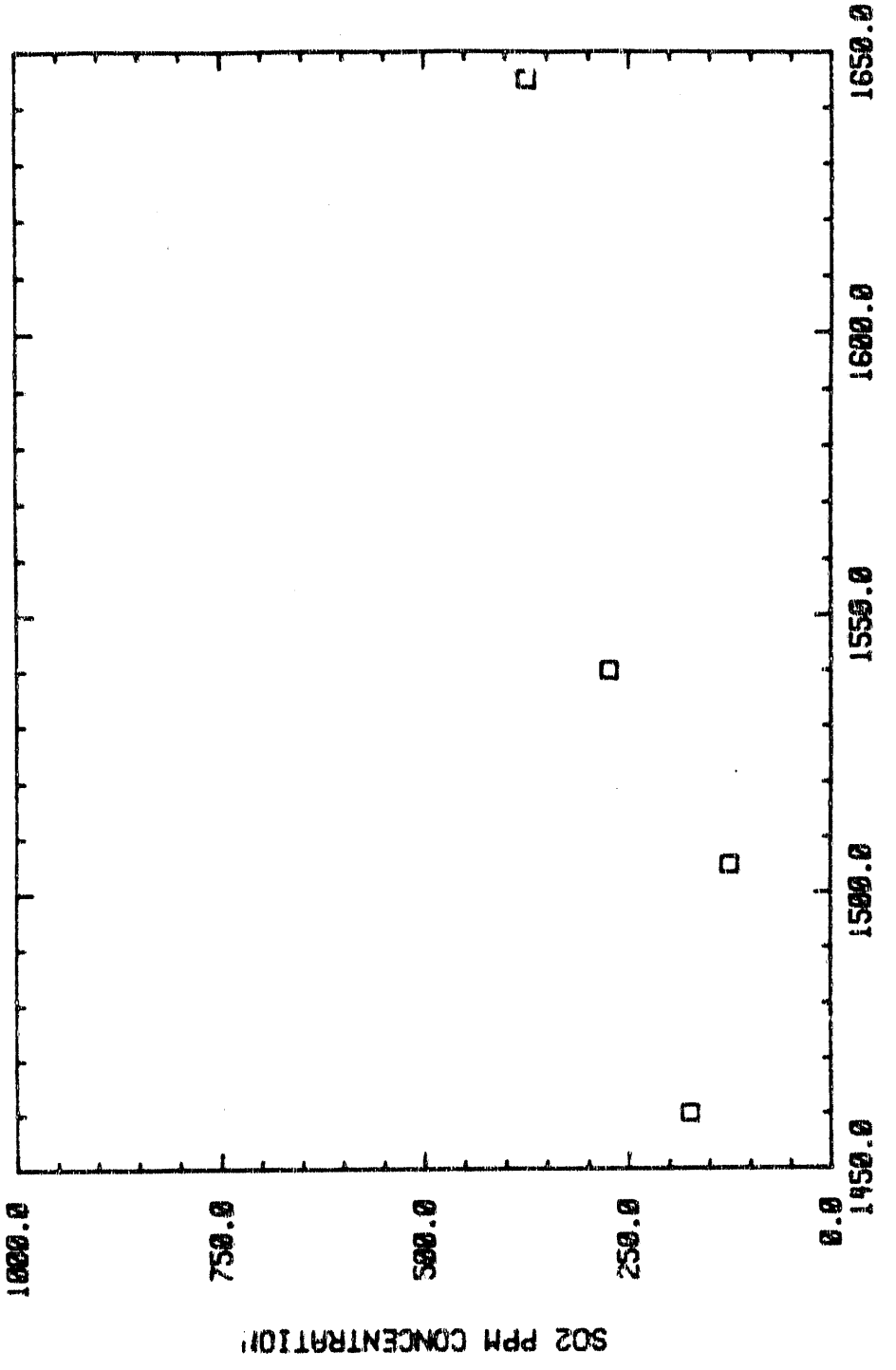

Figure 6. Effect of Bed Temperature on SO_2 Emissions

CONCLUSIONS

Progress has been made this quarter in operating the 4-inch diameter CFBC unit, to establish methods for obtaining recycle ratios and ob ain baseline data, when burning standard IBCSP No. 3 coal. A probe and metering system was designed and fabricated in order to measure the recycle ratios. The CFBC combustor was operated for more than 400 hours, not including samples preparation and maintenance time. Preliminary data from the experiments are presented. Operating personnel have been trained in experimental procedures, and data gathering techniques have been established.

Additional tests on the standard coal are planned to be conducted in the third quarter. The samples of beneficiated coal-water slurry fuels recently received from ISGS will be analyzed and prepared for testing. Combustion testing of the coal-water slurry fuels is also planned for the third quarter.

PROJECT MANAGEMENT REPORT
December 1, 1991, through February 29, 1992

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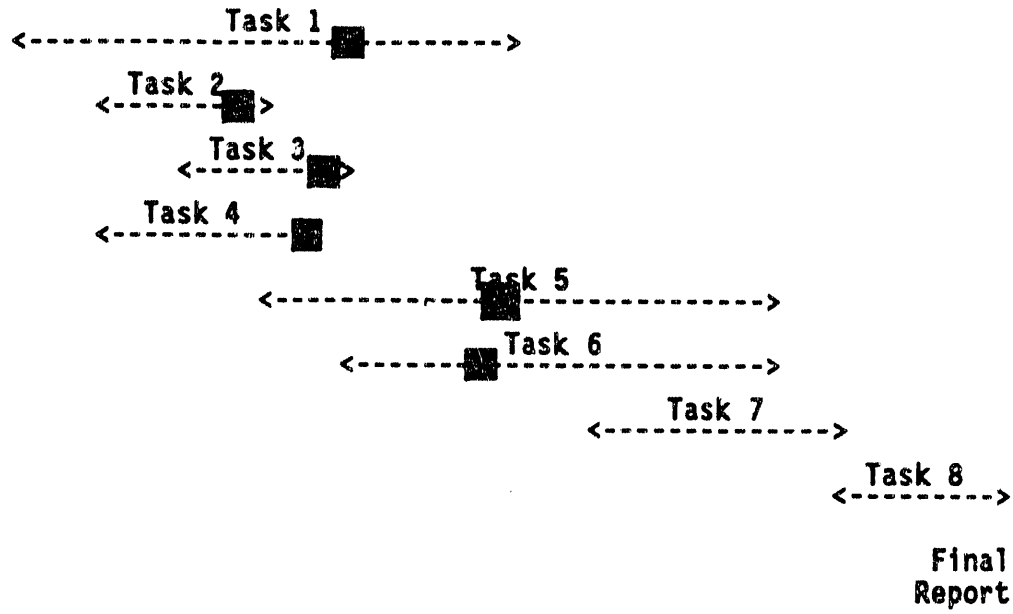
SCHEDULE



Task 1: Fuels Procurement
Task 2: Fuels Testing and Analysis
Task 3: Fuels Preparation
Task 4: Installation of Limestone Feeder
Task 5: Circulating Fluidized Bed Combustor Tests
Task 6: Combustion Residues Analysis
Task 7: Data Analysis
Task 8: Final Report Preparation

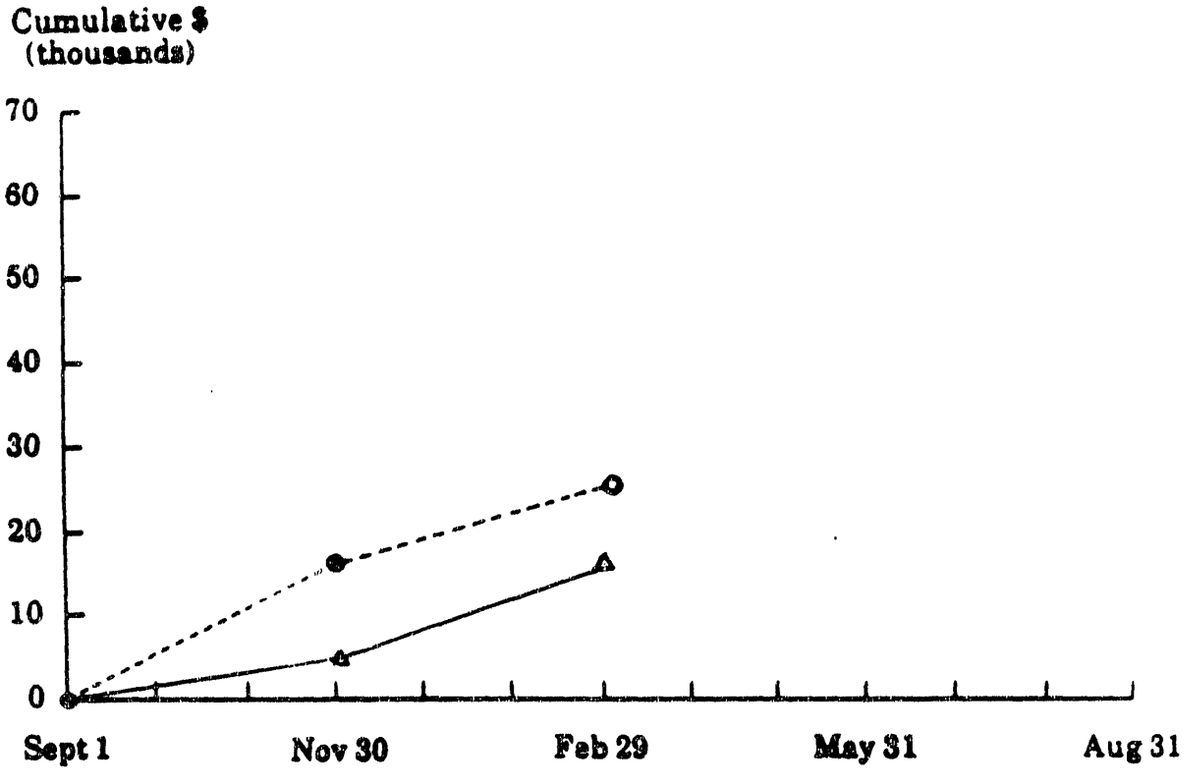
Projected and Estimated Expenditures by Quarter

Quarter*	Types of Cost	Direct Labor	Materials & Supplies	Travel	Major Equipment	Other Direct Costs	Indirect Cost	Total
Sept. 1, 1991 to Nov. 30, 1991	Projected	6667	1125	0	4500	2375	1467	16134
	Estimated	3500	400	0	0	500	1000	5400
Sept. 1, 1991 to Feb. 29, 1992	Projected	13334	2250	0	4500	4750	2843	27317
	Estimated	5900	1300	0	4000	2800	1600	15600
Sept. 1, 1991 to May 31, 1992	Projected							
	Estimated							
Sept. 1, 1991 to Aug. 31, 1992	Projected							
	Estimated							

*Cumulative by quarter

COSTS BY QUARTER - EXHIBIT C

CFBC Evaluation of Fuels Processed from Illinois Coals



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

Δ = [illegible] Expenditures _____

Total CRSC Awarded $67,623

END

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