DOE/PC/95143--T5

ENGINEERING DEVELOPMENT OF COAL-FIRED HIGH-PERFORMANCE POWER SYSTEMS

DE-AC22-95PC95143

TECHNICAL PROGRESS REPORT 6
SEPTEMBER THROUGH DECEMBER 1996

Prepared for
Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania

January 1997

TABLE OF CONTENTS

PAGE NO.

LIST OF FIGURES

FIGURE NO.		PAGE NO.

LIST OF TABLES

ABSTRACT

A High Performance Power System (HIPPS) is being developed. This system is a coal-fired, combined cycle plant with indirect heating of gas turbine air. Foster Wheeler Development Corporation and a team consisting of Foster Wheeler Energy Corporation, AlliedSignal Aerospace Equipment Systems, Bechtel Corporation, University of Tennessee Space Institute and Westinghouse Electric Corporation are developing this system. In Phase 1 of the project, a conceptual design of a commercial plant was developed. Technical and economic analyses indicated that the plant would meet the goals of the project which include a 47 percent efficiency (HHV) and a 10 percent lower cost of electricity than an equivalent size PC plant.

The concept uses a pyrolyzation process to convert coal into fuel gas and char. The char is fired in a High Temperature Advanced Furnace (HITAF). It is a pulverized fuel-fired boiler/air heater where steam and gas turbine air are indirectly heated. The fuel gas generated in the pyrolyzer is then used to heat the gas turbine air further before it enters the gas turbine.

The project is currently in Phase 2 which includes engineering analysis, laboratory testing and pilot plant testing. Research and development is being done on the HIPPS systems that are not commercial or being developed on other projects. Pilot plant testing of the pyrolyzer subsystem and the char combustion subsystem are being done separately, and then a pilot plant with integrated pyrolyzer and char combustion systems will be tested.

In this report, progress in the pyrolyzer pilot plant preparation is reported. The results of laboratory and bench scale testing of representative char are also reported. Preliminary results of combustion modeling of the char combustion system are included. There are also discussions of the auxiliary systems that are planned for the char combustion system pilot plant and the status of the integrated system pilot plant.

EXECUTIVE SUMMARY

The High Performance Power System is a coal-fired, combined cycle power generating system that will have an efficiency of greater than 47 percent (HHV) with NO_x and SO_x less than 0.025 Kg/GJ (0.06 lb/MMBtu). This performance is achieved by combining a coal pyrolyzation process with a High Temperature Advanced Furnace (HITAF). The pyrolyzation process consists of a pressurized fluidized bed reactor which is operated at about 926°C (1700°F) at substoichiometric conditions. This process converts the coal into a low-Btu fuel gas and char. These products are then separated.

The char is fired in the HITAF where heat is transferred to the gas turbine compressed air and to the steam cycle. The HITAF is fired at atmospheric pressure with pulverized fuel burners. The combustion air is from the gas turbine exhaust stream. The fuel gas from the pyrolyzation process is fired in a Multi-Annular Swirl Burner (MASB) where it further heats the gas turbine air leaving the HITAF. This type of system results in very high efficiency with coal as the only fuel.

We are currently in Phase 2 of the project. In Phase 1, a conceptual plant design was developed and analyzed both technically and economically. The design was found to meet the project goals. The purpose of the Phase 2 work is to develop the information needed to design a prototype plant which would be built in Phase 3. In addition to engineering analysis and laboratory testing, the subsystems that are not commercial or being developed on other projects will be tested at pilot plant scale. The FWDC Second-Generation PFB pilot plant in Livingston, New Jersey is being modified to test the pyrolyzer subsystem. The FWDC Combustion and Environmental Test Facility (CETF) in Dansville, NY is being modified to test the char combustion system. When these tests are complete, an integrated pilot plant including both the pyrolyzation and char combustion systems will be built and tested at the University of Tennessee Space Institute (UTSI). This Integrated System Test (IST) will have a coal input of 2724 Kg/h (6000 lb/h).

In the current quarter, work has proceeded on the modification of the Livingston, New Jersey pilot plant for the pyrolyzation tests. Initial testing will be in the bubbling bed mode. The fabrication and subsystem testing for this pilot plant arrangement is nearly complete. The two most significant changes to the pilot plant for these tests were the installation of new systems for the injection of sand and pulverized coal into the pyrolyzer. The pneumatic system for the transport of coal from the silo to the lock hopper system was installed and tested during this quarter. The sand injection system is installed and the shakedown of this system will be done in January. Refractory dryout and pressure testing have also been completed. The first fired shakedown run of the modified plant is scheduled for January.

Modifications to the CETF are being made as they can be practically scheduled with other test programs. The furnace is being modified for arch-firing, and systems are being designed to simulate HIPPS firing conditions. The design of a burner is in progress, and this effort is being

assisted with laboratory and bench scale testing of the char as well as computer modeling. Considerable work was done in these areas. The CETF and IST furnaces have been modeled, and this work has provided design information on furnace dimensions and operating parameters.

Fuel characterization work has been done on HIPPS type char and other low volatile coals that have been used commercially. In this manner, the laboratory analyses for the char can be related to full scale operation by comparison with the fuels for which there is commercial experience. In the current quarter, this work has been extended to a commercially produced char that would be used for part of the CETF combustion system tests. The testing showed that this char is very similar to the HIPPS type char, and it can be used in the CETF tests.

Both the fuel characterization and furnace modeling indicate that good carbon burnout can be expected with the HIPPS type char. Also, the indications are that conversion of fuel nitrogen to NO_x should be lower with the char than with the parent coal. The laboratory and modeling work indicate that some raw coal may need to be fired as a support fuel for ignition and flame stability. The CETF combustion tests will determine if the support coal is really needed.

Design work is proceeding on the IST in areas that do not require input from the results of the pyrolyzer and combustion system tests. The overall heat and material balance has been revised to incorporate changes to the char transport and combustion systems. Preliminary dimensions of the lower furnace modification have been developed, and changes to the structural steel are being evaluated. Work is also being done to update the control system and auxiliary systems such as steam and coal preparation.

INTRODUCTION

In Phase 1 of the project, a conceptual design of a coal-fired high performance power system was developed, and small scale R&D was done in critical areas of the design. The current Phase of the project includes development through the pilot plant stage, and design of a prototype plant that would be built in Phase 3.

Foster Wheeler Development Corporation (FWDC) is leading a team of companies in this effort. These companies are:

- Foster Wheeler Energy Corporation (FWEC)
- AlliedSignal Aerospace Equipment Systems
- Bechtel Corporation
- University of Tennessee Space Institute (UTSI)
- Westinghouse Electric Corporation

The power generating system being developed in this project will be an improvement over current coal-fired systems. Goals have been identified that relate to the efficiency, emissions, costs and general operation of the system. These goals are:

- Total station efficiency of at least 47 percent on a higher heating value basis.
- Emissions:

  NO_x < 0.06 lb/MMBtu
  SO_x < 0.06 lb/MMBtu
  Particulates < 0.003 lb/MMBtu

- All solid wastes must be benign with regard to disposal.
- Over 95 percent of the total heat input is ultimately from coal, with initial systems capable of using coal for at least 65 percent of the heat input.

The base case arrangement of the HIPPS cycle is shown in Figure 1. It is a combined cycle plant. This arrangement is referred to as the All Coal HIPPS because it does not require any other fuels for normal operation. A fluidized bed, air blown pyrolyzer converts coal into fuel gas and

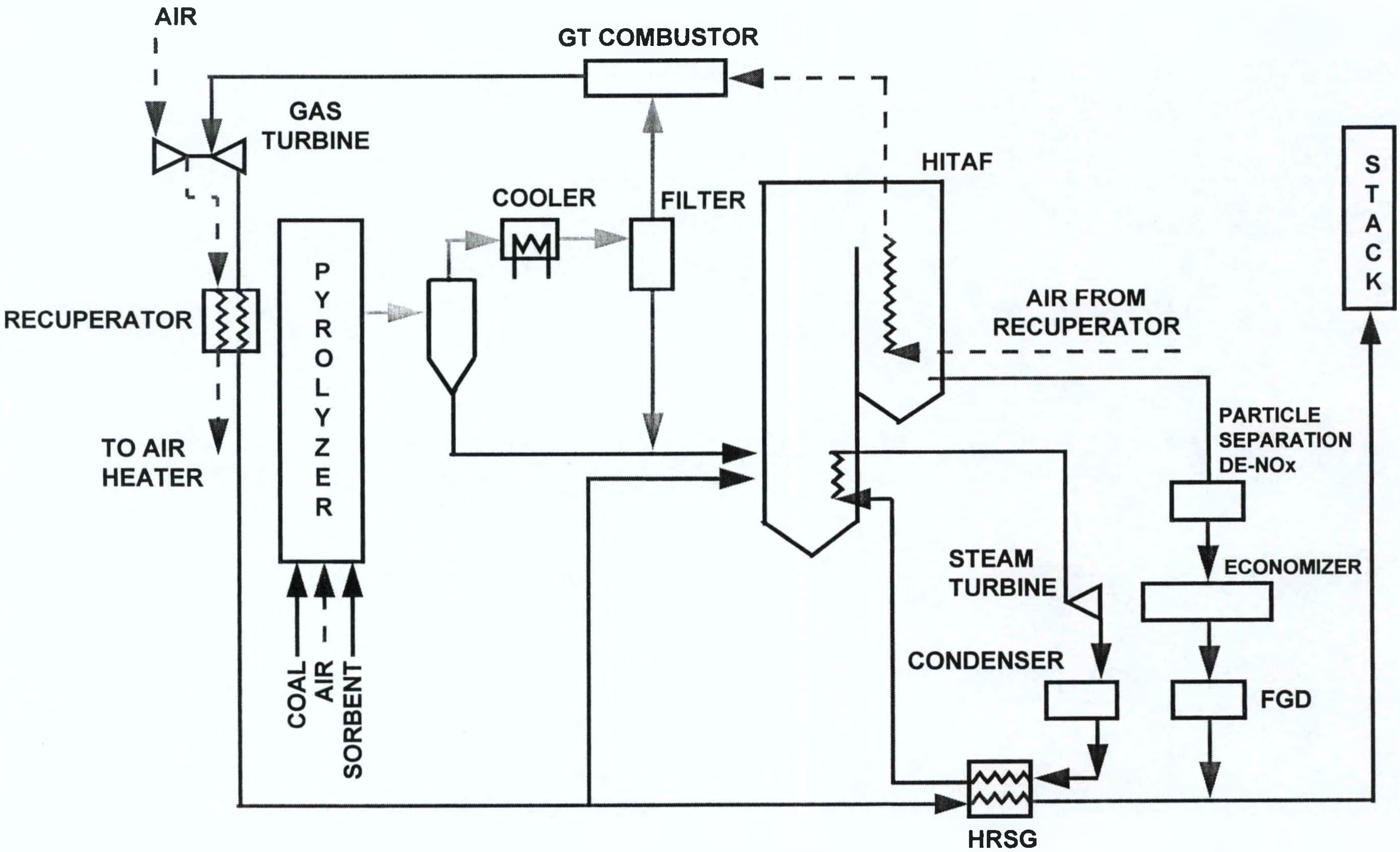


Figure 1 All Coal Fired HIPPS

char. The char is fired in a high temperature advanced furnace (HITAF) which heats both air for a gas turbine and steam for a steam turbine. The air is heated up to 760°C (1400°F) in the HITAF, and the tube banks for heating the air are constructed of alloy tubes. The fuel gas from the pyrolyzer goes to a topping combustor where it is used to raise the air entering the gas turbine to 1288°C (2350°F). In addition to the HITAF, steam duty is achieved with a heat recovery steam generator (HRSG) in the gas turbine exhaust stream and economizers in the HITAF flue gas exhaust stream.

An alternative HIPPS cycle is shown in Figure 2. This arrangement uses a ceramic air heater to heat the air to temperatures above what can be achieved with alloy tubes. This arrangement is referred to as the 35 percent natural gas HIPPS, and a schematic is shown in Figure 2. A pyrolyzer is used as in the base case HIPPS, but the fuel gas generated is fired upstream of the ceramic air heater instead of in the topping combustor. Gas turbine air is heated to 760°C (1400°F) in alloy tubes the same as in the All Coal HIPPS. This air then goes to the ceramic air heater where it is heated further before going to the topping combustor. The temperature of the air leaving the ceramic air heater will depend on technological developments in that component. An air exit temperature of 982°C (1800° F) will result in 35 percent of the heat input from natural gas.

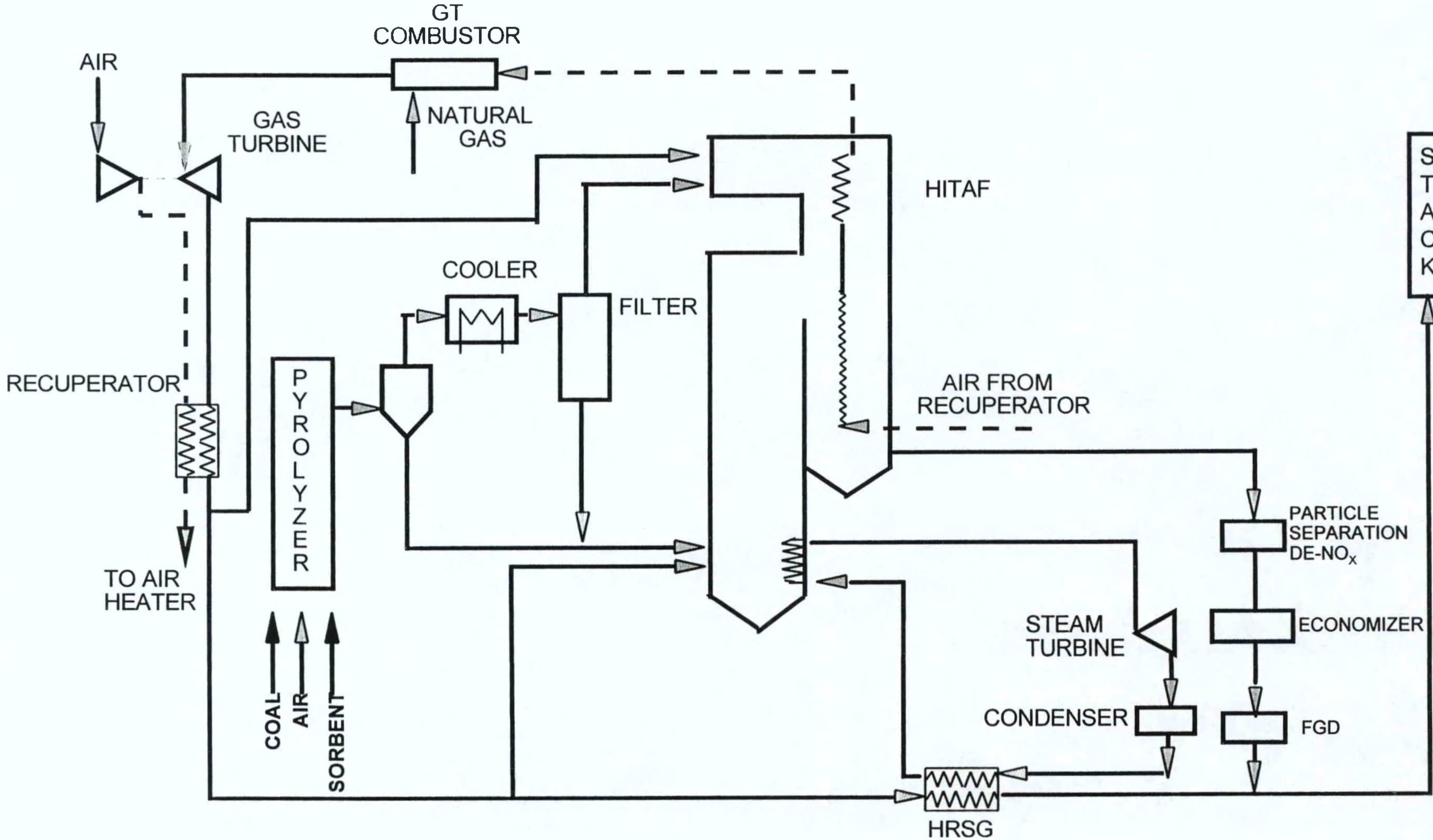


Figure 2 35-Percent Natural Gas HIPPS

TECHNICAL PROGRESS

Task 1 - Project Planning and Management

Work is proceeding in accordance with the Project Plan.

Task 2 - Engineering Research and Development

Subtask 2.4 - Char Combustor Analysis

During this quarter, work has been done on both the characterization of char in laboratory tests and computer modeling of char combustion in an arch-fired furnace. The laboratory tests included standard laboratory coal characterization tests and drop tube furnace tests. The computer modeling was done on PCGC-3, a combustion code developed at Brigham Young University.

Char Characterization

In the last Quarterly Report, laboratory and bench scale testing of Pittsburgh No. 8 char, Pittsburgh No. 8 coal, Narcea anthracite, Wannian anthracite and Wangzhaung bituminous (low volatile) coal were reported. The Pittsburgh No. 8 char was from previous pilot plant tests of the Second-Generation PFB carbonizer. This char is believed to be similar to what will be produced in the HIPPS pyrolyzer. These tests were performed to compare the HIPPS type char with other fuels where more is known about performance at commercial scale. The tests included proximate and ultimate analyses, T_{15} reactivity, thermal gravimetric analysis (TGA), and drop tube tests. During the current quarter, these tests were also done on McClain char which is a commercially produced char. Detailed descriptions of the various tests are contained in Quarterly Report 5 [1].

The McClain char was tested as a possible fuel for use in the combustion system tests that will be performed at the FWDC Combustion and Environmental Test Facility (CETF) in Dansville, New York. This facility will fire over 907 Kg/h (2000 lb/h) of char. The test program planned for the CETF will require more char than will be available from the Livingston, New Jersey pyrolyzer pilot plant. Therefore, it is planned that initial combustion system testing will use commercially produced char with characteristics similar to the HIPPS type Pittsburgh No. 8 char. Final tuning of the combustion system will be done with char from the pyrolyzer pilot plant tests.

Table 1 shows the proximate and ultimate analyses of the McClain parent coal and char and the Pittsburgh No. 8 parent coal and char. The McClain Corporation char is produced from a blend of midwestern coals. The conversion process is proprietary. The analyses differ a little, but it is mainly because the pilot plant generated char has some sorbent in it. This situation increases the percentage of ash, decreases the percentage of carbon and lowers the heating value. Considering this effect, the McClain char is very similar to the HIPPS type char in chemical analysis and heating value.

Table 1 Proximate/Ultimate Analysis of Char and Coals

	Pittsburgh No. 8 Coal	Pittsburgh No. 8 HIPPS type Char/sorb	McClain Coal	McClain Char
Proximate Analysis, %				
Fixed carbon	49.24	49.87	46.00	76.53
Volatile matter	33.84	4.60	33.69	2.33
Ash	13.78	38.81	11.19	20.64
Moisture	3.14	6.72	9.12	0.50
Ultimate Analysis, %				
Carbon	67.73	48.46	66.66	76.62
Hydrogen	4.31	--	4.38	0.01
Oxygen	4.74	2.16	3.85	0.04
Nitrogen	1.86	1.06	1.28	1.05
Sulfur	4.44	2.10	3.52	1.14
Ash	13.78	38.81	11.19	20.64
Moisture	3.14	6.74	9.12	0.50
HHV, Btu/lb	12,241	7,039	11,848	10,618

*Stored char picked up moisture. The volatile matter measurement includes a correction for the sorbent hydration .

Table 2 is a comparison of the TGA, T_{15} reactivity and drop tube test results for the Pittsburgh No. 8 and McClain coals and chars. It can be seen that the T_{15} reactivities were similar for the Pittsburgh No. 8 and McClain raw coals. This similarity would be expected for Eastern and midwestern high volatile bituminous coals. On the other hand, the T_{15} reactivity of the McClain char is about 70^{o}F higher than the HIPPS type Pittsburgh No. 8 char.

Table 2 Comparison of TGA, T_{15} and Drop Tube Results for Coals and Chars

	Pittsburgh No. 8		McClain Corporation	
	Coal	Char/Sorb	Coal	Char
T_{15} reactivity, °C	224	429	226	497
TGA fuel T_{ig}, °C	375	475	310	550
TGA $T_{burn.}$, °C	800	650	790	860
Surface area, m^2/g	27.6	163.8	27.1	9.6
Drop Tube Results				
Combustion eff. %	98.6	97.4	98.8	99.2
NO_x ppm @3% O_2	1045	755	1069	554
lb $NO_x/10^6$ Btu	1.67	1.24	1.63	1.02
N conv. to NO_x, %	33.9	24.3	41.7	28.6

The T_{15} reactivity results are consistent with the TGA results. The raw coals had similar ignition temperatures with the McClain coal being somewhat lower (310°C vs 375°C). However, the McClain char had a significantly higher ignition temperature compared to the HIPPS type Pittsburgh No. 8 char (550°C vs 475°C). The burnout temperature was also determined for samples which had been devolatilized first under nitrogen in the TGA. As shown in Table 2, the burnout temperature was about 200°C higher for the McClain char. This higher TGA burnout temperature appears to correlate with surface area, since the surface area of the McClain char is much lower than that of the Pittsburgh No. 8 char (9.6 vs 163.8 m^2). The burnout temperatures of the raw coals are similar as are the surface areas.

Drop tube furnace tests were conducted with the coals and chars in order to evaluate combustion efficiency and NO_x emissions at conditions simulating a full-scale boiler. In these tests, a 100/+140 mesh sample was combusted in 20 to 25 percent excess air at 1500°C. The particle residence time in the hot zone of the furnace was about 1.2 to 1.5 seconds. Combustion efficiency was calculated using an ash tracer method with the feed and collected ash/char. NO_x emissions were measured in the flue gas from the furnace with a chemiluminescent analyzer.

As shown in Table 2, the combustion efficiency of the coals and chars were fairly similar and in excess of 97 percent. The McClain coal had a similar combustion efficiency as the Pittsburgh No.8 coal (99%). The McClain char had a combustion efficiency which was slightly higher than the HIPPS type Pittsburgh No. 8 char (99.2 vs 97.4%). This combustion efficiency area for the McClain char is surprising, considering its lower surface area and reactivity in the TGA. The much higher particle heating rate in the drop tube may be responsible for the difference in reactivity compared to the TGA.

Emissions are also shown in Table 2 for the coals and chars. These emissions do not include the baseline thermal (120 to 130 ppm) measured with only air passing through the drop tube. The Pittsburgh No. 8 and McClain coals both had similar NO_x on a pound per million Btu basis. The emissions for the chars were also similar, but considerably lower than the raw coals. The chars had a lower conversion of fuel nitrogen to NO_x than the raw coals. The nitrogen conversion to NO_x for the Pittsburgh No. 8 HIPPS type char was considerably lower than reported in the last quarterly report [2]. The char nitrogen content used in the previously reported result was found to be in error. In addition, the McClain coal and char each had higher conversions of fuel nitrogen than the Pittsburgh No. 8 coal and char. The NO_x emissions obtained from the drop tube may not necessarily represent those that will be obtained with arch-firing the fuels, but they should give an indication of the potential for fuel NO_x emissions.

Overall, the McClain char appears to have combustion characteristics similar to the Pittsburgh No.8 HIPPS type char. Since it can be obtained in whatever quantities needed, it will be used in the initial testing at the CETF. The fine tuning of the combustion system will be done with char from the HIPPS pyrolyzer pilot plant. The McClain char is somewhat less reactive than the char generated under HIPPS conditions, but it appears to be as close as we will be able to get from a commercial source. It will be harder to burn than the HIPPS char, so results should be conservative.

Combustion System Modeling

In the last quarterly report, the PCGC-3 combustion computer model was reported in detail along with results of analyzes of the CETF furnace under HIPPS conditions [3]. In the current quarter, this work has been extended to the furnace at the University of Tennessee Space Institute (UTSI).

UTSI Computer Model

A CFD analysis of the UTSI furnace for the HIPPS char burner has been performed using the PCGC computer program. The UTSI furnace for HIPPS application has one char burner located in the arch of the furnace as shown in Figure 3. The burner is designed to fire 2380 lb/hr of char with a support fuel of pulverized coal flow rate of 206 lb/hr (10% of heat input). The flow rate of vitiated air was calculated based on 3.5% mole fraction of oxygen expected in flue gas of the boiler if coal and char are completely burned. Char ultimate and proximate analysis data obtained at the FWDC laboratory are used in the simulation. Particle size distribution is based on 85% through 200 mesh. Char oxidation kinetics (half order with respect to oxygen partial pressure) for a char from high-volatile bituminous-A coal is applied based on a Sandia's research (and verified by BYU testing). The presence of sorbent in the fuel is simulated. The computational block (grid) model for the furnace contains 78,474 (58x41x33) cells with finer grids used near the burner. The waterwalls are internally lined with refractory and operate at atmospheric pressure.

Results

Table 3 lists the input parameters for the UTSI furnace model.

The overall carbon burnout is 98.8%. NO_x concentration at the furnace outlet is 107 ppm. Figure 4 presents gas temperature distribution. Figure 5 presents the NO_x distribution. Figure 6 presents the trajectories and char mass fraction of the 65 micron particles . Temperature of the 65 micron particles is shown in Figure 7.

Future Work

The design of the UTSI burner and furnace will be refined. Combustion (vitiated) air distribution will be optimized. Furthermore, alternate burner concepts(s) will be analyzed for both UTSI and CETF.

Table 3 Summary of UTSI PCGC-3 Inputs

Char		
Mass Flow Rate	lb/hr	2382
Temperature	F	800
Swirl No. (tan/axi)		1.0
Vitiated Air		
Total Mass Flow Rate	lb/hr	39,864
Temperature	F	1124
Composition (by Wt)		
N_2	%	78.50
O_2	%	15.00
H_2O	%	1.70
CO_2	%	4.80
Total	%	100.00
Arch Tertiary Swirl No. (tan/axi)		0.5
Over Fired Air Swirl No. (tan/axi)		1.0
Excess O_2	%	3.5

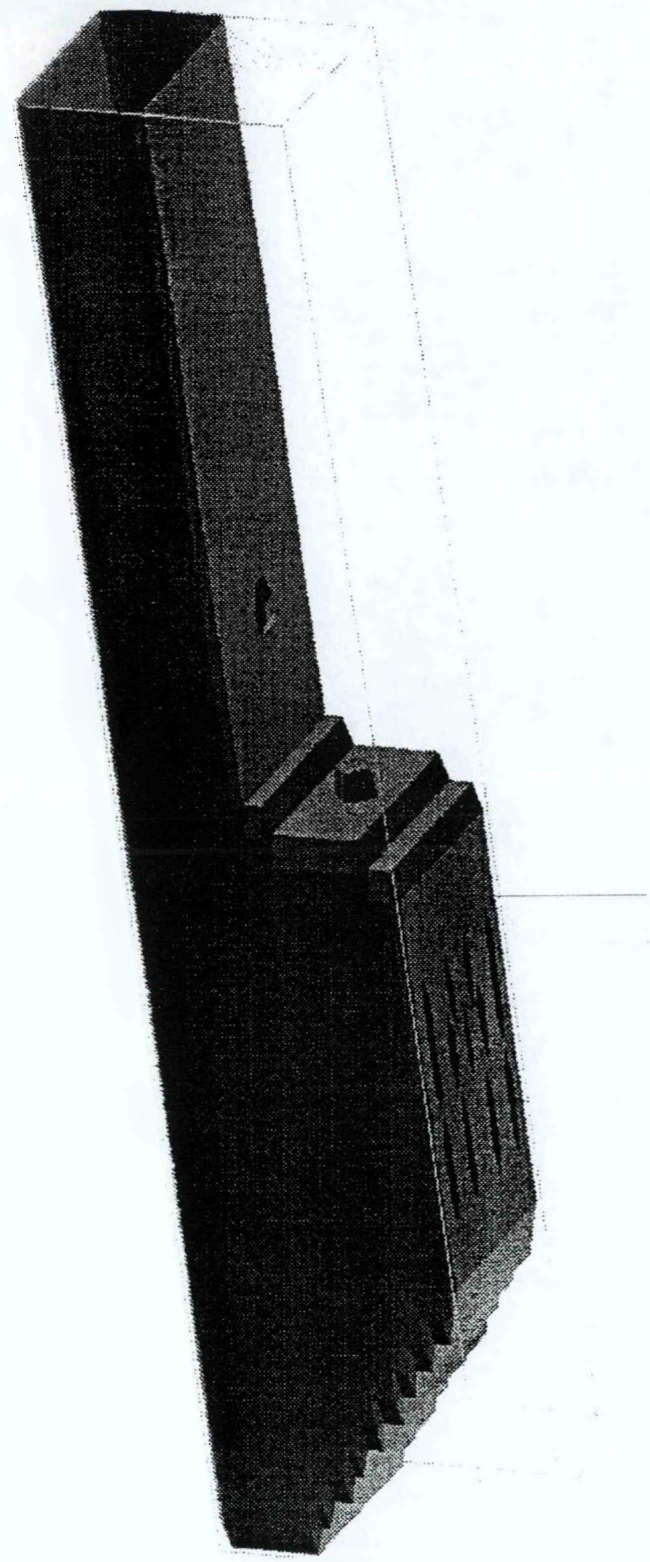


Figure 3 Computational Model

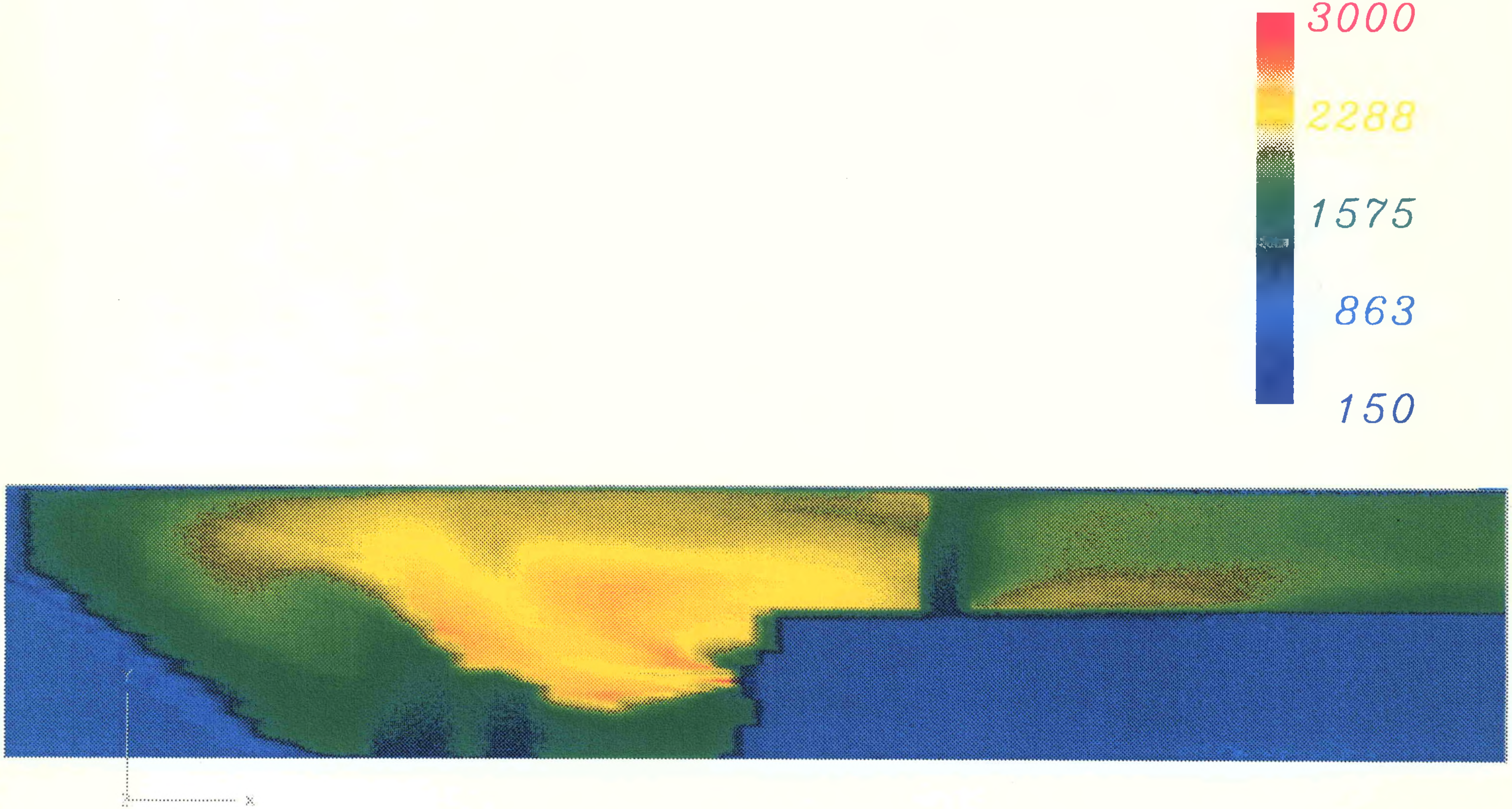


Figure 4 Gas Temperature (F)

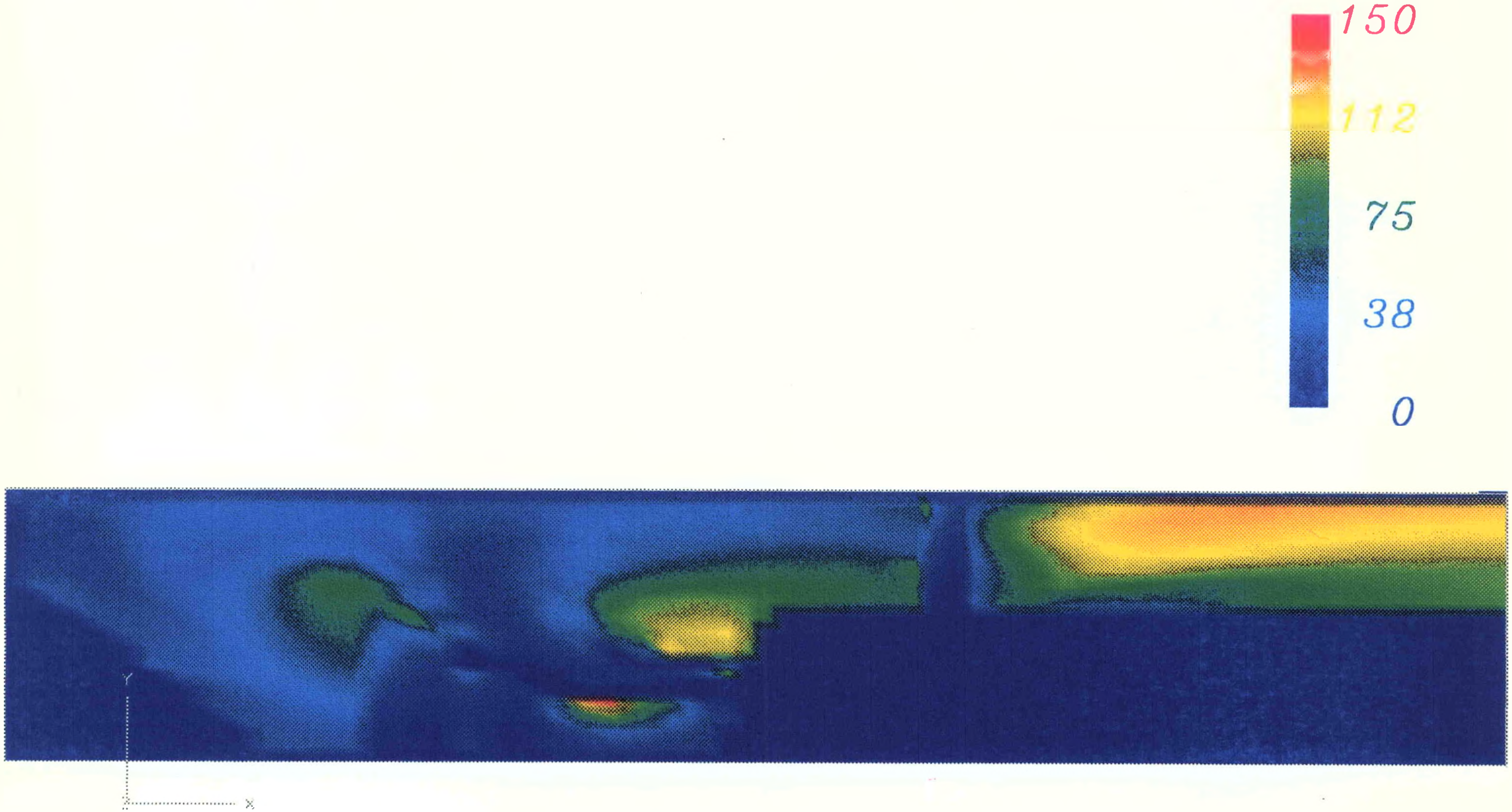


Figure 5 NOx Concentration (ppm)

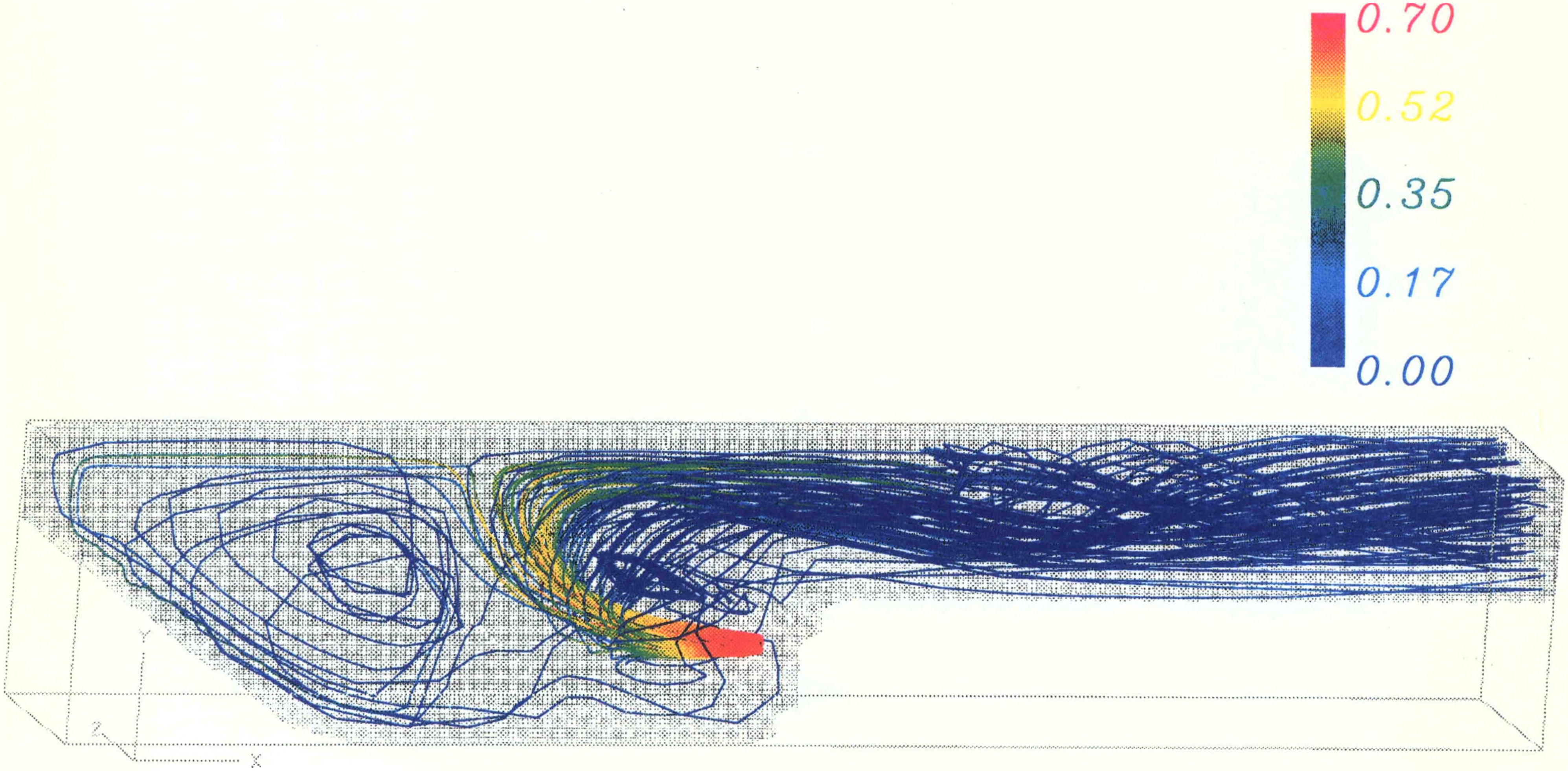


Figure 6 Char Trajectory with Char Mass Fraction (65.3 micron)

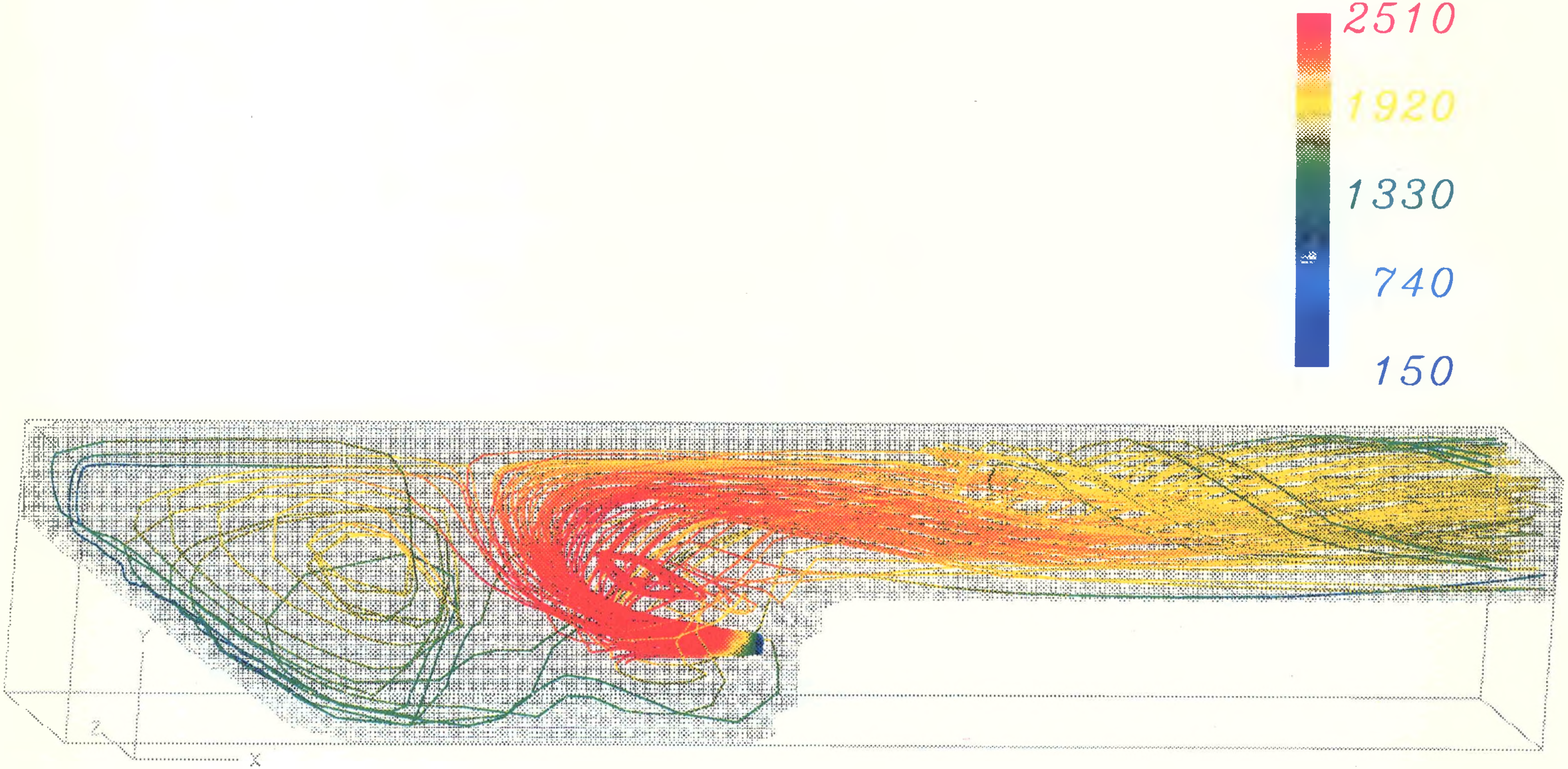


Figure 7 Char Trajectory with Char Temperature (65.3 micron)

Task 3 - Subsystem Test Unit Design

Subtask 3.1 - Pyrolyzer/Char Transport Test Design

The design of the Pyrolyzer/Char Transport Test (PCTT) has been completed. The FWDC Second-Generation PFB pilot plant in Livingston, NJ is being modified for these tests. Two test arrangements have been designed. The first to be tested will be a bubbling bed arrangement. After testing is completed on the bubbling bed arrangement, the pilot plant will be modified to a circulating bed arrangement, and more tests will be run. Procurement of equipment and modification of the pilot plant are in progress. This work is reported under Subtask 4.1.

Subtask 3.2 Char Combustion System Test Design

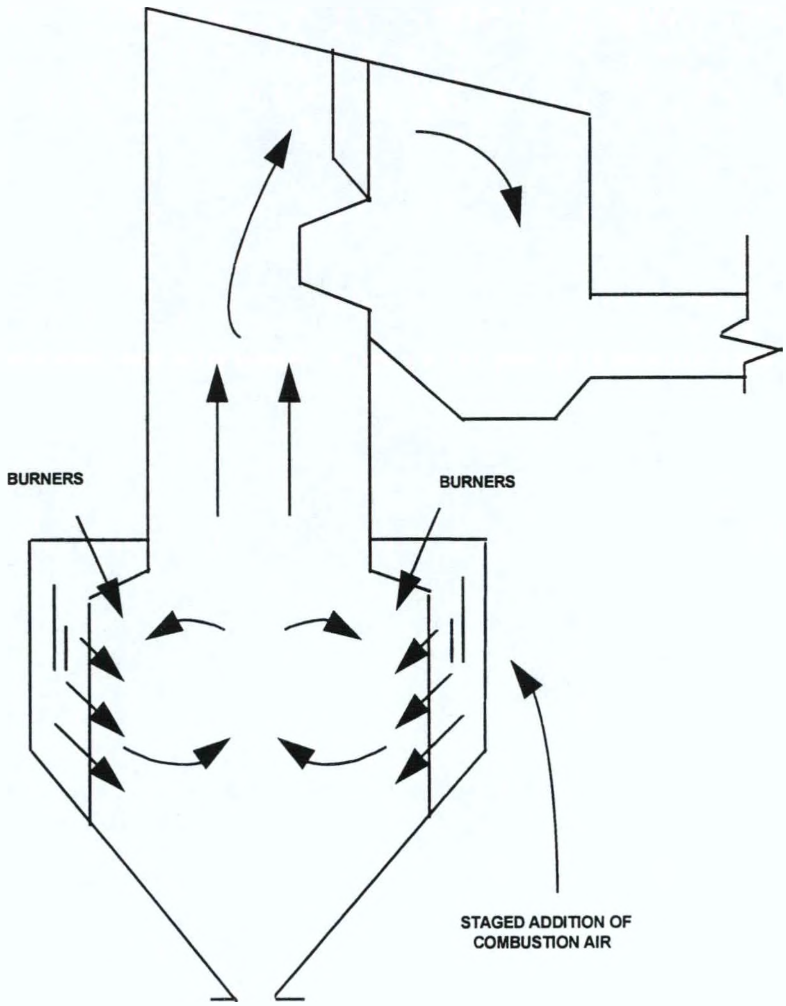
The FWEC arch-fired combustion system is the base case system for char combustion in HIPPS. The concept is illustrated in Figure 8. The lower furnace has two arches where the burners are located. The burners fire down into the furnace, and combustion air is added in stages through the front and rear wall. This type of arrangement causes a long flame path where the air supply is gradually added to the fuel to avoid quenching. This approach also results in essentially a staged combustion which tends to minimize NO_x. In addition to the air staging, the geometry of the furnace promotes recirculation of hot gases from the upper furnace back into the flame. This situation is also a stabilizing influence on the flame and the flame temperature.

Combustion tests will be run at the Foster Wheeler Combustion and Environmental Test Facility (CETF) in Dansville, New York. This facility is used to test burners. It consists of a furnace and convection pass that was designed to simulate conditions in larger scale boilers. Under HIPPS conditions, the facility will be capable of approximately 30MMBtu/h heat input to the furnace. The furnace was originally built for arch-firing, but it was later converted to horizontal-firing. It will be converted back to arch-firing with a design that will facilitate changing back and forth between the two configurations.

The computer combustion modeling work reported in Quarterly Report 5 [4] is being used to provide insight into how the pilot plant will operate under HIPPS conditions. This information has been helpful in making design decisions in both the areas of furnace/burner design and the auxiliary or process type systems. The basic dimensions of the furnace are adequate for operation at approximately 30 MMBtu/h under HIPPS conditions. This is considerably lower than full load of the furnace under standard coal-fired conditions. The need for operation at lower heat inputs is necessitated primarily by the use of lower oxygen combustion air for HIPPS. This situation results in more flue gas per pound of fuel.

The modeling has shown that planned modifications to the furnace will be adequate to explore a range of operating parameters that will allow the optimization of combustion under HIPPS conditions. It has also indicated what parameters will be important to simulate and which can be less stringently applied. It has been determined that the heating of char to simulate the 427°C (800°F) char that will be delivered to the furnace in a complete HIPPS system is not worthwhile. The modeling showed the effect of this temperature to be relatively minor, and the complexity and cost of a system to perform this function are substantial. The oxygen content of the combustion air and its temperature are more important, and these will be simulated in the CETF tests. The instrumentation needs for the test program are being evaluated

Figure 8 Arch Firing



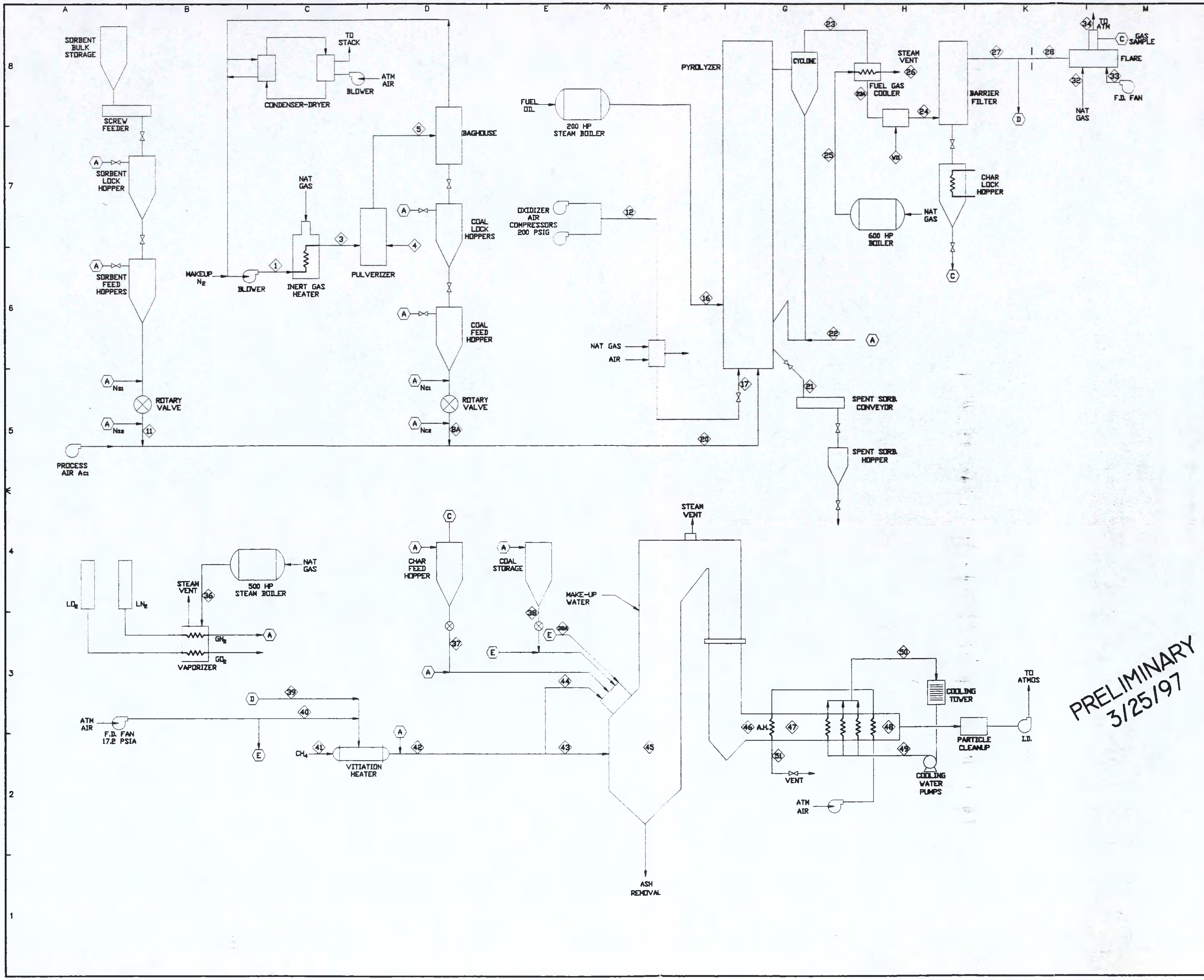
The char combustion system tests are scheduled to begin in October 1997. Most of the tests will be run with commercially produced char, but char generated in the PCTT will also be used to the extent that it is available.

Subtask 3.3 - Integrated System Test Design (IST)

The heat and material balance of the IST has been revised to reflect changes in the char transport and combustion systems. The base case heat and material balance is shown in Figure 9 and Table 3. In order to get a range of possible operating conditions, a low load heat and material balance is also shown in Table 4. This heat and material balance reflects both a 50 percent reduction in heat input, and a lower level of steam injection into the pyrolyzer.

A preliminary layout of the furnace modification that will be required for arch firing has been developed. This layout was incorporated into AutoCAD furnace tower structural drawings to assess modifications that will be required.

Work is being done on the detailed design and procurement of materials for the new 1.7 Mpa gage pressure (250 psig) boiler system. This boiler was purchased to supply the steam that will be injected into the pyrolyzer. Several alternatives for the feedwater preheat system are being reviewed. Boiler spare parts, material for the support stand, and the exhaust stack were procured. Other systems being investigated are the equipment needed to heat and vitiate the combustion air and the thermal oxidizer that will be required to burn off the fuel gas generated by the pyrolyzer.



REVISIONS

REV.	DATE	DR. INT.	DESCRIPTION

NOTES:

ITEM NO.	AMT. REQ'D.	DESCRIPTION/MATERIAL	SIZE

APPROVALS	NAME	DATE
ARRANGEMENT		

PROCESS FLOW DIAGRAM
INTEGRATED SYSTEM TEST

DRAWING NUMBER: RD960-90 — SCALE: NONE — REVISION:

DRAWN BY	S. WISNESKI	7/10/96
CHECKED BY		
APPROVED BY		

Table 4 Integrated System Test Full Load Heat and Material Balance

Display	4	8A	11	12	16	20	Acl	21	23	23A	24	25	26	27	28	31	32
Total Flow(klb/hr)	5.25	5.29	0.70	10.80	2.14	14.23	2.65	0.00	22.92	22.92	22.92	20.00	20.00	15.95	15.95	0.00	0.05
T(F)	70.00	70.00	70.00	150.00	375.00	70.01	150.00		1693.36	1000.0	1000.0	360.00	888.88	967.49	947.49	967.46	70.00
P(psi)	14.70	185.00	185.00	185.00	185.00	185.00	185.00		178.00	178.00	177.50	150.00	150.00	175.10	15.00	175.10	14.70
Gas																	
N2		1.000	1.000	0.749	0.000		0.749		0.570	0.570	0.570	0.000	0.000	0.570	0.570	1.000	0.000
O2		0.000	0.000	0.230	0.000		0.230		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H2O		0.000	0.000	0.008	1.000		0.008		0.086	0.086	0.086	1.000	1.000	0.086	0.086	0.000	0.000
CH4		0.000	0.000	0.000	0.000		0.000		0.010	0.010	0.010	0.000	0.000	0.010	0.010	0.000	1.000
CO2		0.000	0.000	0.001	0.000		0.001		0.131	0.131	0.131	0.000	0.000	0.131	0.131	0.000	0.000
H2		0.000	0.000	0.000	0.000		0.000		0.012	0.012	0.012	0.000	0.000	0.012	0.012	0.000	0.000
CO		0.000	0.000	0.000	0.000		0.000		0.181	0.181	0.181	0.000	0.000	0.181	0.181	0.000	0.000
H2S		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NH3		0.000	0.000	0.000	0.000		0.000		0.003	0.003	0.003	0.000	0.000	0.003	0.003	0.000	0.000
Ar		0.000	0.000	0.013	0.000		0.013		0.008	0.008	0.008	0.000	0.000	0.008	0.008	0.000	0.000
SO2		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C2H6		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C2H4		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO2		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SO3		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C12		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
m(klb/hr)	0.000	0.324	0.082	10.804	2.144	8.642	2.649	0.000	20.752	20.752	20.752	20.000	20.000	15.952	15.952	0.000	0.045
density(lb/ft^3)		0.912	0.912	0.815	0.372		0.815		0.187	0.276	0.275	0.331	0.188	0.277	0.024	0.320	0.041
Average MW		28.013	28.013	28.829	18.015		28.829		24.264	24.264	24.264	18.015	18.015	24.264	24.264	28.013	16.043
Sorbent																	
H2O			0.020			0.020		0.000	0.000	0.000	0.000						
CaCO3			0.955			0.955		0.000	0.000	0.000	0.000						
MgCO3			0.016			0.016		0.023	0.023	0.023	0.023						
CaS			0.000			0.000		0.805	0.805	0.805	0.805						
CaO			0.000			0.000		0.159	0.159	0.159	0.159						
MgO			0.000			0.000		0.000	0.000	0.000	0.000						
SiO2			0.000			0.000		0.000	0.000	0.000	0.000						
CaSO4			0.000			0.000		0.000	0.000	0.000	0.000						
Fe2O3			0.010			0.010		0.014	0.014	0.014	0.014						
m(klb/hr)	0.000	0.000	0.619	0.000	0.000	0.619	0.000	0.000	0.422	0.422	0.422	0.000	0.000	0.000	0.000	0.000	0.000
density(lb/ft^3)			170.477			170.477		162.410	162.446	164.375	164.375						
Average MW			100.153			100.153		69.731	69.731	69.731	69.731						
Fuel																	
Proxanal(mf%)	Coal	Coal				Coal		Char	Char	Char	Char						
Moisture	7.300	2.000				2.000		0.000	0.000	0.000	0.000						
FC	49.018	52.823				52.823		68.392	68.392	68.392	68.392						
VM	39.622	35.817				35.817		0.000	0.000	0.000	0.000						
Ash	11.359	11.360				11.360		31.608	31.608	31.608	31.608						
Ultanal(%)																	
Ash	11.360	11.360				11.360		31.608	31.608	31.608	31.608						
C	73.190	73.190				73.190		64.660	64.660	64.660	64.660						
H	4.900	4.900				4.900		0.234	0.234	0.234	0.234						
N	1.290	1.290				1.290		1.140	1.140	1.140	1.140						
CI	0.070	0.070				0.070		0.062	0.062	0.062	0.062						
S	3.890	3.890				3.890		1.926	1.926	1.926	1.926						
O	5.310	5.310				5.310		0.371	0.371	0.371	0.371						
Sulfanal(%)																	
Pyritic	1.700	1.710				1.710		0.000	0.000	0.000	0.000						
Sulfate	0.000	0.000				0.000		0.000	0.000	0.000	0.000						
Organic	2.190	2.180				2.180		1.926	1.926	1.926	1.926						
m(klb/hr)	5.252	4.968	0.000	0.000	0.000	4.968	0.000	0.000	1.750	1.750	1.750	0.000	0.000	0.000	0.000	0.000	0.000
density(lb/ft^3)	87.473	87.478				87.478			144.059	144.059	144.059						

Table 4 Integrated System Test Full Load Heat and Material Balance (continued)

Display	33	34	37	38	38A	39	40	41	42	43	44	45	A(to 8A)	A(to 11)	A(to 42)	A(toPyro)
Total Flow(klb/hr)	47.76	63.76	2.17	0.18	0.35	4.80	31.46	0.24	37.55	24.41	13.14	40.25	0.08	0.32	1.05	1.33
T(F)	70.00	1800.01	800.00	70.00	70.01	967.49	70.00	70.00	1125.24	1125.24	1125.24	2500.00	70.00	70.00	70.00	70.00
P(psi)	14.70	14.70	174.90	14.70	14.70	175.10	14.70	14.70	14.70	14.70	14.70	14.70	185.00	185.00	14.70	185.00
Gas																
N2	0.770	0.719			0.749	0.570	0.749	0.000	0.728	0.728	0.728	0.703	1.000	1.000	1.000	1.000
O2	0.230	0.111			0.230	0.000	0.230	0.000	0.150	0.150	0.150	0.037	0.000	0.000	0.000	0.000
H2O	0.000	0.054			0.008	0.086	0.008	0.000	0.048	0.048	0.048	0.049	0.000	0.000	0.000	0.000
CH4	0.000	0.000			0.000	0.010	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CO2	0.000	0.113			0.001	0.131	0.001	0.000	0.038	0.038	0.038	0.189	0.000	0.000	0.000	0.000
H2	0.000	0.000			0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CO	0.000	0.000			0.000	0.181	0.000	0.000	0.023	0.023	0.023	0.000	0.000	0.000	0.000	0.000
H2S	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NH3	0.000	0.001			0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ar	0.000	0.002			0.013	0.008	0.013	0.000	0.012	0.012	0.012	0.011	0.000	0.000	0.000	0.000
SO2	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000
C2H6	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
C2H4	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO2	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SO3	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000
Cl2	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
m(klb/hr)	47.764	63.761	0.000	0.000	0.352	4.800	31.458	0.243	37.553	24.409	13.143	39.336	0.082	0.324	1.051	1.333
density(lb/ft^3)	0.075	0.017			0.075	0.277	0.075	0.041	0.024	0.024	0.024	0.014	0.072	0.072	0.072	0.072
Average MW	28.840	28.728			28.829	24.264	28.829	16.043	28.277	28.277	28.277	29.638	28.013	28.013	28.013	28.013
Sorbent																
H2O			0.000									0.000				
CaCO3			0.000									0.000				
MgCO3			0.023									0.020				
CaS			0.805									0.000				
CaO			0.159									0.963				
MgO			0.000									0.000				
SiO2			0.000									0.000				
CaSO4			0.000									0.000				
Fe2O3			0.014									0.017				
m(klb/hr)	0.000	0.000	0.422	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.344	0.000	0.000	0.000	0.000
density(lb/ft^3)			164.626									268.779				
Average MW			69.731									57.099				
Fuel																
Proxanal(mf%)			Char	Coal								Ash				
Moisture			0.000	2.000								0.000				
FC			68.392	49.018								0.000				
VM			0.000	39.622								0.000				
Ash			31.608	11.359								100.000				
Ultanal(%)																
Ash			31.608	11.360								100.000				
C			64.660	73.190								0.000				
H			0.234	4.900								0.000				
N			1.140	1.290								0.000				
Cl			0.062	0.070								0.000				
S			1.926	3.890								0.000				
O			0.371	5.310								0.000				
Sulfanal(%)																
Pyritic			0.000	1.700								0.000				
Sulfate			0.000	0.000								0.000				
Organic			1.926	2.190								0.000				
m(klb/hr)	0.000	0.000	1.750	0.176	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.573	0.000	0.000	0.000	0.000
density(lb/ft^3)			144.059	87.473								217.679				

Table 5 Integrated System Test 50% Load Heat and Material Balance

Display	4	8A	11	12	16	20	Acl	21	23	23A	24	25	26	27(A)	28	31	32
Total Flow(klb/hr)	2.87	2.90	0.38	5.43	0.59	7.83	1.50	0.00	11.52	11.52	11.52	20.000	20.000	9.32	9.32	0.00	0.05
T(F)	70.00	70.00	70.00	150.00	332.00	70.01	150.00		1693.48	1000.00	1000.00	360.00	610.19	960.77	939.23	960.74	70.00
P(psi)	14.70	106.00	14.70	106.00	106.00	106.00	106.00		99.00	99.00	98.50	150.00	150.00	96.10	15.00	96.10	14.70
Gas																	
N2		1.000	0.000	0.749	0.000		0.749		0.598	0.598	0.598	0.000	0.000	0.598	0.598	1.000	0.000
O2		0.000	0.000	0.230	0.000		0.230		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H2O		0.000	1.000	0.008	1.000		0.008		0.053	0.053	0.053	1.000	1.000	0.053	0.053	0.000	0.000
CH4		0.000	0.000	0.000	0.000		0.000		0.011	0.011	0.011	0.000	0.000	0.011	0.011	0.000	1.000
CO2		0.000	0.000	0.001	0.000		0.001		0.101	0.101	0.101	0.000	0.000	0.101	0.101	0.000	0.000
H2		0.000	0.000	0.000	0.000		0.000		0.011	0.011	0.011	0.000	0.000	0.011	0.011	0.000	0.000
CO		0.000	0.000	0.000	0.000		0.000		0.216	0.216	0.216	0.000	0.000	0.216	0.216	0.000	0.000
H2S		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NH3		0.000	0.000	0.000	0.000		0.000		0.003	0.003	0.003	0.000	0.000	0.003	0.003	0.000	0.000
Ar		0.000	0.000	0.013	0.000		0.013		0.009	0.009	0.009	0.000	0.000	0.009	0.009	0.000	0.000
SO2		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C2H6		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C2H4		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO2		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SO3		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C12		0.000	0.000	0.000	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
m(klb/hr)	0.000	0.186	0.047	5.433	0.585	4.782	1.499	0.000	10.277	10.277	10.277	20.000	20.000	9.317	9.317	0.000	0.045
density(lb/ft^3)		0.522	62.257	0.815	0.225		0.815		0.105	0.155	0.154	0.331	0.241	0.155	0.025	0.177	0.041
Average MW		28.013	18.015	28.829	18.015		28.829		24.544	24.544	24.544	18.015	18.015	24.544	24.544	28.013	16.043
Sorbent																	
H2O			0.020			0.020		0.000	0.000	0.000	0.000						
CaCO3			0.955			0.955		0.000	0.000	0.000	0.000						
MgCO3			0.016			0.016		0.023	0.023	0.023	0.023						
CaS			0.000			0.000		0.801	0.801	0.801	0.801						
CaO			0.000			0.000		0.162	0.162	0.162	0.162						
MgO			0.000			0.000		0.000	0.000	0.000	0.000						
SiO2			0.000			0.000		0.000	0.000	0.000	0.000						
CaSO4			0.000			0.000		0.000	0.000	0.000	0.000						
Fe2O3			0.010			0.010		0.014	0.014	0.014	0.014						
m(klb/hr)	0.000	0.000	0.338	0.000	0.000	0.338	0.000	0.000	0.230	0.230	0.230	0.000	0.000	0.000	0.000	0.000	0.000
density(lb/ft^3)			170.477			170.477		162.540	162.577	164.511	164.511						
Average MW			100.153			100.153		69.668	69.668	69.668	69.668						
Fuel																	
Proxanal(mf%)	Coal	Coal				Coal		Char	Char	Char	Char						
Moisture	7.300	2.000				2.000		0.000	0.000	0.000	0.000						
FC	49.018	52.823				52.823		70.107	70.107	70.107	70.107						
VM	39.622	35.817				35.817		0.000	0.000	0.000	0.000						
Ash	11.359	11.360				11.360		29.893	29.893	29.893	29.893						
Ultanal(%)																	
Ash	11.360	11.360				11.360		29.893	29.893	29.893	29.893						
C	73.190	73.190				73.190		66.281	66.281	66.281	66.281						
H	4.900	4.900				4.900		0.240	0.240	0.240	0.240						
N	1.290	1.290				1.290		1.168	1.168	1.168	1.168						
Cl	0.070	0.070				0.070		0.063	0.063	0.063	0.063						
S	3.890	3.890				3.890		1.974	1.974	1.974	1.974						
O	5.310	5.310				5.310		0.381	0.381	0.381	0.381						
Sulfanal(%)																	
Pyritic	1.700	1.710				1.710		0.000	0.000	0.000	0.000						
Sulfate	0.000	0.000				0.000		0.000	0.000	0.000	0.000						
Organic	2.190	2.180				2.180		1.974	1.974	1.974	1.974						
m(klb/hr)	2.868	2.712	0.000	0.000	0.000	2.712	0.000	0.000	1.010	1.010	1.010	0.000	0.000	0.000	0.000	0.000	0.000
density(lb/ft^3)	87.473	87.478				87.478			143.230	143.230	143.230						

Table 5 Integrated System Test 50% Load Heat and Material Balance (continued)

Display	33	34	37	38	38A	39	40	41	42	43	44	45	A(to 8A)	A(to 11)	A(to 42)	A(to Pyro)
Total Flow(klb/hr)	31.81	41.18	1.24	0.10	0.21	0.96	16.35	0.17	17.60	11.44	6.16	19.15	0.19	0.05	0.12	0.72
T(F)	70.00	1799.92	800.00	70.00	70.00	960.77	70.00	70.00	1080.19	1080.19	1080.19	2500.00	70.00	70.00	70.00	70.00
P(psi)	14.70	14.70	95.90	14.70	14.70	96.10	14.70	14.70	14.70	14.70	14.70	14.70	106.00	106.00	14.70	106.00
Gas																
N2	0.770	0.730			0.749	0.598	0.749	0.000	0.736	0.736	0.736	0.703	1.000	1.000	1.000	1.000
O2	0.230	0.116			0.230	0.000	0.230	0.000	0.168	0.168	0.168	0.038	0.000	0.000	0.000	0.000
H2O	0.000	0.042			0.008	0.053	0.008	0.000	0.038	0.038	0.038	0.040	0.000	0.000	0.000	0.000
CH4	0.000	0.000			0.000	0.011	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CO2	0.000	0.109			0.001	0.101	0.001	0.000	0.034	0.034	0.034	0.195	0.000	0.000	0.000	0.000
H2	0.000	0.000			0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CO	0.000	0.000			0.000	0.216	0.000	0.000	0.012	0.012	0.012	0.000	0.000	0.000	0.000	0.000
H2S	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NH3	0.000	0.001			0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ar	0.000	0.002			0.013	0.009	0.013	0.000	0.012	0.012	0.012	0.012	0.000	0.000	0.000	0.000
SO2	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000
C2H6	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
C2H4	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO2	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SO3	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000
Cl2	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
m(klb/hr)	31.813	41.175	0.000	0.000	0.206	0.960	16.353	0.167	17.598	11.439	6.159	18.646	0.186	0.047	0.118	0.717
density(lb/ft^3)	0.075	0.018			0.075	0.155	0.075	0.041	0.025	0.025	0.025	0.014	0.072	0.072	0.072	0.072
Average MW	28.840	28.910			28.829	24.544	28.829	16.043	28.459	28.459	28.459	29.914	28.013	28.013	28.013	28.013
Sorbent																
H2O			0.000									0.000				
CaCO3			0.000									0.000				
MgCO3			0.023									0.022				
CaS			0.801									0.000				
CaO			0.162									0.961				
MgO			0.000									0.000				
SiO2			0.000									0.000				
CaSO4			0.000									0.000				
Fe2O3			0.014									0.017				
m(klb/hr)	0.000	0.000	0.230	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.188	0.000	0.000		
density(lb/ft^3)			164.763									268.624				
Average MW			69.668									57.124				
Fuel																
Proxanal(mf%)			Char	Coal								Ash				
Moisture			0.000	2.000								0.000				
FC			70.107	49.018								0.000				
VM			0.000	39.622								0.000				
Ash			29.893	11.359								100.000				
Ultanal(%)																
Ash			29.893	11.360								100.000				
C			66.281	73.190								0.000				
H			0.240	4.900								0.000				
N			1.168	1.290								0.000				
Cl			0.063	0.070								0.000				
S			1.974	3.890								0.000				
O			0.381	5.310								0.000				
Sulfanal(%)																
Pyritic			0.000	1.700								0.000				
Sulfate			0.000	0.000								0.000				
Organic			1.974	2.190								0.000				
m(klb/hr)	0.000	0.000	1.010	0.103	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.313	0.000	0.000		
density(lb/ft^3)			143.230	87.473								217.679				

Task 4 - Subsystem Test Unit Construction

Subtask 4.2 - Char Combustion System Construction

Wall panels have been ordered to convert the furnace wall and windbox to arch-firing. A scrubber system is required in order to burn the HIPPS char in the CETF. A bid package was prepared for this equipment, and a vendor has been selected. Specifications are also being developed for other auxiliary equipment that will be required.

Subtask 4.3 - IST Construction

The IST testing will be performed at the UTSI Coal Fired Flow Facility (CFFF). Work is in progress modifying and upgrading the facility for the HIPPS testing. The coal pulverization facilities have been upgraded, and this system is ready to prepare coal for the pyrolyzer tests in Livingston. The facility control system is also being upgraded, and the base components of the distributed control system are scheduled for delivery in early January. The CFFF control room has been modified in preparation for the new hardware.

A solids flow test loop has been set up at UTSI to investigate the transport of char from the pyrolyzer char lock hopper to the HITAF char feed hopper. The flow loop consisted of a char feed tank at ground level and a char receiver tank located 15 m (50 ft) horizontally and 10.7 m (35 ft) vertically from the char feed tank. The char feed line was a 1.9 cm (3/4") ID Synflex hose with 1.6 cm (5/8") fittings. The testing was done at 620 Kpa (90 psig) and ambient temperature.

With this system, flow rates of 0.9 Kg/s (7100 lb/h) were achieved and no flow instabilities or blockages were encountered. The char temperature during the IST will be 430°C (800°F) so plans for initial IST testing will incorporate modest contingency plans for dealing with hot char flow instabilities. This includes specifying peak char flow at least double the HITAF required char flow rate to allow accumulation of char in the char feed hopper and thus mitigate potential IST shut downs due to any short-term char flow blockages.

REFERENCES

1. Foster Wheeler Development Corporation, "Engineering Development of High Performance Power Systems -- Technical Progress Report 5 (July through September 1996)," DOE PETC Under Contract DE-AC22-95PC95143, November 1996, pg. 8-13.

2. Ibid, pg. 3, 20

3. Ibid, pg. 28-35

4. Ibid