ENGINEERING DEVELOPMENT OF COAL-FIRED HIGH-PERFORMANCE POWER SYSTEMS

DE-AC22-95PC95143

TECHNICAL PROGRESS REPORT NO. 16
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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, 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 pyrolysis process to convert coal into fuel gas and char. The char is fired in a High Temperature Advanced Furnace (HITAF). The HITAF is a pulverized fuel-fired boiler/air heater where steam is generated and gas turbine air is 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 after each experimental program has been completed, a larger scale pyrolyzer will be tested at the Power Systems Development Facility (PSDF) in Wilsonville, AL. The facility is equipped with a gas turbine and a topping combustor, and as such, will provide an opportunity to evaluate integrated pyrolyzer and turbine operation.

This report addresses the areas of technical progress for this quarter. Analysis of the arch-fired burner continued during this quarter. Unburned carbon and NOx performance are included in this report. Construction commenced this quarter to modify the CETF for horizontal firing. A new indirect feed system will be required to provide a more stable fuel feed to the new wall-fired burner. The conceptual design of the char transfer system for the PSDF is complete. Final detailed design will commence after FETC has completed all cold model testing. DOE-FETC is utilizing an existing experimental facility to evaluate the performance of the proposed char transfer system.

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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^{o}C (1700^{o}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/commercial plant. At this time, Phase 3 of the overall HIPPS contract has been suspended pending additional funding. 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, NJ, has been modified to test the pyrolyzer subsystem. The FWDC Combustion and Environmental Test Facility (CETF) in Dansville, NY, has been modified to test the char combustion system. Integrated operation of a larger scale pyrolyzer and a commercial gas turbine are planned for the PSDF in Wilsonville, AL.

Construction has begun to modify the CETF for horizontal firing. Data analysis continues for the evaluation of the arch-fired burner. Final conceptual design of the char transfer system has been completed.

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)
- 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 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.

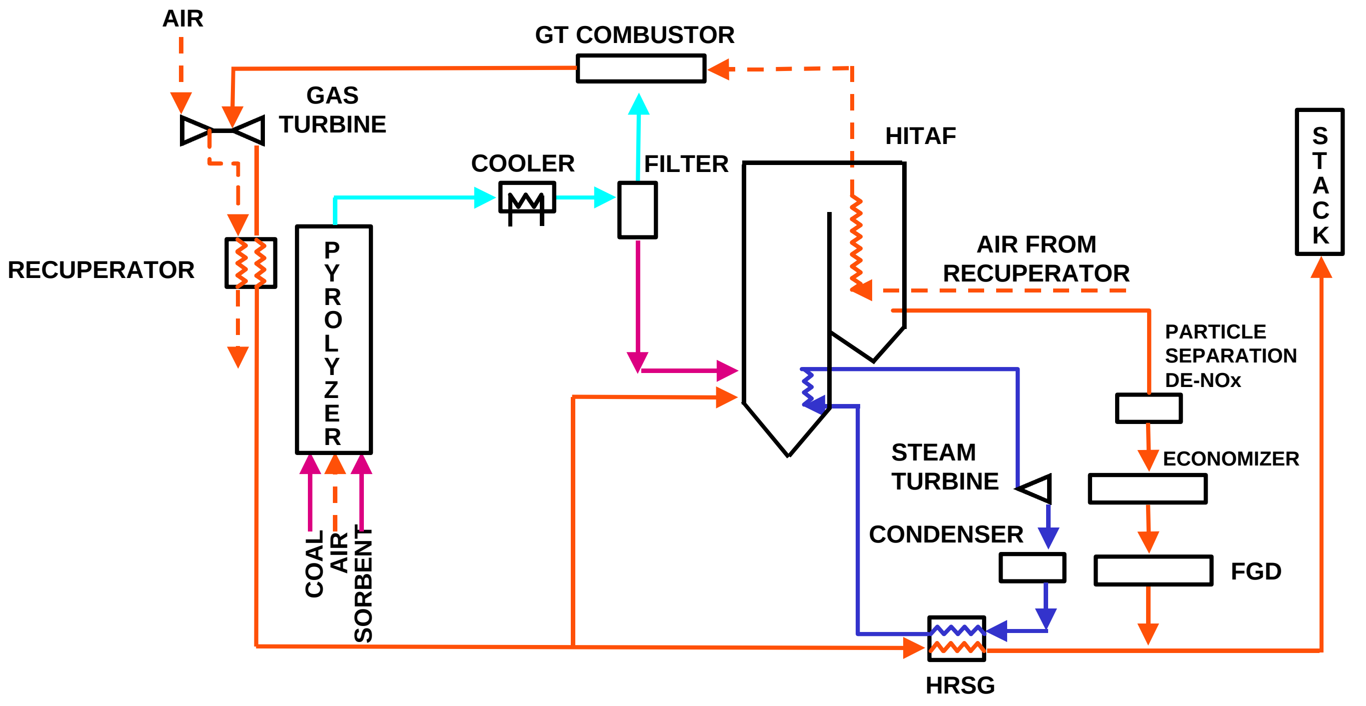

Figure 1 All Coal Fired HIPPS

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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^{o}C (1400^{o}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^{o}C (1800^{o} F) will result in 35 percent of the heat input from natural gas.

A simplified version of the HIPPS arrangement can be applied to existing boilers. Figure 3 outlines the potential application of the HIPPS technology for repowering existing pulverized coal fired plants. In the repowering application, the gas turbine exhaust stream provides the oxidant for co-fired combustion of char and coal. The existing boiler and steam turbine infrastructure remain intact. The pyrolyzer, ceramic barrier filter, gas turbine, and gas turbine combustor are integrated with the existing boiler to improve overall plant efficiency and increase generating capacity.

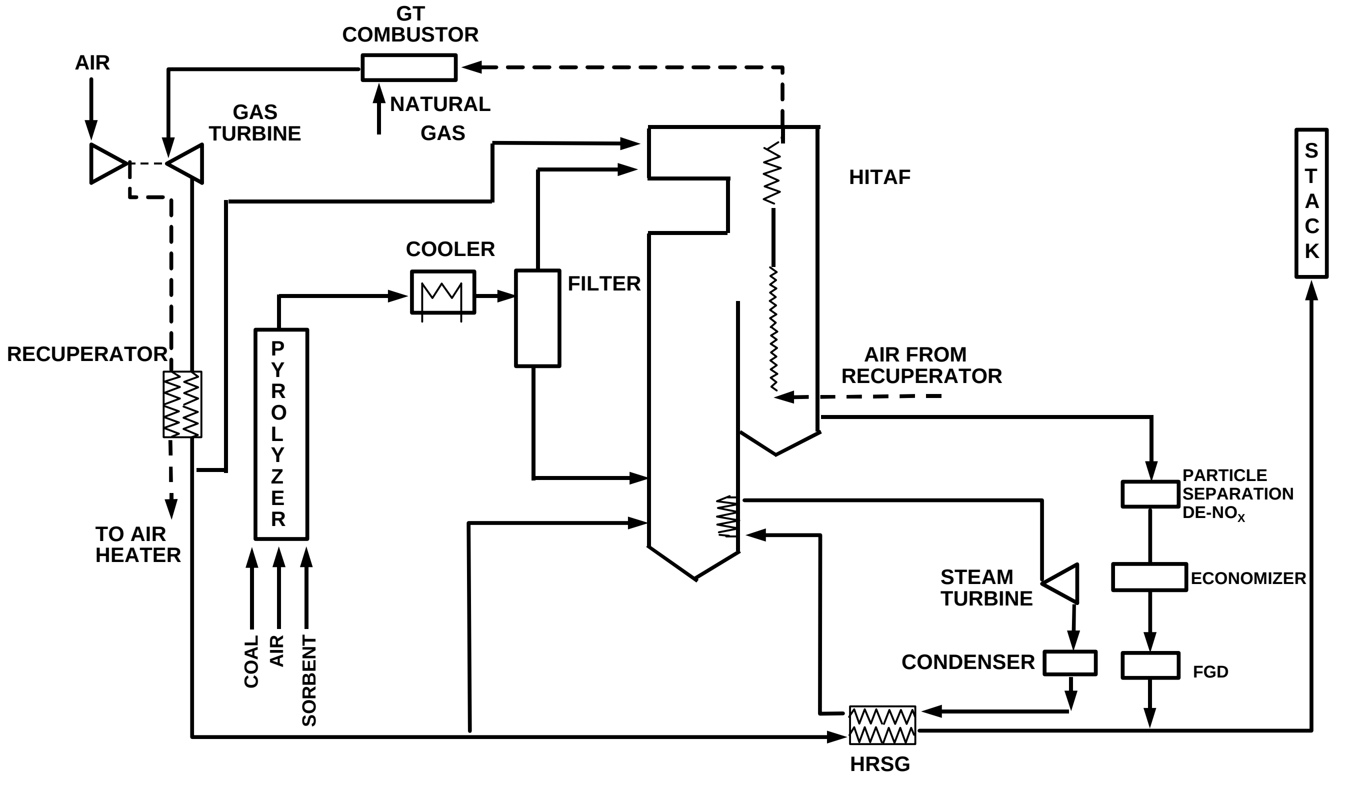

Figure 2 35-Percent Natural Gas HIPPS

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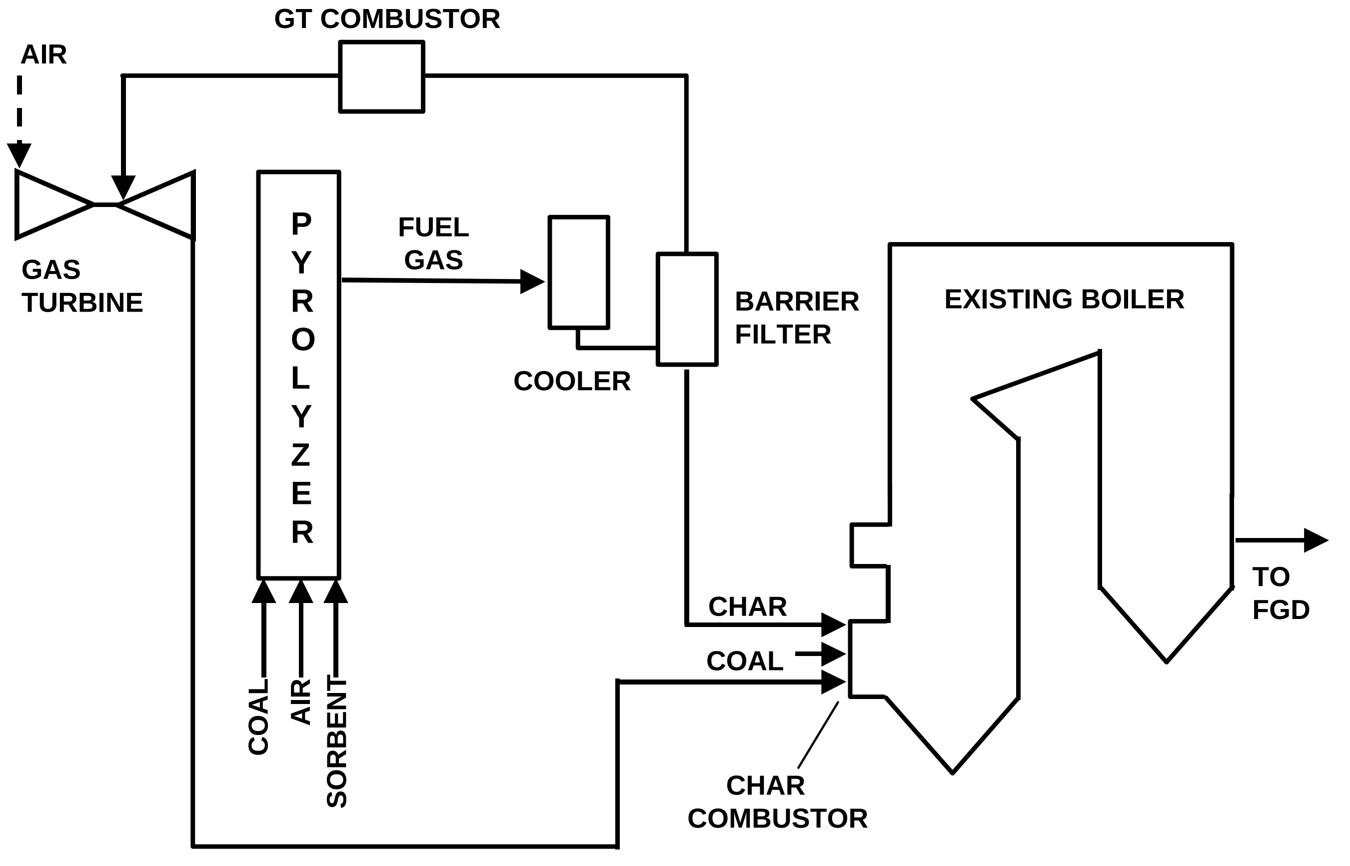


Figure 3 Simplified HIPPS Repowering Process Flow Diagram

TECHNICAL PROGRESS

Task 1 - Project Planning and Management

Work is proceeding in accordance with the Project Plan.

Task 3 - Subsystem Test Unit Design

Subtask 3.3 – Wilsonville Pilot Plant Design

Foster Wheeler Development Corporation (FWDC), in cooperation with Southern Company Services (SCS), has designed a char transfer system for the Power Systems Development Facility (PSDF) in Wilsonville, AL. This system will replace the existing “N” valve char transfer arrangement (see Figure 4), creating a suitable configuration for both Advanced Pressurized Fluidized Bed Combustion (APFBC) and High Performance Power System (HIPPS) program development. Although the “N” valve configuration represents a low cost arrangement for commercial APFBC application (since there is no cooling involved), insufficient data exists to support its predictable and stable operation at the PSDF.

The newly proposed char cooling/transfer system incorporates several advantages over the existing “N” valve configuration. These advantages include:

- Elimination of refractory lined valve.
- Use of rotary valves, creating a positive seal between process conditions.
- Cooled solid sample ports provide capability of on-line analysis for char composition and particle size distribution.
- Char feed-hopper with 4-hour surge capacity provides uniform feed characteristics while acting as a buffer, enabling improved control of integrated pilot plant operation.
- A rotary-valve metered, pneumatically transported, char delivery system to the combustor.
- Redundant transport-line ball valves providing positive, fail-safe, isolation between reducing and oxidizing atmospheres.

The proposed char transfer arrangement, unlike the “N” valve system, is designed to cool 2,500 lb/hr of char from 1800EF to 500EF. To accomplish this, a fluidized bed cooler is placed below both the pyrolyzer overflow outlet and cyclone solids discharge. Each cooler is conservatively designed to handle 80 percent of the total solids flow. Implementing an independent cooler design facilitates separate controls of the fluidizing media for both coarse solids (overflow outlet) and fine (cyclone solids discharge) char streams. The cooled char, from both coolers, is directed to a common feed hopper. Hot filter fines, which are not cooled, are also directed to the feed hopper. These represent only a fraction of the total mass flow and will be cooled via blending. The feed hopper is designed with a storage capacity of 500 ft^3. This capacity provides adequate inventory to assure steady feed rates to the combustor, while providing a 4-hour buffer for process integration upsets. This system, designed for full load conditions, provides technical, operational and economical benefits to both APFBC and HIPPS test programs.

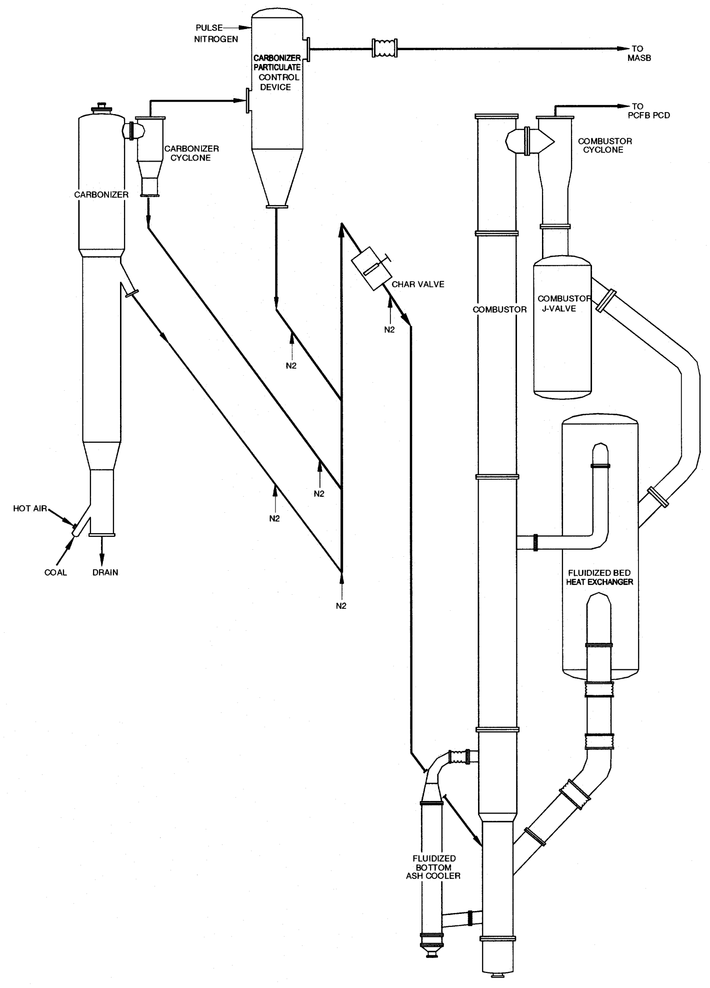


Figure 4
Existing "N" Valve Configuration

Subtask 3.3.1 – Development

Pilot plant tests have been completed at FWDC's Livingston, NJ and Dansville, NY test facilities under Phase 2 of the HIPPS project. The Livingston facility tested a pyrolyzer, generating approximately two hundred and fifty pounds of char per hour. This char was collected and transported to the Dansville facility where it was fired in a char combustor. The fuel gas generated by the pyrolyzer was flared in a thermal-oxidizer.

Integrated operation of a larger scale pyrolyzer and gas turbine is needed for commercial development of the HIPPS technology. The Power Systems Development Facility (PSDF), in Wilsonville, AL, is to be used for integrated operation testing. Currently, the PSDF is demonstrating

2nd Generation Advanced Pressurized Fluidized Bed Combustion (APFBC) components. Two major components being tested under the APFBC program, that would be utilized for HIPPS, are the Carbonizer and the Particulate Control Device (PCD). The Carbonizer would be operated as a Pyrolyzer and the PCD function would remain unchanged. Since, the DOE sponsors both HIPPS and APFBC programs; it is economical to utilize these existing components and infrastructure to test both technologies at one site.

Subtask 3.3.2 – General Arrangement

Currently the PSDF site is configured with an “N” valve (Figure 4). The “N” valve was designed to serve two functions, to supply char (generated in the Carbonizer) to the Combustor, and to create a pressure seal between reducing and oxidizing environments. However, concerns have been raised relating to the operability of such a device in a pilot plant application. These concerns are as follows:

- Fluidization difficulties in the riser, due to various particle size distributions introduced at three separate locations.
- PCD pulse gases possibly eliminating seal between reducing and oxidizing environments.
- Lack of solid inventory buffer; making process upsets, in either reactor, troublesome.

FWDC, supported by the HIPPS project, has reviewed the existing configuration and offer an alternate arrangement. This arrangement addresses the above concerns by:

- Separating the solid streams for individual processing
- Implementing rotary valves to provide positive seals
- Instituting a common reservoir, providing a buffer against process upsets.

These recommendations satisfy requirements for APFBC operation, while accommodating future HIPPS testing, without significant modifications to the existing structure. A complete P&ID drawing of the process is shown in Figure 12.

Figure 5 presents a schematic representation of the APFBC mode of operation. The char, generated in the carbonizer, is split into three separate streams: overflow, cyclone drain and cyclone outlet. Both overflow and cyclone drain streams are directed to separate fluidized bed coolers. Each cooler is outfitted with a tube bundle through which a heat transfer fluid is passed. The coolers are fluidized with nitrogen and cool the solids from 1800ºF to 500ºF. Cooled solids proceed through rotary valves, which provide necessary differential process pressure seals, to the char feed hopper. The feed hopper, operating at the Particulate Control Device (PCD) pressure, collects all three solid streams. Here, an inventory of solids provides a buffer against process perturbations, while the 500-ft^3-storage capacity offers operational flexibility in merging the gasification and combustion technologies. A rotary valve at the feed hopper outlet, just upstream of the pneumatic transfer line, controls the solid feed rate to the combustor. The transfer line is outfitted with fast acting ball valves providing redundant, fail-safe, positive isolation between reducing and oxidizing environments.

An additional benefit to this new modular arrangement, is the flexibility it offers. Recent interests in operating APFBC mode without a cyclone could easily be accommodated. This modification would require; the installation of an internal bypass to cyclone (or removal of the cyclone), relocating cyclone cooler to the PCD outlet and fabricating a short run of piping from cooler outlet to feed hopper.

Figure 6 shows the HIPPS configuration. This arrangement requires little modification from APFBC mode operation. Although the cyclone vessel is not depicted in this arrangement, it will remain in place. It is anticipated that an internal by-pass spool piece will be both feasible and more economical than the removal of the vessel. Coolers from APFBC mode, also not shown, may remain in place by mechanically isolating them from the process through plugging and blinding of nozzles. The only new piece of equipment required for HIPPS testing is the char cooler at the feed hopper outlet.

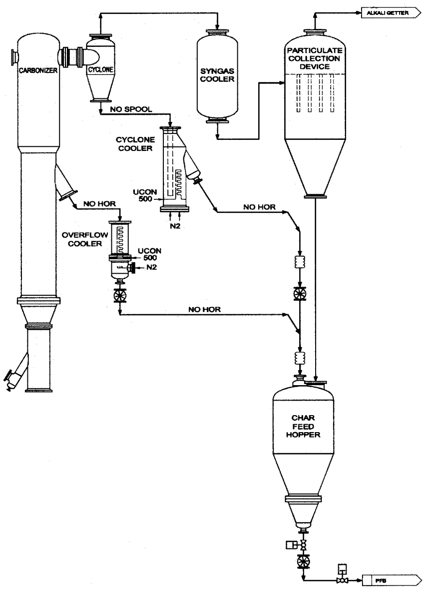


Figure 5
APFBC Configuration

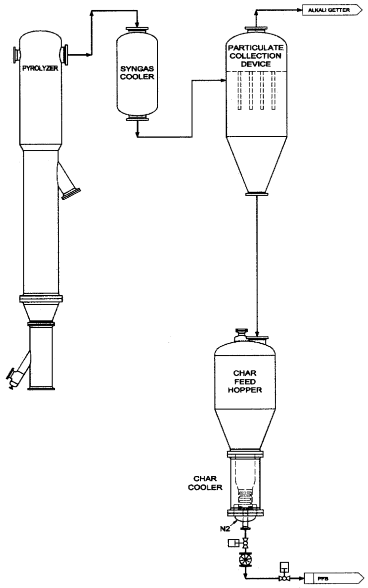


Figure 6
HIPPS Configuration

Subtask 3.3.3 – Bed Overflow Cooler

Operating as a bubbling fluidized bed, the overflow char cooler (Figure 7) is conservatively designed to handle 80% of the total (2500 lbs/hr) char generated. It employs UCON 500 as a heat transfer fluid. The packing density of the cooling coil arrangement is 11.2%. The parallel path cooling circuit is comprised of (6) ¾” diameter tubes, having a surface area of ~25sq.ft. To assure proper heat transfer, the superficial gas (nitrogen) velocity is set at twice the minimum fluidization velocity. Particle size distribution for the overflow cooler can be seen in Figure 11; this data is based upon FWDC pilot plant testing (11/97), in support of the Lakeland project. The cooler has a cross-sectional area of 0.44 ft^2, requiring a total nitrogen flow of 107 lbs/hr. Figure 10 illustrates how the heating value of the fuel gas is influenced by the addition of supplemental nitrogen. Minimizing nitrogen consumption was an important factor in developing the design of the cooler. Based upon the performance specifications of the gas turbine, a minimum fuel gas heating value of 110 Btu/scf is required. An outlet rotary valve will achieve bed level control, necessary to assure the submersion of all tubes for proper heat transfer.

Fluidization design data:

- Bulk Density = 37 lb/ft^3
- Particle Density = 73 lb/ft^3
- Sphericity = 0.65
- Mean Particle Size (Dp_{50}) = 975 microns
- Sauter Mean Diameter = 647 microns
- Minimum Fluidizing Velocity = 0.115 FPS
- Temperature (Bulk Mean) = 1150 °F
- Pressure = 165 psig
- N_2 Gas Density = 0.29 lb/ft^3
- N_2 Gas Viscosity = 0.000025 lb./ft/sec

Heat Transfer design data:

- Char Flow = 2000 lb./hr
- Char Inlet Temperature = 1800 °F
- Char Outlet Temperature = 500 °F
- Char C_P = 0.3 Btu/lb$_m$• °F
- UCON Flow = 8,207 lb./hr
- UCON Inlet Temperature = 190 °F
- UCON Outlet Temperature = 300 °F
- UCON C_P = .54 Btu/lb$_m$• °F
- Delta T_{lm} = 754.8 °F
- Overall Heat Xfer Coeff. = 50 BTU/hr • °F • ft^2

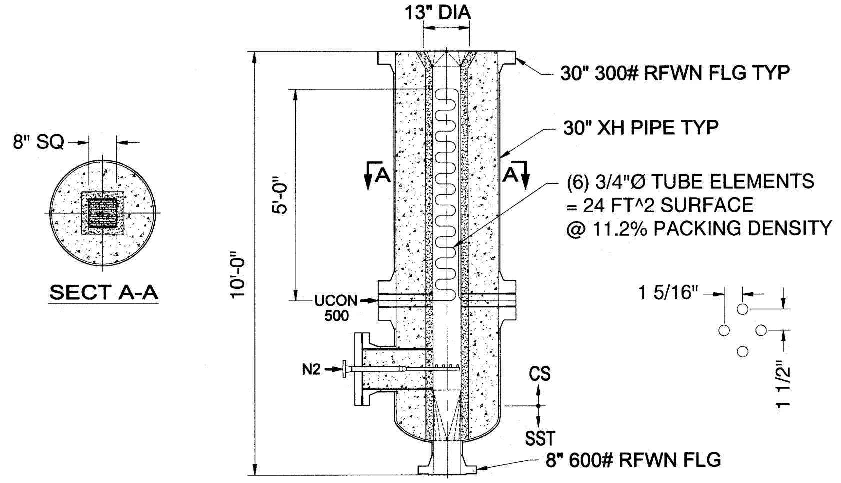


Figure 7

Subtask 3.3.4 – Cyclone Drain Cooler

The cyclone cooler, shown in Figure 8, is also designed to handle 80% of total char flow. It is very similar to the overflow cooler, with differences being fluidizing properties and loop configuration. Tube configuration and cross-sectional fluidized areas are also identical to the bed overflow cooler. Particle size distribution for the cyclone cooler can be seen in Figure 11. The loop configuration offers simplified operation, in that no bed-level controls are required. It will also serve to provide information regarding cooled loop seals.

Fluidization design data:

- Bulk Density = 20 lb/ft^3
- Particle Density = 40 lb/ft^3
- Sphericity = 0.65
- Mean Particle Size (Dp_{50}) = 168 microns
- Sauter Mean Diameter = 69 microns
- Minimum Fluidizing Velocity = 0.0008 FPS
- Temperature (Bulk Mean) = 1150 °F
- Pressure = 165 psig
- N_2 Gas Density = 0.29 lb/ft^3
- N_2 Gas Viscosity = 0.000025 lb./ft/sec

Heat Transfer design data:

- Char Flow = 2000 lb./hr
- Char Inlet Temperature = 1800 °F
- Char Outlet Temperature = 500 °F
- Char C_P = 0.3 Btu/lb$_m$• °F
- UCON Flow = 8,207 lb/hr
- UCON Inlet Temperature = 190 °F
- UCON Outlet Temperature = 300 °F
- UCON C_P = .54 Btu/lb$_m$• °F
- Delta T_{lm} = 754.8 °F
- Overall Heat Xfer Coeff. = 50 BTU/hr • °F • ft^2

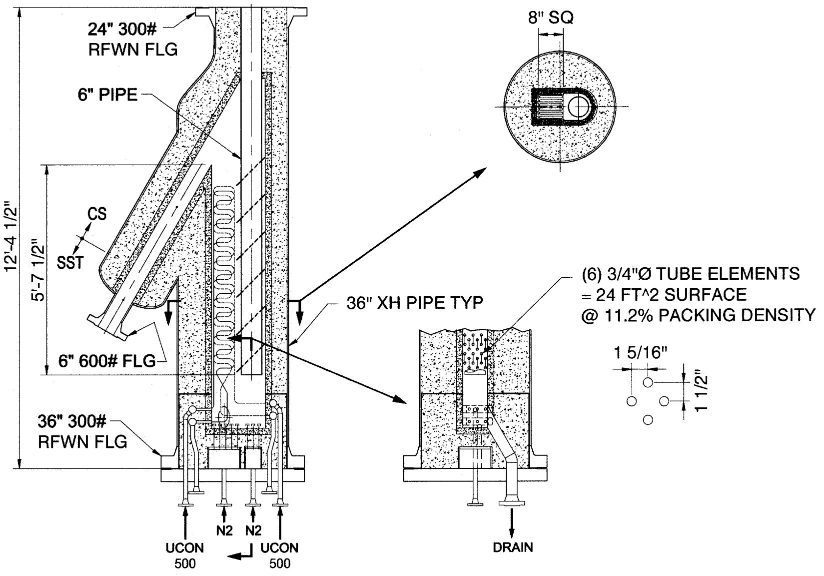


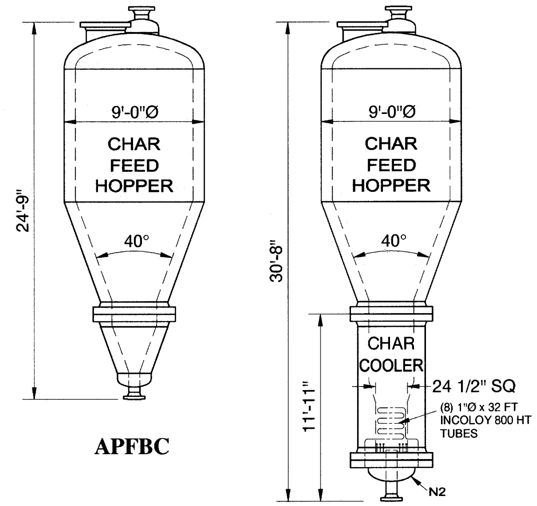
Figure 8

Subtask 3.3.5 – Char Feed Hopper

The char feed hopper is a refractory lined multi-purpose vessel with a capacity of 500 ft^3. It is designed as a combination surge/feed hopper and operates at the same pressure as the PCD for both HIPPS and APFBC technologies. For HIPPS, the additional function of char cooling is added by substituting a bubbling fluidized bed char cooler for the lower conical section of the vessel. The two arrangements are shown in Figure 9.

By providing a surge capacity, two significant benefits are added. First, by maintaining a modest inventory, or buffer, in the hopper ensures a stable feed rate out of the hopper. This buffer eliminates the effects of process perturbations in either system, an advantage not afforded by the "N" valve arrangement. Secondly, a surge reservoir provides 4 hours of generating char, without feeding from the hopper, to correct potential process integration upsets.

Operation of the fluidized bubbling bed cooler for HIPPS is comparable to the APFBC overflow cooler, with major differences being mass flow, particle size and fluidization requirements. It is anticipated that much of the instrumentation and hardware for this cooling circuit will be borrowed from the overflow cooler.



APFBC

HIPPS

HIPPS

Fluidization design data:

Bulk Density = 20 lb/ft^3
Particle Density = 40 lb/ft^3
Sphericity = 0.65
Mean Particle Size (Dp50) = 43.6 microns
Sauter Mean Diameter = 57 microns
Minimum Fluidizing Velocity = 0.0006 FPS
Temperature (Bulk Mean) = 1150 °F
Pressure = 165 psig
N2 Gas Density = 0.29 lb/ft^3
N2 Gas Viscosity = 0.000025 lb./ft/sec

Heat Transfer design data:

Char Flow = 2500 lb./hr
Char Inlet Temp. = 1800 °F
Char Outlet Temp. = 500 °F
Char Cp = 0.3 Btu/lb$_m$• °F
UCON Flow = 16,414 lb./hr
UCON Inlet Temp. = 190 °F
UCON Outlet Temp. = 300 °F
UCON Cp = 0.54 Btu/lb$_m$• °F
Delta T(lm) = 754.8 °F
Heat Xfer Coeff. = 50 Btu/hr • °F • ft^2

Figure 9

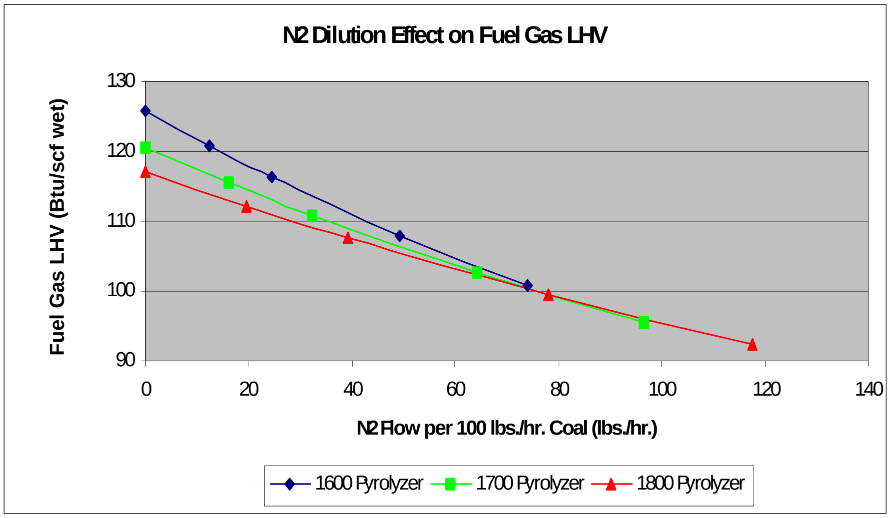

N2 Dilution Effect on Fuel Gas LHV
Fuel Gas LHV (Btu/scf wet)
130
120
110
100
90
0
20
40
60
80
100
120
140
N2 Flow per 100 lbs./hr. Coal (lbs./hr.)
1600 Pyrolyzer
1700 Pyrolyzer
1800 Pyrolyzer

Fig. 10

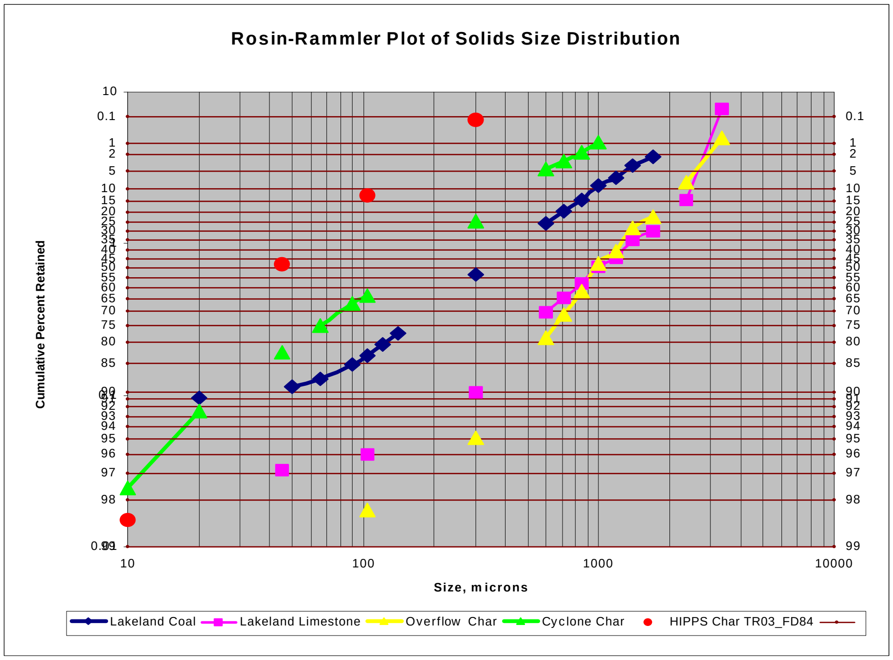

Rosin-Rammler Plot of Solids Size Distribution
Cumulative Percent Retained
10
0.1
1
2
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
91
92
93
94
95
96
97
98
99
0.99
10
100
1000
10000
Size, microns
Lakeland Coal
Lakeland Limestone
Overflow Char
Cyclone Char
HIPPS Char TR03_FD84

Fig. 11

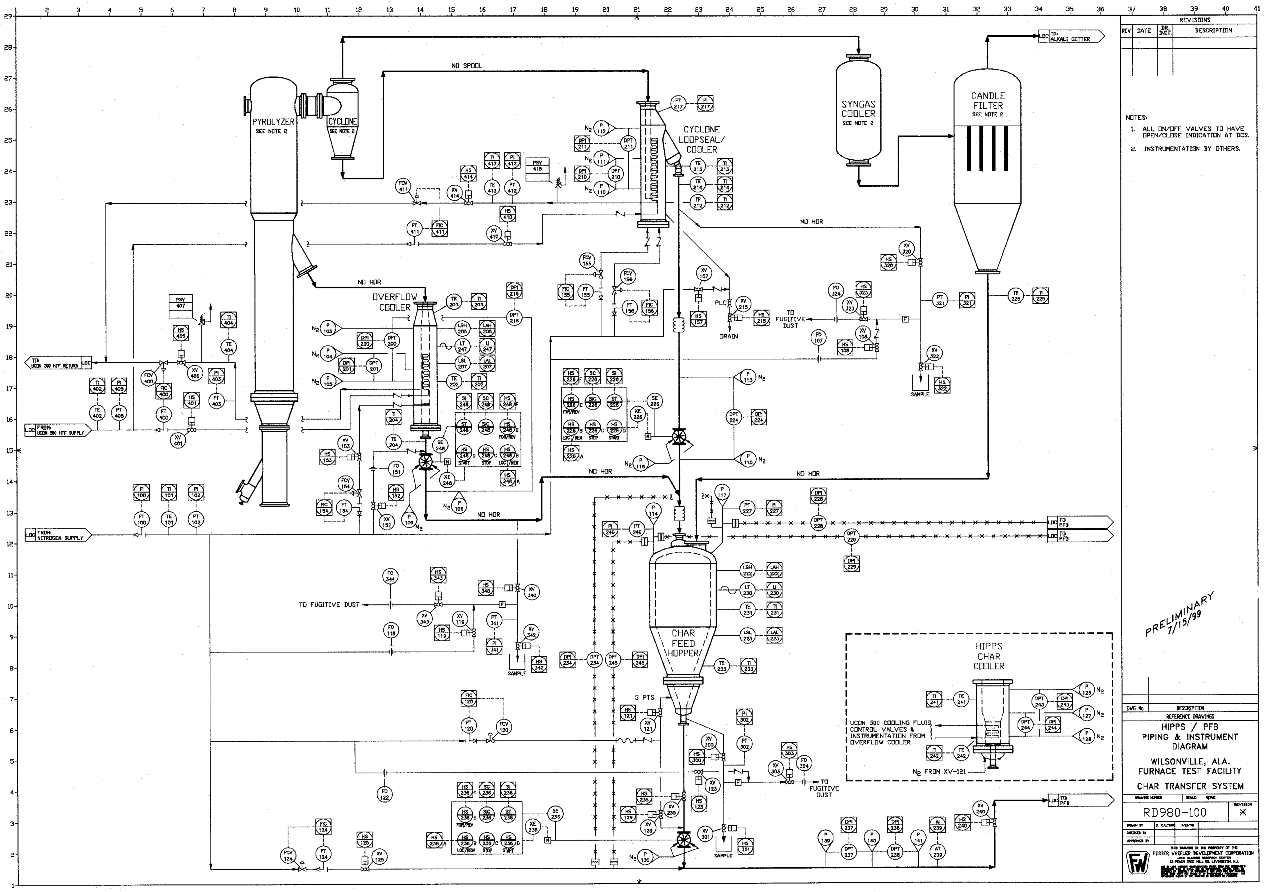

PYROLYZER
SEE NOTE 2
CYCLONE
SEE NOTE 2
ND SPOOL
CYCLONE LOOPSEAL/ COOLER
SYNGAS COOLER
SEE NOTE 2
CANDLE FILTER
SEE NOTE 2
TO ALKALI GETTER
OVERFLOW COOLER
ND HDR
TO UCON 500 HTF RETURN
FROM UCON 500 HTF SUPPLY
FROM NITROGEN SUPPLY
TO FUGITIVE DUST
DRAIN
SAMPLE
CHAR FEED HOPPER
3 PTS
TO PFB
HIPPS CHAR COOLER
UCON 500 COOLING FLUID CONTROL VALVES & INSTRUMENTATION FROM OVERFLOW COOLER
N2 FROM XV-121
REVISIONS
REV
DATE
DR. INIT.
DESCRIPTION
NOTES:
1. ALL ON/OFF VALVES TO HAVE OPEN/CLOSE INDICATION AT DCS.
2. INSTRUMENTATION BY OTHERS.
PRELIMINARY 7/15/99
DWG No.
DESCRIPTION
REFERENCE DRAWINGS
HIPPS / PFB
PIPING & INSTRUMENT DIAGRAM
WILSONVILLE, ALA.
FURNACE TEST FACILITY
CHAR TRANSFER SYSTEM
DRAWING NUMBER
SCALE NONE
RD980-100
REVISION
*
DRAWN BY
CHECKED BY
APPROVED BY
THIS DRAWING IS THE PROPERTY OF THE
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Figure 12

FWDC, in an effort to accommodate the progress of APFBC and HIPPS technologies at the PSDF, offers this conceptual char-transfer-system design as an alternate arrangement to the “N” valve configuration. As a comparison to the “N” valve arrangement; this system offers key advantages, important to the development of pilot scale operations, which include:

- **Process Parameters**

  - Segregation Issues
  - De-coupling of oxidizing and reducing environments
  - Consistent flow of char
  - Inventory buffer, facilitates merging of gasification and combustion technologies

- **Configuration Flexibility**

  - APFBC with cyclone
  - APFBC without cyclone
  - HIPPS

This report represents FWDC’s conceptual char-transfer-system design. Final and detailed design work will proceed upon completion of DOE’s segregation tests. The finalized design will include:

- Finalized P&ID drawings
- General arrangement drawings
- Detailed drawings (Vessel & Major piping), necessary to obtain vendor bids
- Instrument specifications
- Interlock description
- Process heat and material balance for char transport system

Task 4 - Subsystem Test Unit Construction

Initial work commenced this quarter to modify the CETF for horizontal firing.

Task 5 – Subsystem Test Unit Testing

Subtask 5.2 – Char Combustion System Testing

Final combustion tests of the HIPPS Char Combustor were conducted this quarter at FWDC’s Combustion and Environmental Test Facility (CETF) in Dansville, NY. Table 1 identifies the test matrix designed using a Statistical Design of Experiments (SDOE) method to achieve optimum burner performance with a minimal number of tests. Initial test data reduction and analysis was performed and Table 2 lists the test results.

Note that the test numbers in Table 1 DO NOT correspond to the test numbers identified in Table 2. Some tests defined in the test matrix did not result in data being collected because of poor flame stability due to the conditions imposed by the test matrix. The results in Table 2 represent raw values for those tests where stable flame and flow conditions remained constant for at least one hour, where 1 hour was deemed to be the minimum test duration.

For those tests where over fire air (OFA) was utilized, the flow was 20% of the total airflow to the furnace, unless otherwise noted. The value "ARCH FLOW" referred to in Table 2, is merely the sum of the tertiary air and the burner air flows, and is reported as the percentage of total furnace airflow. Figure 13 depicts the airflow distribution to the furnace at the CETF.

Airflow split in the lower windbox was defined as a test parameter in the test matrix and was to be varied between three settings, see Table 1. Due to poor flame stability at the 10/30/60 (upper/middle/lower) and 50/50/30 flow splits, all tests listed in Table 2 had the lower air wall split of 100/100/20. Where each value represents the percentage of full open for the dampers associated with that section of the lower windbox. For similar reasons, the straightening vane position was removed as a test parameter. For all tests listed in Table 2 the straightening vanes were fixed in the "OUT" position. This gave the char/air mixture the most amount of turbulence at the flame front to increase flame stability.

In Table 2, tests 1 - 16 were conducted using McClain Char as the primary fuel, where tests 17 - 19 were conducted using char generated at FWDC's Livingston Pilot Plant as the primary fuel. For those tests where pulverized coal (PC) support was required, the coal fired was Pittsburgh #8, with a fineness 70% < 200mesh, (74 m). Table 3 contains the proximate and ultimate analyses of the fuels fired.

The data collected from the burner testing was entered into a statistical analysis program, STATISTICA, which used the data to generate a model of the burner. The burner model was fed the conditions for each of the tests performed and the model predicted UBC and NO_X values for each test. These predicted UBC and NO_X values from the burner model were compared to the actual values measured for the corresponding tests performed at the CETF. Figures 14 and 15 represent the correlation between the predictions and the actual values for the HIPPS Char Combustor. As the figures suggest, the burner model performance closely matches the actual burner performance. With a certain confidence level, the burner model may be used to mathematically analyze the effects of changes to testing parameters on UBC and NO_X.

Regression analyses are being performed using a furnace-modeling package to extrapolate the CETF UBC and NO_X data to commercial unit conditions. Furnace exit gas temperature (FEGT) measurements at the CETF during testing of the HIPPS Char Combustor were much cooler than typically measured at a commercial unit. The particle residence time at the CETF under HIPPS conditions is appreciably less than what a commercial arch fired unit is designed for. Results of these analyses will be presented once completed.

The CETF will be converted to horizontal firing mode for future HIPPS testing of a horizontal burner. An upgraded indirect feed system is to be installed which will provide a more stable fuel feed to the burners. The arch burner will remain in place to allow further testing under these more stable feed conditions as well.

Table 1. Test Matrix

Test #	O_2 in Vitiated Air, % vol. wet	O_2 in Flue Gas, % vol. wet	Air Flow to Burner, lbs/hr	Tertiary Air Flow, lbs/hr	OFA, % total flow	Air Wall Bias, % open (t/m/b)	Support Fuel, % heat input	Straight. Vanes, relative position
1	18.0	2.0	2000	8800	20	100/100/20	10	IN
2	18.0	4.5	2000	4400	20	10/30/60	0	IN
3	18.0	2.0	4000	4400	20	100/100/20	0	OUT
4	15.5	3.3	3000	6600	10	50/50/30	5	MID
5	18.0	4.5	4000	8800	20	10/30/60	10	OUT
6	13.0	4.5	2000	4400	20	100/100/20	10	OUT
7	13.0	2.0	4000	4400	20	10/30/60	10	IN
8	13.0	4.5	2000	8800	0	10/30/60	10	IN
9	18.0	4.5	2000	8800	0	100/100/20	0	OUT
10	18.0	2.0	2000	4400	0	10/30/60	10	OUT
11	15.5	3.3	3000	6600	10	50/50/30	5	MID
12	18.0	4.5	4000	4400	0	100/100/20	10	IN
13	13.0	4.5	4000	4400	0	10/30/60	0	OUT
14	13.0	4.5	4000	8800	20	100/100/20	0	IN
15	13.0	2.0	2000	4400	0	100/100/20	0	IN
16	13.0	2.0	2000	8800	20	10/30/60	0	OUT
17	18.0	2.0	4000	8800	0	10/30/60	0	IN
18	13.0	2.0	4000	8800	0	100/100/20	10	OUT
19	15.5	3.3	4000	6000	0	100/100/20	10	IN
20	15.5	3.3	4000	6000	10	100/100/20	10	IN
21	15.5	3.3	4000	6000	0	100/100/20	0	IN

Table 2. CETF HIPPS Char Combustor UBC & NOX Results

	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8	TEST 9	TEST 10	TEST 11	TEST 12	TEST 13	TEST 14	TEST 15	TEST 16	TEST 17**	TEST 18**	TEST 19**
FINENESS, % < 200mesh	95.4%	95.4%	95.4%	88.1%	88.1%	85.4%	78.9%	92.6%	92.6%	95.9%	93.3%	93.3%	95.0%	97.7%	95.0%	95.0%	73.1%	73.1%	73.1%
AVERAGE WINDBOX O2, %	19.3%	19.5%	19.3%	19.4%	14.7%	15.9%	19.3%	18.9%	14.1%	17.9%	18.1%	15.6%	18.2%	15.5%	17.9%	15.9%	15.5%	15.6%	15.3%
FURNACE O2, %	4.2%	4.8%	3.1%	5.4%	3.8%	4.8%	4.7%	4.7%	5.2%	4.5%	4.5%	5.3%	4.8%	3.4%	4.2%	5.4%	8.4%	7.5%	8.3%
BURNER AIR, #/HR	1785	2180	1751	1504	1946	2941	1498	1426	2179	2075	2160	2325	3434	4272	1748	4278	2747	2572	2867
TERTIARY AIR, #/HR	3620	3914	3543	3343	4012	5878	3270	3173	4285	4061	5200	4665	5821	7264	4313	4714	4392	4153	4471
ARCH FLOW, %TOTAL	16.5%	18.7%	17.8%	14.4%	14.7%	17.4%	17.1%	16.8%	17.0%	24.5%	24.8%	15.8%	24.5%	26.8%	19.9%	20.4%	24.1%	20.5%	23.0%
OFA, Y/N ?	Y	N	N	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	N	N	N	N	Y (10%)
COAL FLOW, #/HR	242	244	0	0	247	389	0	0	0	0	0	241	241	241	241	241	241	241	241
CHAR FLOW, #/HR	3053	3004	3189	3083	3258	3163	3120	3295	3081	2858	2971	2928	2891	2976	2945	2950	1725	2011	2043
NOx, PPM	207	287	243	231	205	251	234	185	124	202	324	323	401	342	249	351	263	304	299
NOx, PPM (corrected for 3.5% furnace O2)	215	310	238	259	208	271	252	198	137	215	343	361	433	341	259	395	367	395	414
UBC, % IN REFUSE	19.6%	14.6%	19.3%	24.7%	32.8%	34.7%	31.5%	34.0%	29.6%	30.4%	33.6%	18.0%	25.7%	23.1%	26.8%	21.3%	4.4%	2.9%	1.8%

NOTE: ** Denotes FWDC Char as primary fuel

Table 3. Fuel Analyses

	McCLAIN CHAR	**FWDC CHAR**	**PITT #8 COAL**
PROXIMATE ANALYSIS, wt %			
FIXED CARBON	75.16	36.19	54.70
VOLATILE MATTER	2.39	12.00	36.00
ASH	21.98	49.73	8.14
MOISTURE	0.47	2.09	1.16
TOTAL	100.00	100.00	100.00
ULTIMATE ANALYSIS, wt %			
CARBON	75.18	52.66	79.11
HYDROGEN	0.12	0.33	5.12
OXYGEN	0.05	-10.34	3.24
NITROGEN	0.97	0.67	1.52
SULFUR	1.25	4.87	1.71
ASH	21.98	49.73	8.14
MOISTURE	0.47	2.09	1.16
TOTAL	100.00	100.00	100.00
HHV, BTU/LB	10234	7715	13438

NOTE: THE (-) OXYGEN VALUE FOR FWDC CHAR IS DUE TO THE CaS OXIDIZING TO $CaSO_4$ DURING THE LAB PROCEDURE.

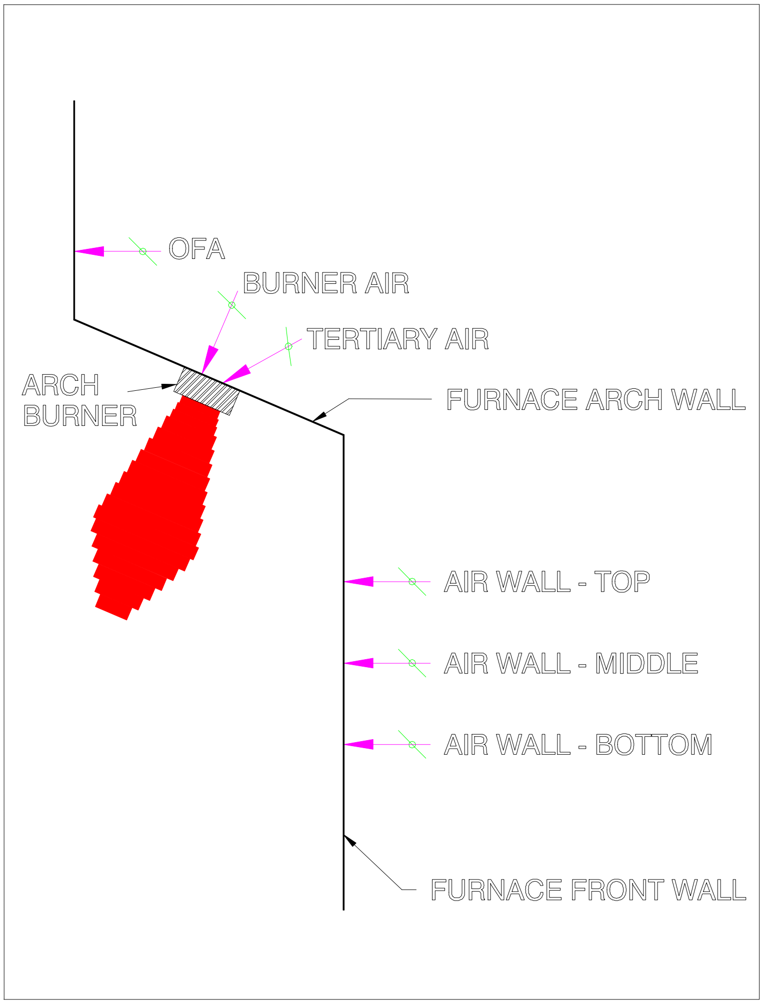

Figure 13 CETF Air Wall Distribution

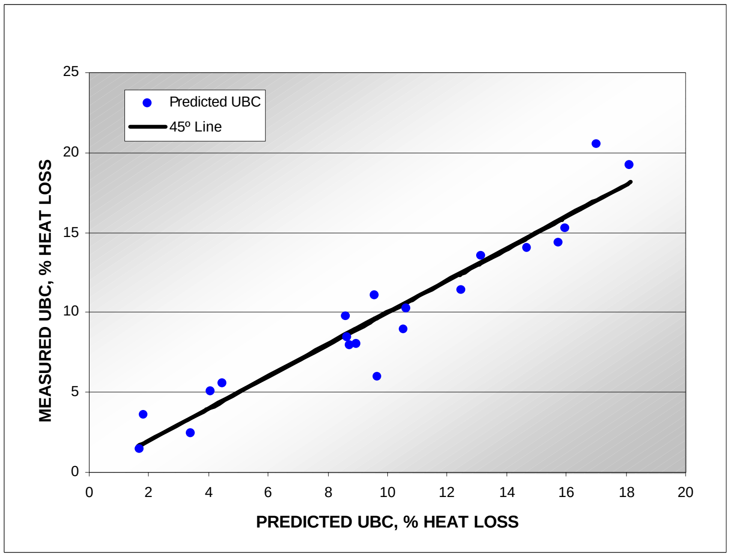

Figure 14 Predicted UBC Correlation

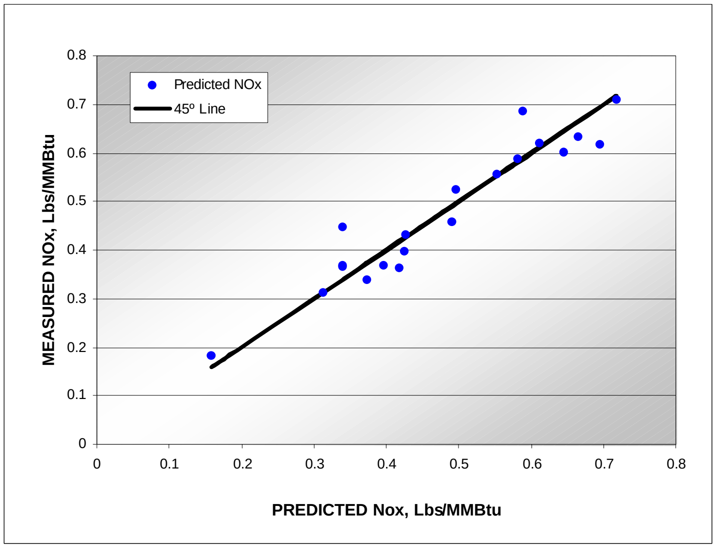

Figure 15 Predicted NO_X Correlation