# ENGINEERING DEVELOPMENT OF COAL-FIRED HIGH-PERFORMANCE POWER SYSTEMS

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## TECHNICAL PROGRESS REPORT NO. 12
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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 pyrolyzation 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.

The design of the char burner was completed during this quarter. The burner is designed for arch-firing and has a maximum capacity of 30 MMBtu/hr. This size represents a half scale version of a typical commercial burner. The burner is outfitted with nozzles for separate injection of char, coal , and limestone. Burner performance will be rated according to three criteria, carbon conversion efficiency, NOx generation, and flame stability. If initial testing in the arch configuration proves succesful, further tests will be performed in the wall-fired arrangement.

A complete set of process and instrumentation drawings (P&ID's) were completed for the Combustion and Environmental Test Facility (CETF) this quarter. These drawings established an ISA approved instrument tagging structure, and provided a coherent database for the development of a data acquisition system. The data acquisition system polls tag information (value, range, engineering units, etc.) from the distributed control system (DCS) highway, and provides a platform for data reduction.

The quadropole mass spectrometer, used during the pyrolyzer tests performed at the pilot plant in Livingston, N.J., has been redesigned for use at the CETF. The mass spectrometer is designed to provide on-line gas analysis by identifying all of the chemical components within the secondary air line, the flue gas recycle line, and the furnace exit ducting.

The construction effort at the CETF continued this quarter with the completion of the char storage system, reheat burner, flue gas recycle piping, and the pulverized coal feed 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 plant that 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, 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.

The results of the “cold” two-phase flow tests were used to determine the design of the char combustor for “hot” operation at the CETF. The design of the burner was completed during this quarter, and is outfitted with separate injection nozzles for char, coal, and limestone. The burner is based upon a cyclone design, where the char and the limestone are mixed with hot vitiated air (appx. 800 Deg. F.) to effectively preheat the fuel before firing into the boiler. This preheat concept is employed to promote stable combustion of the char, as its lack of volatile matter makes it a particularly hard to burn fuel. The char burner is also equipped with swirler vanes to impart rotation to the tertiary air. This swirling effect tends to stabilize and control the burner flame front in an effort to increase carbon conversion efficiency and to reduce NOx generation. A series of nine scanners were installed on the north wall of the boiler to provide a mapping of the burner flame. These scanners are to be calibrated to a fixed source, and will output a 4-20 ma signal to the DCS proportional to the intensity of the flame. These scanners will serve to quantitatively define the stability and shape of the flame.

The construction effort continued during this quarter with the completion of the following items:

1. Flue Gas Recycle Piping
2. Pulverized Coal Feed System
3. Char Storage Feed System
4. Reheat Burner

Installation of the char burner is scheduled for next quarter.

# 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.

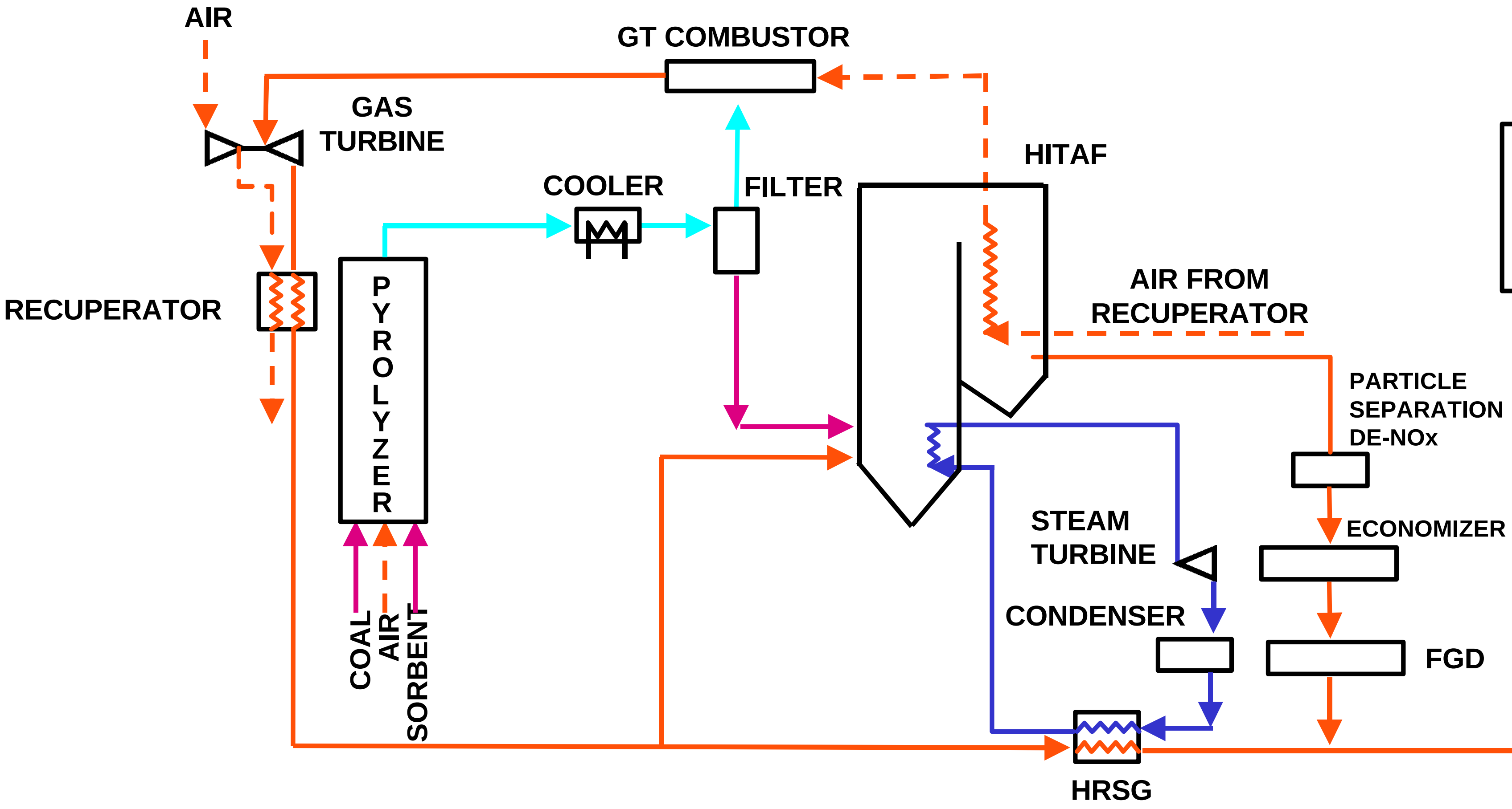

Figure 1 All Coal Fired HIPPS

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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.

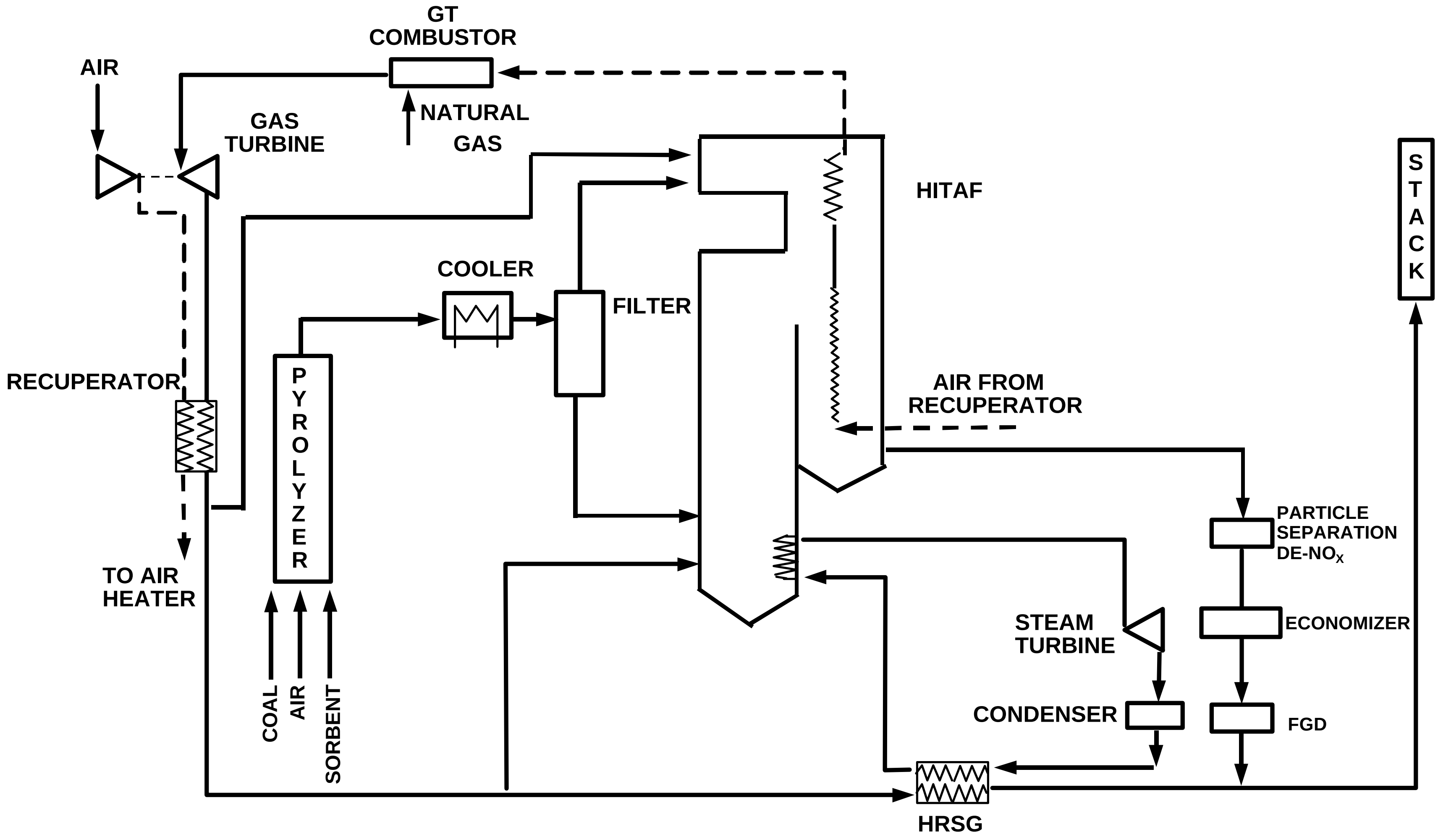

**Figure 2 35-Percent Natural Gas HIPPS**

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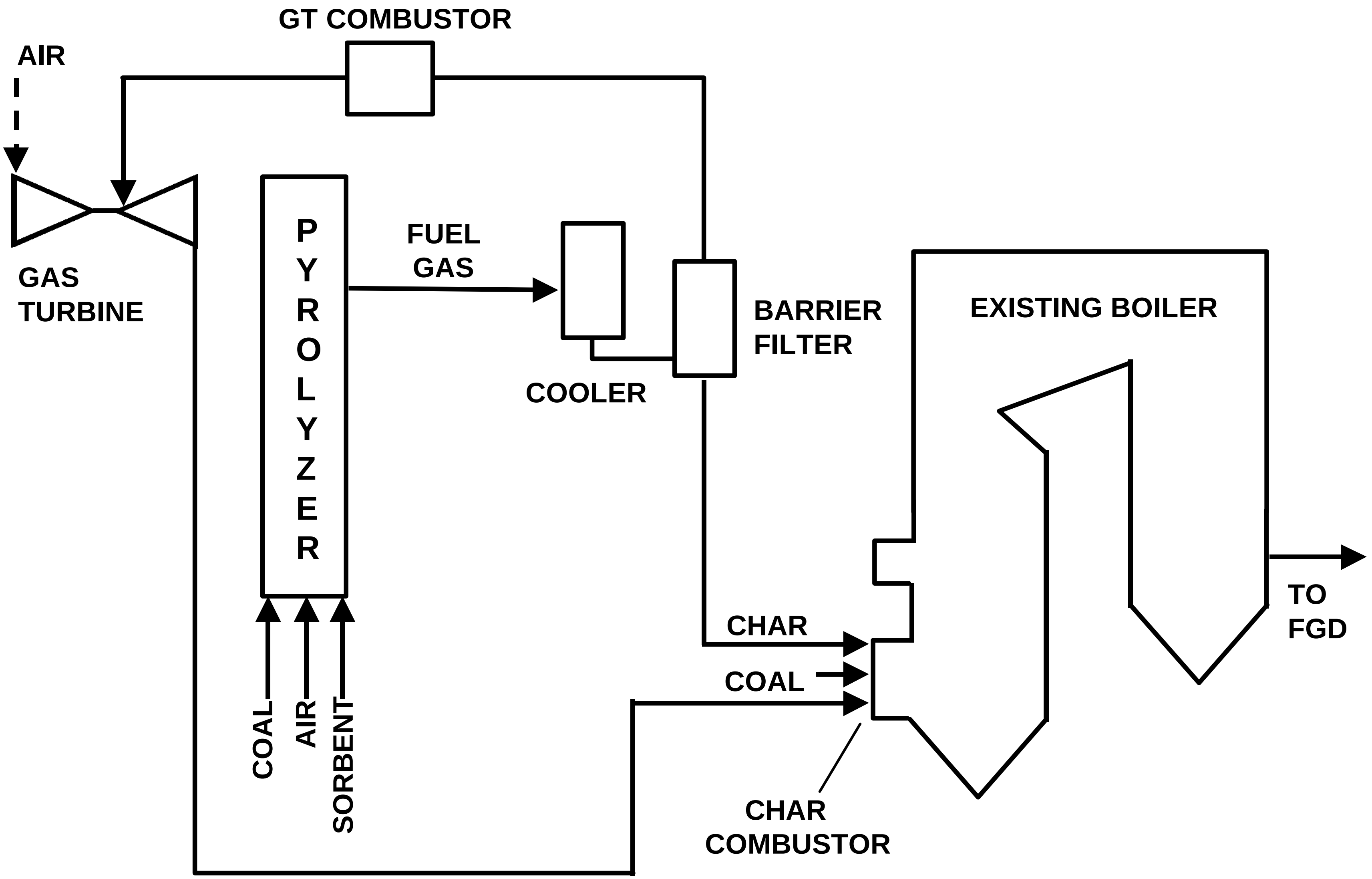

Figure 3 Simplified HIPPS Repowering Process Flow Diagram

## TECHNICAL PROGRESS

### Task 1 - Project Planning and Management

Work is proceeding in accordance with the Project Plan.

### Task 2 – Engineering Research and Development

### Subtask 2.1 – Char Combustor Two-Phase Flow Model Test

A HIPPS char combustor will be tested at Foster Wheeler's Combustion and Environmental Test Facility (CETF). In order to gain an understanding of the fuel injector pressure drop and air-solids mixing characteristics prior to hot combustion testing at CETF, two-phase modeling of a one-half scale HIPPS fuel injector is conducted at the Two-Phase Cold Flow Test Facility in Livingston, NJ.

During this reporting period, the test article was fabricated, the test facility was modified, necessary instruments were installed, and tests were conducted as detailed below.

A schematic of the model layout is shown in Figure 4 and photographs of the arrangement are provided in Figure 5. The injector design required three piping arrangements with one piping arrangement each for the heated primary air, ambient tertiary air, and ambient pumice/carrier air. Two fans were employed to provide the three air streams. Piping from a 7.5 hp fan was divided into two runs, with one flow stream used for the tertiary air and the other stream passing across an electric heater and entering the injector's tangential inlet. Another 7.5 hp fan was used to provide the required flow and outlet pressure to convey the pumice along the seven feet of vertical run and eleven feet of horizontal run to the injector. A screw feeder below the pumice hopper was used to control the mass flow rate of the pumice. The pumice was then fed into a rotary airlock valve that discharged the solids into the 2 inch sch80 carbon steel carrier air piping.

Instrumentation for the intermediate piping and the injector model included thermocouples, pressure taps, pitot-static tubes, orifice, Dietrich Standard Annubar and Veris Verabar. The tertiary air dynamic pressure was measured with a Dietrich Standard Annubar. This value and the flow rate were recorded on the ROC data acquisition system. The flow rate was confirmed with a pitot-static tube placed within the tertiary air pipe thirteen diameters downstream of a 51% open perforated plate used to straighten the flow. The primary air dynamic pressure was also measured with a Veris Verabar prior to an electric heater. The dynamic pressure and flow rate were recorded onto a LOTUS spreadsheet. The primary air flow rate was also measured with a pitot-static tube at the injector's tangential inlet. A 51% open perforated plate was placed upstream of the pitot-static tube in order to straighten the flow. The pressure differential across the pumice carrier air orifice was measured with a water-filled manometer (0.1 inch wc resolution) and was used to calculate the mass flow rate. The orifice was located prior to the discharge of solids and had 40 diameters upstream and 17 diameters downstream of straight piping run.

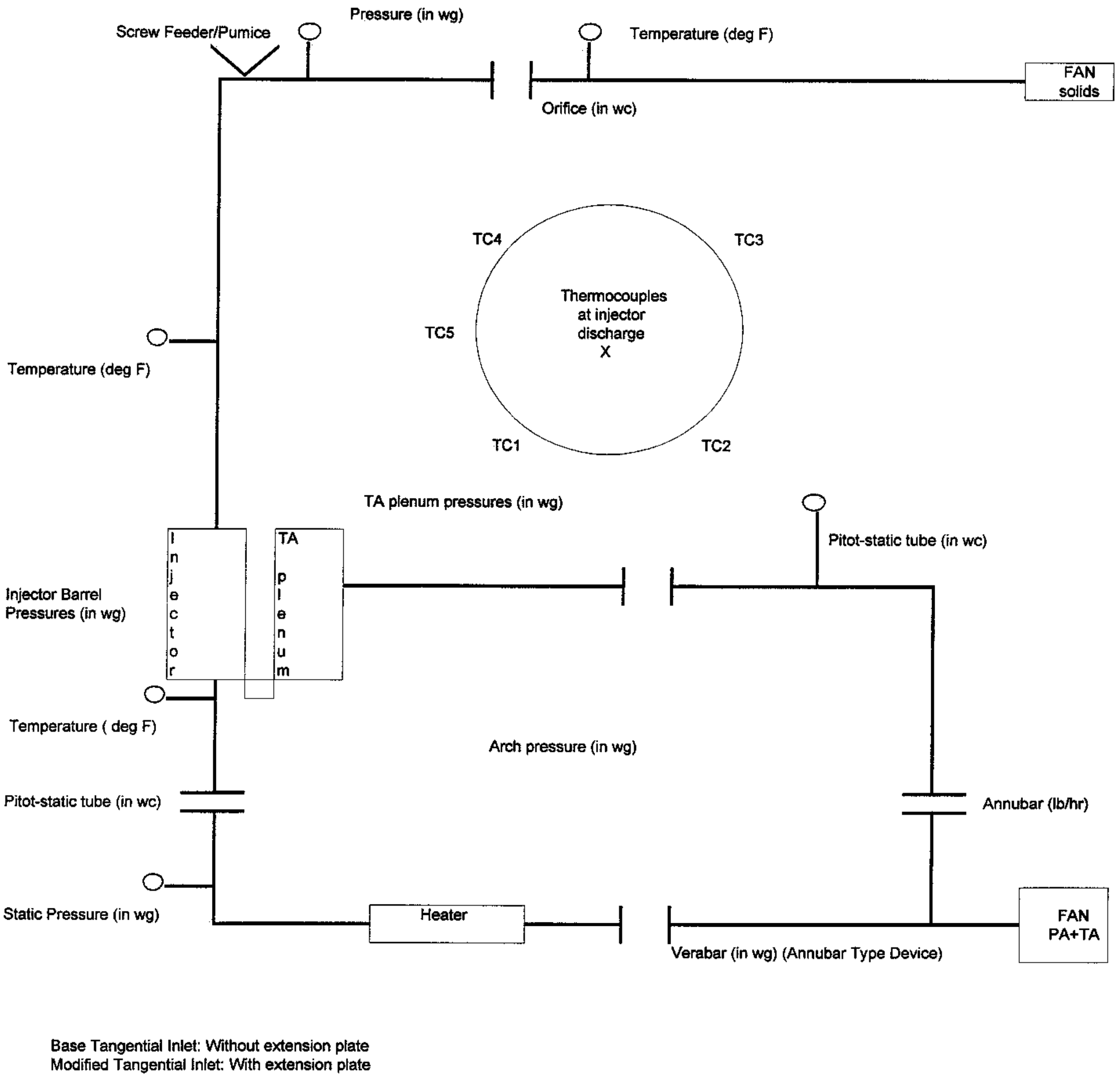

Figure 4  Two-Phase Flow Model Schematic

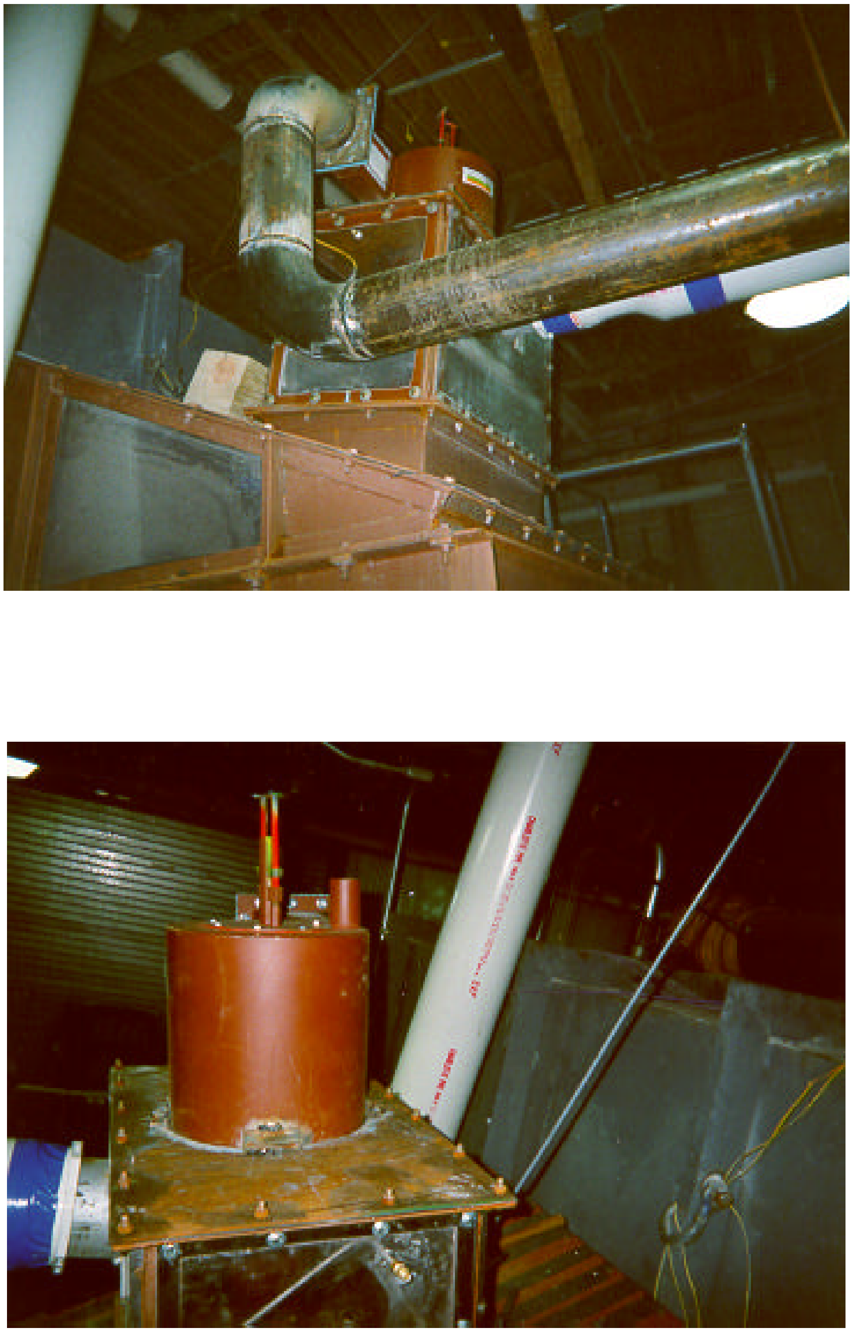

Figure 5  Two-Phase Flow Injector

Pressure taps were placed in various locations in order to obtain accurate density calculations and to observe trends along the system. A pressure tap was included in the primary air line prior to the electric heater. Three pressure taps were placed along the perimeter of the tertiary air plenum which fed into the tertiary air tube. Three pressure taps were also placed circumferentially along the barrel of the injector model ten inches from the barrel top. The pressure taps associated with the tertiary air plenum and injector barrel were put in place in the event that additional data was necessary to make a pressure drop correlation. This was not the case and pitot-static information was sufficient in providing pressure drop data. A pressure tap was also placed prior to the discharge of the pumice into the 2 inch sch80 pipe. Pressure readings were also recorded at the pitot-static tubes. The dynamic pressure and pressure readings from the pitot-static tubes were recorded and averaged using a Solomat Zephyr micromanometer. Pressure tap lines were fed into a Pressure Systems, pressure scanner (Model 9010) that saved the pressure data in an EXCEL format for later review. The pressure scanner had an accuracy of .0015 inch wc.

Omega Type K thermocouples were placed at various locations along the system in order to calculate density and energy balances. Thermocouples were placed at the pumice carrier air fan outlet, inside the pumice hopper, and in the pumicer/carrier air stream prior to the inlet to the injector. Five thermocouples were also placed along the periphery of the injector outlet to record the outlet air/pumice mixture temperature discharging into the exhaust chamber. A thermocouple was placed at the injector’s tangential inlet to record the heated primary air temperature. The primary air temperature before the electric heater was also measured. The thermocouples were wired to a rotary-switch digital panel meter so that temperature could be more easily recorded. Ambient temperature, pressure, and relative humidity were also recorded for each test.

A test sequence typically included the following steps. The injector’s straightening vanes were set to the desired test position. The exhaust ID fan was started followed by the primary air fan and pumice carrier air fan. The tertiary air and primary air flows were set to the desired values. The primary air electric heater was started with a set point between 150 deg F and 200 deg F for heated air tests. Although dependent on ambient conditions, steady-state operation required approximately thirty minutes. Pressure, flow, and temperature data were recorded once steady-state operation was achieved. Most tests included a clean air condition (no solids) followed by solids flow condition. All of the data was recorded on a standard test data sheet. Once the data was collected for the clean air tests, the desired solids flow rate was selected and a K-TRON screw feeder/MAC rotary airlock fed the pumice into the 2 inch sch80 line. The data was then recorded for the solids operation. Pumice mass flow rate was measured by recording the change in the pumice hopper load cell measurements (Sensortronics 65059 TWA) over the test period. Tests continued with different straightening vane settings, primary air flow, and solids flow.

A total of 140 tests were conducted and the major test parameters are presented in Table 1. Test data will be analyzed and the results will be reported in the next report.

| Test # | PA Flow (lb/hr) | Pumice (lb/hr) | Solids/PA | PA Density (lbm/ft3) | PA Inlet Velocity (ft/sec) | PA Vel HD (in wc) | PA Static (in wg) | Arch Static (in wc) | PA static - Arch static (in wc) | Inlet Loss Coef. | Vhoutlet | Outlet Loss Coef. | Straighteni ng Vanes | Tangential Inlet |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| a5-11 | 1287 | 0 | 0 | 0.074 | 50.67 | 0.57 | 4.40 | -0.50 | 4.90 | 9.59 | 2.21 | 2.47 | Inserted | w/o Extension |
| a5-12 | 1078 | 0 | 0 | 0.075 | 42.10 | 0.40 | 2.32 | -0.47 | 2.80 | 8.04 | 1.71 | 1.86 | Inserted | w/o Extension |
| a5-12b | 1104 | 0 | 0 | 0.062 | 52.41 | 0.51 | 3.31 | -0.41 | 3.71 | 8.34 | 1.98 | 2.13 | Inserted | w/o Extension |
| a5-14 | 1232 | 0 | 0 | 0.073 | 49.16 | 0.53 | 3.87 | -0.56 | 4.43 | 9.36 | 2.08 | 2.39 | Inserted | w/o Extension |
| a5-15a | 1073 | 0 | 0 | 0.065 | 48.20 | 0.45 | 3.16 | -0.38 | 3.54 | 8.81 | 1.87 | 2.13 | Inserted | w/o Extension |
| a5-26b | 1206 | 0 | 0 | 0.061 | 57.72 | 0.61 | 4.81 | -0.27 | 5.08 | 9.35 | 2.29 | 2.49 | Inserted | w/o Extension |
| a5-26c | 660 | 0 | 0 | 0.060 | 32.17 | 0.19 | 1.03 | -0.25 | 1.28 | 7.89 | 1.08 | 1.36 | Inserted | w/o Extension |
| a5-28a | 669 | 0 | 0 | 0.060 | 32.55 | 0.19 | 0.84 | -0.52 | 1.36 | 8.13 | 1.09 | 1.43 | Inserted | w/o Extension |
| a5-28b | 816 | 0 | 0 | 0.060 | 39.57 | 0.28 | 1.64 | -0.43 | 2.07 | 8.33 | 1.37 | 1.71 | Inserted | w/o Extension |
| a5-29a | 1205 | 0 | 0 | 0.062 | 57.30 | 0.60 | 4.91 | -0.38 | 5.29 | 9.76 | 2.23 | 2.65 | Inserted | w/o Extension |
| a5-29b | 1563 | 0 | 0 | 0.062 | 73.96 | 1.01 | 9.37 | -0.33 | 9.70 | 10.59 | 3.30 | 3.25 | Inserted | w/o Extension |
| a5-29f | 1002 | 0 | 0 | 0.060 | 48.67 | 0.43 | 2.80 | -0.25 | 3.05 | 8.16 | 1.78 | 1.96 | Inserted | w/o Extension |
| a6-5d | 1120 | 0 | 0 | 0.061 | 56.67 | 0.59 | 4.98 | -0.34 | 5.32 | 10.08 | 1.99 | 2.96 | Inserted | w/ Extension |
| a6-5e | 819 | 0 | 0 | 0.061 | 41.85 | 0.32 | 3.01 | -0.30 | 3.31 | 11.46 | 1.39 | 2.62 | Inserted | w/ Extension |
| a6-5f | 663 | 0 | 0 | 0.060 | 34.45 | 0.21 | 2.12 | -0.29 | 2.41 | 12.41 | 1.09 | 2.40 | Inserted | w/ Extension |
| a6-5g | 1207 | 0 | 0 | 0.061 | 61.18 | 0.68 | 5.75 | -0.26 | 6.01 | 9.81 | 2.30 | 2.91 | Inserted | w/ Extension |
| a6-5h | 1561 | 0 | 0 | 0.061 | 79.12 | 1.14 | 8.98 | -0.23 | 9.21 | 9.08 | 3.32 | 3.12 | Inserted | w/ Extension |
| a6-5i | 1559 | 0 | 0 | 0.061 | 78.89 | 1.14 | 9.01 | -0.19 | 9.20 | 9.10 | 3.31 | 3.12 | Inserted | w/ Extension |
| a6-17a | 1536 | 0 | 0 | 0.062 | 76.72 | 1.09 | 8.79 | -0.63 | 9.42 | 9.66 | 3.19 | 3.29 | Inserted | w/ Extension |
| a6-17b | 1533 | 0 | 0 | 0.062 | 76.45 | 1.08 | 8.66 | -0.53 | 9.19 | 9.49 | 3.19 | 3.22 | Inserted | w/ Extension |
| a6-17c | 1193 | 0 | 0 | 0.061 | 60.47 | 0.67 | 5.58 | -0.46 | 6.03 | 10.06 | 2.24 | 2.99 | Inserted | w/ Extension |
| a6-17d | 1095 | 0 | 0 | 0.061 | 55.50 | 0.56 | 4.94 | -0.42 | 5.36 | 10.55 | 1.86 | 3.18 | Inserted | w/ Extension |
| a6-17e | 809 | 0 | 0 | 0.060 | 41.69 | 0.31 | 3.06 | -0.39 | 3.45 | 12.07 | 1.00 | 3.77 | Inserted | w/ Extension |
| a6-17f | 650 | 0 | 0 | 0.060 | 33.49 | 0.20 | 2.15 | -0.37 | 2.52 | 13.52 | 1.06 | 2.56 | Inserted | w/ Extension |
| a6-24c | 757 | 0 | 0 | 0.061 | 38.12 | 0.27 | 2.59 | -0.48 | 3.07 | 12.54 | 1.25 | 2.68 | Inserted | w/ Extension |
| a6-24d | 650 | 0 | 0 | 0.061 | 32.89 | 0.20 | 2.06 | -0.46 | 2.52 | 13.78 | 1.04 | 2.61 | Inserted | w/ Extension |
| a6-24e | 744 | 0 | 0 | 0.071 | 32.35 | 0.22 | 2.70 | -0.45 | 3.14 | 15.15 | 1.13 | 2.98 | Inserted | w/ Extension |
| a6-24f | 860 | 0 | 0 | 0.071 | 37.45 | 0.30 | 2.95 | -0.42 | 3.37 | 12.32 | 1.34 | 2.74 | Inserted | w/ Extension |
| a6-24g | 613 | 0 | 0 | 0.071 | 26.81 | 0.15 | 1.68 | -0.40 | 2.08 | 14.71 | 0.91 | 2.44 | Inserted | w/ Extension |
| h6-24a | 1093 | 0 | 0 | 0.062 | 54.42 | 0.55 | 4.94 | -0.44 | 5.38 | 10.79 | 1.97 | 3.01 | Inserted | w/ Extension |
| h6-24b | 1092 | 0 | 0 | 0.062 | 54.90 | 0.55 | 2.31 | -0.44 | 2.75 | 5.97 | 0.89 | 3.72 | Inserted | w/ Extension |
| a6-26f | 1138 | 0 | 0 | 0.071 | 49.77 | 0.52 | 3.75 | -0.34 | 4.09 | 8.83 | 1.86 | 2.48 | Inserted | w/ Extension |
| aa6-26f | 1143 | 0 | 0 | 0.070 | 50.25 | 0.53 | 1.55 | -0.35 | 1.90 | 4.58 | 0.86 | 2.84 | Inserted | w/ Extension |
| a6-30b | 1164 | 0 | 0 | 0.072 | 50.05 | 0.54 | 3.26 | -0.36 | 3.61 | 7.71 | 1.70 | 2.44 | Inserted | w/ Extension |
| h6-30a | 1153 | 0 | 0 | 0.059 | 60.01 | 0.64 | 4.17 | -0.37 | 4.54 | 8.11 | 2.16 | 2.40 | Inserted | w/ Extension |
| a5-15b | 1057 | 0 | 0 | 0.065 | 47.93 | 0.44 | 2.46 | -0.31 | 2.77 | 7.25 | 1.83 | 1.76 | Retracted | w/o Extension |
| a5-15c | 1195 | 0 | 0 | 0.071 | 49.02 | 0.51 | 3.29 | -0.26 | 3.55 | 7.92 | 2.03 | 2.00 | Retracted | w/o Extension |
| a5-19 | 1186 | 0 | 0 | 0.061 | 57.04 | 0.59 | 3.48 | -0.47 | 3.95 | 7.67 | 2.21 | 2.06 | Retracted | w/o Extension |
| a5-20 | 1195 | 0 | 0 | 0.062 | 56.73 | 0.59 | 3.59 | -0.36 | 3.95 | 7.67 | 2.24 | 2.03 | Retracted | w/o Extension |
| a5-22a | 667 | 0 | 0 | 0.061 | 31.92 | 0.19 | 0.35 | -0.55 | 0.90 | 5.82 | 1.09 | 0.99 | Retracted | w/o Extension |
| a5-22b | 827 | 0 | 0 | 0.061 | 39.65 | 0.29 | 1.16 | -0.38 | 1.55 | 6.39 | 1.39 | 1.32 | Retracted | w/o Extension |
| a5-22c | 1207 | 0 | 0 | 0.061 | 57.77 | 0.61 | 3.89 | -0.34 | 4.23 | 7.94 | 2.28 | 2.12 | Retracted | w/o Extension |
| a5-26a | 1209 | 0 | 0 | 0.062 | 57.58 | 0.61 | 3.93 | -0.30 | 4.23 | 7.95 | 2.28 | 2.12 | Retracted | w/o Extension |
| a5-29c | 1561 | 0 | 0 | 0.062 | 74.35 | 1.02 | 7.06 | -0.29 | 7.35 | 8.24 | 3.30 | 2.53 | Retracted | w/o Extension |
| a5-29d | 1201 | 0 | 0 | 0.061 | 57.86 | 0.61 | 4.00 | -0.26 | 4.27 | 8.02 | 2.27 | 2.15 | Retracted | w/o Extension |
| a5-29e | 996 | 0 | 0 | 0.060 | 48.54 | 0.42 | 2.23 | -0.24 | 2.47 | 6.85 | 1.77 | 1.64 | Retracted | w/o Extension |
| a6-3a | 1211 | 0 | 0 | 0.061 | 61.68 | 0.69 | 4.77 | -0.38 | 5.15 | 8.47 | 2.31 | 2.53 | Retracted | w/ Extension |
| a6-3b | 1571 | 0 | 0 | 0.061 | 79.37 | 1.15 | 7.40 | -0.31 | 7.70 | 7.69 | 3.35 | 2.64 | Retracted | w/ Extension |
| a6-3c | 1570 | 0 | 0 | 0.061 | 79.32 | 1.15 | 7.35 | -0.27 | 7.62 | 7.63 | 3.35 | 2.62 | Retracted | w/ Extension |
| a6-3d | 663 | 0 | 0 | 0.060 | 34.16 | 0.21 | 1.84 | -0.25 | 2.09 | 11.01 | 1.09 | 2.11 | Retracted | w/ Extension |
| a6-5a | 667 | 0 | 0 | 0.060 | 34.37 | 0.21 | 1.51 | -0.53 | 2.04 | 10.64 | 1.11 | 2.03 | Retracted | w/ Extension |
| a6-5b | 828 | 0 | 0 | 0.061 | 42.17 | 0.32 | 2.47 | -0.45 | 2.92 | 10.06 | 1.42 | 2.29 | Retracted | w/ Extension |
| a6-5c | 1122 | 0 | 0 | 0.061 | 56.96 | 0.59 | 4.17 | -0.40 | 4.57 | 8.74 | 2.08 | 2.48 | Retracted | w/ Extension |
| a6-18a | 1540 | 0 | 0 | 0.061 | 78.44 | 1.12 | 7.19 | -0.61 | 7.80 | 7.99 | 3.31 | 2.69 | Retracted | w/ Extension |
| a6-18b | 1187 | 0 | 0 | 0.061 | 59.77 | 0.66 | 4.34 | -0.50 | 4.84 | 8.39 | 2.19 | 2.51 | Retracted | w/ Extension |
| a6-18c | 1095 | 0 | 0 | 0.061 | 55.41 | 0.56 | 3.95 | -0.43 | 4.38 | 8.83 | 1.96 | 2.53 | Retracted | w/ Extension |
| a6-18d | 808 | 0 | 0 | 0.061 | 41.29 | 0.31 | 2.46 | -0.38 | 2.85 | 10.24 | 1.34 | 2.35 | Retracted | w/ Extension |
| a6-18e | 659 | 0 | 0 | 0.060 | 33.85 | 0.21 | 1.77 | -0.36 | 2.13 | 11.32 | 1.05 | 2.21 | Retracted | w/ Extension |
| a6-18f | 1530 | 0 | 0 | 0.061 | 77.80 | 1.10 | 7.28 | -0.33 | 7.61 | 7.93 | 3.22 | 2.71 | Retracted | w/ Extension |
| a6-23a | 749 | 0 | 0 | 0.073 | 31.77 | 0.22 | 1.66 | -0.65 | 2.31 | 11.49 | 1.13 | 2.23 | Retracted | w/ Extension |
| a6-23b | 868 | 0 | 0 | 0.073 | 36.86 | 0.30 | 2.28 | -0.59 | 2.86 | 10.69 | 1.34 | 2.36 | Retracted | w/ Extension |
| a6-24a | 651 | 0 | 0 | 0.065 | 31.01 | 0.19 | 1.50 | -0.54 | 2.04 | 11.94 | 1.02 | 2.18 | Retracted | w/ Extension |
| a6-24b | 758 | 0 | 0 | 0.062 | 37.92 | 0.27 | 2.22 | -0.50 | 2.72 | 11.25 | 1.25 | 2.39 | Retracted | w/ Extension |
| a6-26e | 1146 | 0 | 0 | 0.071 | 49.97 | 0.53 | 3.11 | -0.34 | 3.45 | 7.53 | 1.87 | 2.13 | Retracted | w/ Extension |
| aa6-26e | 1146 | 0 | 0 | 0.070 | 50.33 | 0.53 | 1.17 | -0.35 | 1.52 | 3.85 | 0.85 | 2.41 | Retracted | w/ Extension |
| a6-30a | 1165 | 0 | 0 | 0.072 | 50.10 | 0.54 | 2.74 | -0.39 | 3.14 | 6.82 | 1.74 | 2.11 | Retracted | w/ Extension |
| h6-30b | 1153 | 0 | 0 | 0.060 | 59.81 | 0.64 | 3.52 | -0.37 | 3.88 | 7.10 | 2.15 | 2.10 | Retracted | w/ Extension |
| a5-29g | 999 | 0 | 0 | 0.060 | 48.45 | 0.42 | 2.63 | -0.22 | 2.85 | 7.74 | 1.78 | 1.84 | +4.75" | w/o Extension |
| a6-2a | 1107 | 0 | 0 | 0.061 | 56.20 | 0.57 | 4.60 | -0.51 | 5.11 | 9.90 | 2.02 | 2.82 | +4.75" | w/ Extension |
| a6-2b | 998 | 0 | 0 | 0.060 | 51.17 | 0.47 | 3.82 | -0.41 | 4.23 | 9.97 | 1.77 | 2.66 | +4.75" | w/ Extension |
| a6-26a | 1110 | 0 | 0 | 0.072 | 47.80 | 0.49 | 3.01 | -0.46 | 3.48 | 8.10 | 1.79 | 2.22 | +8.75" | w/ Extension |
| a6-26b | 742 | 0 | 0 | 0.071 | 32.22 | 0.22 | 1.29 | -0.40 | 1.69 | 8.64 | 1.08 | 1.76 | +8.75" | w/ Extension |
| a6-26c | 741 | 0 | 0 | 0.071 | 32.27 | 0.22 | 1.15 | -0.38 | 1.53 | 7.95 | 1.09 | 1.62 | +16.75" | w/ Extension |
| a6-26d | 1106 | 0 | 0 | 0.071 | 48.16 | 0.49 | 2.68 | -0.37 | 3.05 | 7.19 | 1.78 | 1.99 | +16.75" | w/ Extension |

**Table 1  Test Data for Two-Phase HIPPS Model**

| Test # | PA Flow (lb/hr) | Pumice (lb/hr) | Solids/PA | PA Density (lbm/ft3) | PA Inlet Velocity (ft/sec) | PA Vel HD (in wc) | PA Static (in wg) | Arch Static (in wc) | PA static - Arch static (in wc) | Loss Coef. | Vhoutlet (in wc) | Outlet Loss Coef. | Straighteni ng Vanes | Tangential Inlet |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| s5-11 | 1293 | 1030 | 0.80 | 0.074 | 50.90 | 0.58 | 4.36 | -0.46 | 4.81 | 9.36 | 1.90 | 2.84 | Inserted | w/o Extension |
| s5-12 | 1075 | 996 | 0.93 | 0.075 | 41.93 | 0.39 | 3.18 | -0.41 | 3.60 | 10.13 | 1.52 | 2.63 | Inserted | w/o Extension |
| s5-12b | 1110 | 969 | 0.87 | 0.062 | 52.87 | 0.51 | 3.97 | -0.36 | 4.33 | 9.43 | 1.63 | 2.97 | Inserted | w/o Extension |
| s5-14 | 1230 | 1080 | 0.88 | 0.073 | 49.29 | 0.53 | 3.94 | -0.40 | 4.34 | 9.18 | 1.38 | 3.53 | Inserted | w/o Extension |
| s5-15a | 1070 | 1177 | 1.10 | 0.065 | 48.22 | 0.45 | 3.71 | -0.31 | 4.03 | 9.92 | 1.55 | 2.89 | Inserted | w/o Extension |
| s5-26b | 1206 | 1136 | 0.94 | 0.061 | 57.72 | 0.61 | 4.72 | -0.25 | 4.97 | 9.16 | 1.90 | 2.94 | Inserted | w/o Extension |
| s5-26c | 659 | 580 | 0.88 | 0.060 | 32.22 | 0.19 | 1.51 | -0.24 | 1.75 | 10.44 | 0.93 | 2.09 | Inserted | w/o Extension |
| s5-28a | 668 | 640 | 0.96 | 0.060 | 32.61 | 0.19 | 1.32 | -0.45 | 1.76 | 10.26 | 0.94 | 2.08 | Inserted | w/o Extension |
| s5-28b | 815 | 748 | 0.92 | 0.061 | 39.46 | 0.28 | 2.19 | -0.39 | 2.58 | 10.17 | 1.18 | 2.42 | Inserted | w/o Extension |
| s5-29a | 1204 | 1132 | 0.94 | 0.061 | 57.53 | 0.61 | 4.70 | -0.35 | 5.05 | 9.34 | 2.05 | 2.76 | Inserted | w/o Extension |
| s5-29b | 1561 | 1148 | 0.74 | 0.062 | 74.23 | 1.01 | 7.22 | -0.31 | 7.53 | 8.43 | 2.87 | 2.98 | Inserted | w/o Extension |
| s5-29f | 1000 | 975 | 0.98 | 0.060 | 48.49 | 0.42 | 3.28 | -0.23 | 3.51 | 9.29 | 1.47 | 2.68 | Inserted | w/o Extension |
| s6-5d | 1121 | 1154 | 1.03 | 0.061 | 56.63 | 0.59 | 5.23 | -0.31 | 5.54 | 10.45 | 1.71 | 3.58 | Inserted | w/ Extension |
| s6-5e | 818 | 715 | 0.87 | 0.060 | 41.94 | 0.32 | 2.86 | -0.28 | 3.14 | 10.91 | 1.20 | 2.88 | Inserted | w/ Extension |
| s6-5f | 663 | 582 | 0.88 | 0.060 | 34.45 | 0.21 | 1.93 | -0.27 | 2.20 | 11.42 | 0.95 | 2.54 | Inserted | w/ Extension |
| s6-5g | 1207 | 1059 | 0.88 | 0.061 | 61.18 | 0.68 | 5.99 | -0.24 | 6.22 | 10.12 | 1.93 | 3.58 | Inserted | w/ Extension |
| s6-5h | 1560 | 1325 | 0.85 | 0.061 | 78.68 | 1.13 | 9.17 | -0.20 | 9.37 | 9.27 | 2.87 | 3.66 | Inserted | w/ Extension |
| s6-5i | 1565 | 1066 | 0.68 | 0.062 | 78.68 | 1.14 | 9.15 | -0.18 | 9.32 | 9.20 | 2.89 | 3.62 | Inserted | w/ Extension |
| s6-17a | 1534 | 1080 | 0.70 | 0.062 | 76.87 | 1.09 | 8.76 | -0.55 | 9.31 | 9.55 | 2.79 | 3.73 | Inserted | w/ Extension |
| s6-17b | 1529 | 1360 | 0.89 | 0.061 | 77.50 | 1.09 | 8.91 | -0.47 | 9.38 | 9.57 | 2.78 | 3.77 | Inserted | w/ Extension |
| s6-17c | 1186 | 1093 | 0.92 | 0.061 | 59.92 | 0.66 | 5.71 | -0.43 | 6.13 | 10.35 | 1.88 | 3.61 | Inserted | w/ Extension |
| s6-17d | 1089 | 1216 | 1.12 | 0.061 | 55.38 | 0.56 | 5.06 | -0.39 | 5.45 | 10.78 | 1.65 | 3.64 | Inserted | w/ Extension |
| s6-17e | 809 | 754 | 0.93 | 0.060 | 41.48 | 0.31 | 2.90 | -0.38 | 3.27 | 11.56 | 1.17 | 3.06 | Inserted | w/ Extension |
| s6-17f | 660 | 600 | 0.91 | 0.060 | 34.18 | 0.21 | 1.96 | -0.36 | 2.32 | 12.13 | 0.93 | 2.72 | Inserted | w/ Extension |
| s6-24c | 757 | 865 | 1.14 | 0.061 | 38.12 | 0.27 | 2.47 | -0.47 | 2.94 | 12.04 | 1.05 | 3.05 | Inserted | w/ Extension |
| s6-24d | 659 | 805 | 1.22 | 0.061 | 33.35 | 0.20 | 1.82 | -0.45 | 2.27 | 12.19 | 0.91 | 2.72 | Inserted | w/ Extension |
| s6-24e | 743 | 882 | 1.19 | 0.071 | 32.26 | 0.22 | 2.22 | -0.43 | 2.65 | 12.98 | 0.96 | 2.99 | Inserted | w/ Extension |
| s6-24f | 860 | 905 | 1.05 | 0.071 | 37.45 | 0.30 | 2.91 | -0.40 | 3.31 | 12.13 | 1.18 | 3.06 | Inserted | w/ Extension |
| s6-24g | 613 | 764 | 1.25 | 0.071 | 26.81 | 0.15 | 1.54 | -0.38 | 1.93 | 13.70 | 0.80 | 2.60 | Inserted | w/ Extension |
| s6-30b | 1164 | 1076 | 0.92 | 0.072 | 49.91 | 0.54 | 3.46 | -0.36 | 3.83 | 8.13 | 1.73 | 2.52 | Inserted | w/ Extension |
| s5-15b | 1055 | 1234 | 1.17 | 0.065 | 47.84 | 0.44 | 2.75 | -0.25 | 3.00 | 7.79 | 1.52 | 2.26 | Retracted | w/o Extension |
| s5-15c | 1191 | 1122 | 0.94 | 0.071 | 49.06 | 0.51 | 3.15 | -0.20 | 3.36 | 7.57 | 1.74 | 2.22 | Retracted | w/o Extension |
| s5-19 | 1191 | 1237 | 1.04 | 0.061 | 57.47 | 0.60 | 3.29 | -0.38 | 3.66 | 7.12 | 1.88 | 2.27 | Retracted | w/o Extension |
| s5-20 | 1194 | 994 | 0.83 | 0.061 | 56.96 | 0.59 | 3.24 | -0.30 | 3.55 | 6.96 | 1.94 | 2.14 | Retracted | w/o Extension |
| s5-22a | 665 | 597 | 0.90 | 0.061 | 32.09 | 0.19 | 0.61 | -0.40 | 1.01 | 6.41 | 0.99 | 1.21 | Retracted | w/o Extension |
| s5-22b | 827 | 760 | 0.92 | 0.061 | 39.58 | 0.29 | 1.43 | -0.36 | 1.80 | 7.27 | 1.21 | 1.72 | Retracted | w/o Extension |
| s5-22c | 1206 | 1113 | 0.92 | 0.061 | 58.10 | 0.61 | 3.51 | -0.31 | 3.82 | 7.24 | 1.92 | 2.31 | Retracted | w/o Extension |
| s5-26a | 1208 | 1132 | 0.94 | 0.061 | 57.91 | 0.61 | 3.42 | -0.27 | 3.70 | 7.04 | 2.04 | 2.11 | Retracted | w/o Extension |
| s5-29c | 1559 | 1127 | 0.72 | 0.061 | 74.49 | 1.02 | 5.45 | -0.27 | 5.72 | 6.63 | 2.87 | 2.35 | Retracted | w/o Extension |
| s5-29d | 1200 | 1126 | 0.94 | 0.061 | 58.00 | 0.61 | 3.45 | -0.25 | 3.70 | 7.08 | 1.91 | 2.26 | Retracted | w/o Extension |
| s5-29e | 996 | 960 | 0.96 | 0.060 | 48.62 | 0.42 | 2.47 | -0.23 | 2.70 | 7.38 | 1.91 | 1.64 | Retracted | w/o Extension |
| s6-3a | 1210 | 1101 | 0.91 | 0.061 | 61.84 | 0.69 | 4.93 | -0.33 | 5.26 | 8.61 | 1.99 | 2.99 | Retracted | w/ Extension |
| s6-3b | 1571 | 1097 | 0.70 | 0.061 | 79.37 | 1.15 | 7.67 | -0.29 | 7.95 | 7.91 | 2.93 | 3.11 | Retracted | w/ Extension |
| s6-3c | 1570 | 1360 | 0.87 | 0.061 | 79.32 | 1.15 | 7.83 | -0.25 | 8.08 | 8.03 | 2.89 | 3.19 | Retracted | w/ Extension |
| s6-3d | 673 | 595 | 0.88 | 0.060 | 34.68 | 0.22 | 1.56 | -0.24 | 1.80 | 9.34 | 0.99 | 2.03 | Retracted | w/ Extension |
| s6-5a | 677 | 613 | 0.91 | 0.060 | 34.71 | 0.22 | 1.29 | -0.47 | 1.76 | 9.12 | 0.98 | 2.02 | Retracted | w/ Extension |
| s6-5b | 836 | 700 | 0.84 | 0.061 | 42.65 | 0.33 | 2.23 | -0.41 | 2.64 | 9.01 | 1.23 | 2.41 | Retracted | w/ Extension |
| s6-5c | 1119 | 1163 | 1.04 | 0.061 | 56.72 | 0.59 | 4.21 | -0.35 | 4.56 | 8.78 | 1.76 | 2.92 | Retracted | w/ Extension |
| s6-18a | 1537 | 1357 | 0.88 | 0.061 | 78.55 | 1.11 | 7.37 | -0.52 | 7.89 | 8.07 | 2.81 | 3.20 | Retracted | w/ Extension |
| s6-18b | 1186 | 1048 | 0.88 | 0.062 | 59.62 | 0.65 | 4.46 | -0.44 | 4.90 | 8.51 | 1.86 | 2.99 | Retracted | w/ Extension |
| s6-18c | 1096 | 1162 | 1.06 | 0.061 | 55.55 | 0.56 | 4.00 | -0.39 | 4.39 | 8.82 | 1.66 | 2.99 | Retracted | w/ Extension |
| s6-18d | 808 | 730 | 0.90 | 0.060 | 41.36 | 0.31 | 2.29 | -0.36 | 2.66 | 9.61 | 1.18 | 2.51 | Retracted | w/ Extension |
| s6-18e | 659 | 600 | 0.91 | 0.060 | 33.79 | 0.21 | 1.55 | -0.34 | 1.89 | 10.20 | 0.92 | 2.28 | Retracted | w/ Extension |
| s6-18f | 1530 | 1090 | 0.71 | 0.061 | 77.68 | 1.10 | 7.43 | -0.30 | 7.73 | 8.05 | 2.82 | 3.13 | Retracted | w/ Extension |
| s6-23a | 749 | 535 | 0.71 | 0.073 | 31.72 | 0.22 | 1.44 | -0.60 | 2.04 | 10.31 | 1.03 | 2.20 | Retracted | w/ Extension |
| s6-23b | 866 | 900 | 1.04 | 0.073 | 36.80 | 0.29 | 2.10 | -0.54 | 2.63 | 9.95 | 1.17 | 2.50 | Retracted | w/ Extension |
| s6-24a | 662 | 802 | 1.21 | 0.065 | 31.49 | 0.19 | 1.24 | -0.51 | 1.75 | 10.09 | 0.91 | 2.13 | Retracted | w/ Extension |
| s6-24b | 749 | 866 | 1.16 | 0.061 | 37.90 | 0.26 | 1.90 | -0.49 | 2.39 | 10.10 | 1.07 | 2.47 | Retracted | w/ Extension |
| s6-30a | 1164 | 1071 | 0.92 | 0.072 | 49.98 | 0.54 | 2.89 | -0.40 | 3.29 | 7.12 | 1.73 | 2.21 | Retracted | w/ Extension |
| s5-29g | 998 | 960 | 0.96 | 0.060 | 48.40 | 0.42 | 3.10 | -0.21 | 3.31 | 8.83 | 1.58 | 2.36 | +4.75" | w/o Extension |
| s6-2a | 1106 | 1185 | 1.07 | 0.061 | 56.52 | 0.58 | 4.86 | -0.42 | 5.28 | 10.15 | 1.69 | 3.47 | +4.75" | w/ Extension |
| s6-2b | 996 | 1153 | 1.16 | 0.060 | 51.15 | 0.47 | 4.04 | -0.36 | 4.39 | 10.34 | 1.45 | 3.36 | +4.75" | w/ Extension |
| s6-26a | 1104 | 1043 | 0.94 | 0.072 | 47.74 | 0.49 | 3.07 | -0.40 | 3.47 | 8.14 | 1.58 | 2.51 | +8.75" | w/ Extension |
| s6-26b | 741 | 849 | 1.15 | 0.071 | 32.27 | 0.22 | 1.25 | -0.39 | 1.63 | 8.39 | 0.96 | 1.93 | +8.75" | w/ Extension |
| s6-26c | 740 | 854 | 1.15 | 0.071 | 32.32 | 0.22 | 1.04 | -0.37 | 1.41 | 7.41 | 0.96 | 1.70 | +16.75" | w/ Extension |
| s6-26d | 1099 | 1100 | 1.00 | 0.071 | 47.99 | 0.49 | 2.74 | -0.35 | 3.08 | 7.33 | 1.56 | 2.29 | +16.75" | w/ Extension |

**Table 1  Test Data for Two-Phase HIPPS Model (continued)**

## Task 3 - Subsystem Test Unit Design

### Subtask 3.2 - Char Combustion Subsystem Design

Based on the extremely low volatile content of the char the HIPPS burner was to be designed for, an arch fired burner arrangement was chosen. This offers a greater residence time for particle burnout in an effort to reduce unburned carbon in the flyash. Foster Wheeler has vast experience in the design of arch fired burners, and the HIPPS burner was designed using these standards as loose guidelines.

The basic design is that of a cyclone without an outlet nozzle. A vortex tube was included in the design to maintain the effect of keeping the solids at the outer wall. The burner was designed to have char pneumatically transported separate from the burner air and enter via a 2” Schedule 40 pipe from the roof of the burner. A center core pipe carrying bituminous coal was also included in the design. This center stream of fuel will be used to stabilize flame if the char proves to be difficult to burn alone. This center 1-1/2” Sch. 40 pipe extends the entire length of the burner and ends flush with the outlet nozzle tip.

The center pipe was designed as a pipe within a pipe design. Between the two pipes a layer of insulation will be wrapped along with four (4) thermocouples. The intent is to prevent the internal pipe from heating up enough to cause the bituminous coal to stick to the walls. The thermocouples allow operators to monitor the transport pipe wall temperature.

A third stream was included in the CETF HIPPS burner design, also to the roof of the burner, to carry sorbent to the burner via a 1½” Schedule 40 pipe. This stream was designed because the synthetic char to be tested doesn’t contain any sorbent, which is present in the char that would be burned coming directly from a pyrolyzer unit. The two streams entering the roof of the burner are located 180° from each other.

Straightening vanes, internal to the burner, were designed to be adjustable along the entire length of the burner. These vanes will be adjusted to see the effect on flame stability by reducing the swirl of the fuel particles. The vanes were designed such that when they are fully retracted they will be located inside the vortex tube, and when fully inserted, located flush with the outlet nozzle tip. Figure 6 shows the burner arrangement. The dimensions of the burner are as follows:

Barrel Diameter = 23” ID
Barrel Length = 23”
Hopper Length = 23”
Outlet Diameter = 8” ID (8” Schedule 40)
Outlet Nozzle Length = 18”
Inlet Height = 11.5”
Inlet Width = 4.8”
Vortex Diameter = 8.6” OD (8” Schedule 40)
Vortex Length = 14.5”

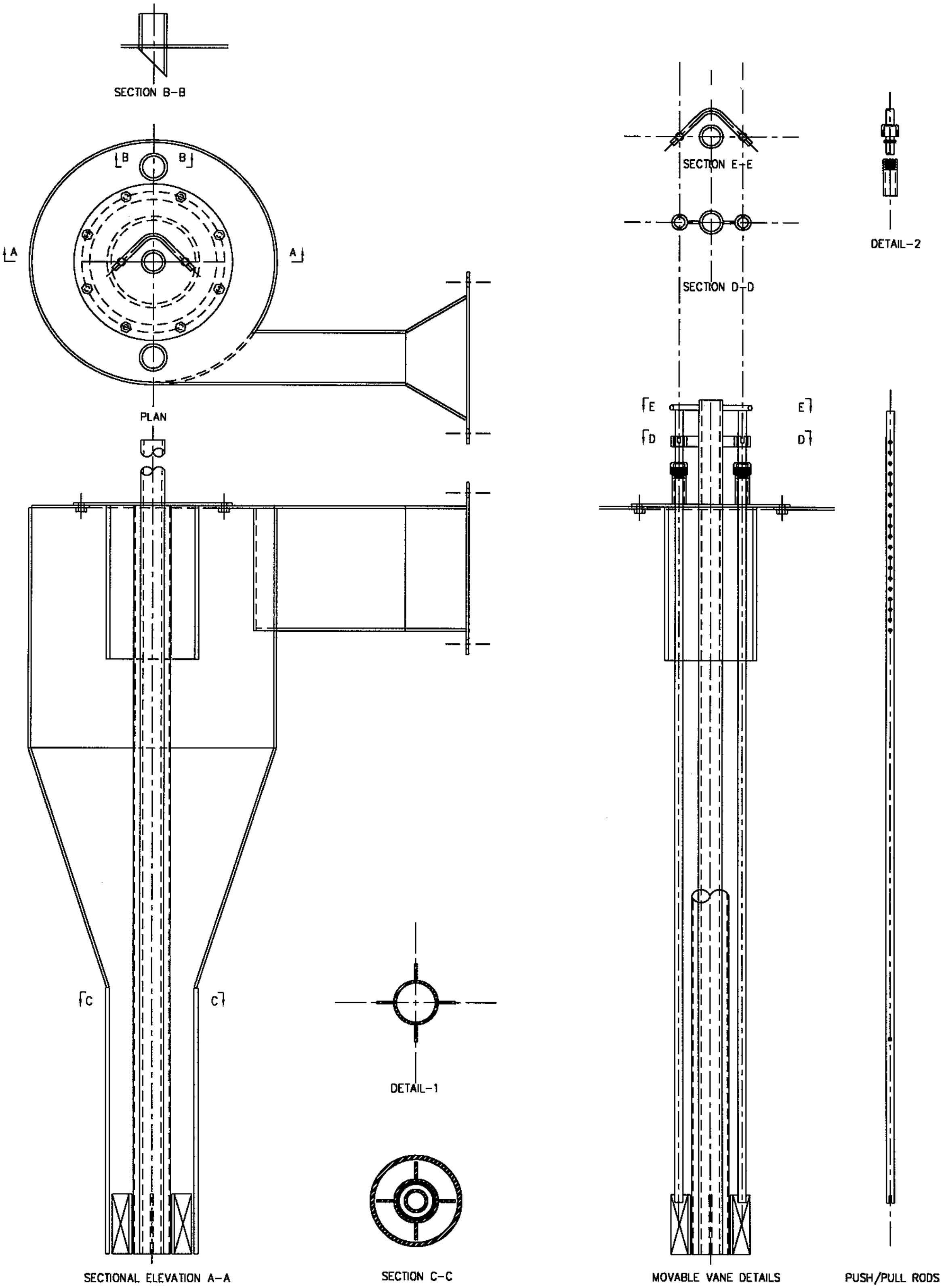

Figure 6 Char Burner (Elevation)

Tertiary air to the burner will be provided from the windbox, and will enter the furnace around the outlet nozzle through a tertiary air can. A tertiary air swirler was designed based on Foster Wheeler experience with horizontal burner registers. The swirler was designed to be 5¾” high with 50º vane angles and a 14.5” OD. The vanes are designed with a ¼” overlap. This design is intended to produce a strong swirl, which will assist in maintaining flame stability with the char. The swirler is removable. Figure 7 shows the design of the tertiary air swirler.

Prior to entering the storage silo, samples of the char are to be taken to monitor any changes in fuel size and/or composition. The first sample will be taken from the outlet of the weighfeeder that feeds the ball mill. An automatic sampling device has been designed to take a sample as the coarse fuel drops off the weighfeeder. The system is pneumatic and will be operated locally by an operator. The sampling cup will make a traverse across the width of the weighbelt to collect the fuel.

When the fuel exits the ball mill a second sample will be taken. This sampling station will be located in the 12” transport pipe between the mill exhauster and the char storage silo. The sample will be taken using an ASME iso-kinetic sampling probe. A similar sampling station to this will be placed at the furnace exit to collect flyash for UBC determination.

Once the flyash sample is taken, the unburned carbon (UBC) will be measured. The UBC measuring system located at the CETF consists of a muffle furnace, capable of variable atmosphere, and an accurate scale. The flyash sample is weighed and placed into the muffle furnace set at 975ºC, in an $O_2$ atmosphere. The $O_2$ atmosphere is intended to speed up the ashing process. After ashing is complete, the flyash sample is removed and weighed. The weight difference divided by the initial weight is the percent UBC in the flyash. This simple method will give the operators an idea of how the burner is operating and how any changes made to the burner arrangement affect the UBC. Flyash samples will be sent to FWDC’s Chemistry Lab for a more accurate analysis of UBC and ash composition.

The sampling system for the mass spectrometer was designed to provide chemical composition identification for three separate streams. A general process schematic is outlined in Figure 8. Sample probes are connected to the vitiated air line into the burner and windbox, the furnace exit, and the inlet line to the stack. The sample lines are heat traced to maintain the sample gas above the water dewpoint prior to entering the instrument. Since the pressure at each one of the sample points is different, the extraction pump will operate at various power levels to maintain constant flow. A primary speed loop is designed into the sampling system to provide sufficient gas flow to maintain a representative “real time” sample at the instrument inlet at all times. The vitiated air line is monitored to determine the oxygen concentration of the mixture of recycle flue gas and incoming air, the furnace exhaust is monitored to aid in determining carbon conversion efficiency, and the stack inlet gas composition is sampled to determine the air heater leak rates. The mass spectrometer is capable of monitoring for O2, N2, CO, CO2, Ar, NOx, and SOx simultaneously.

A full set of process and instrumentation drawings were created during this quarter, and are used to define the database of tags for the data archiving system. An Instrument Society of America (ISA) format was used.

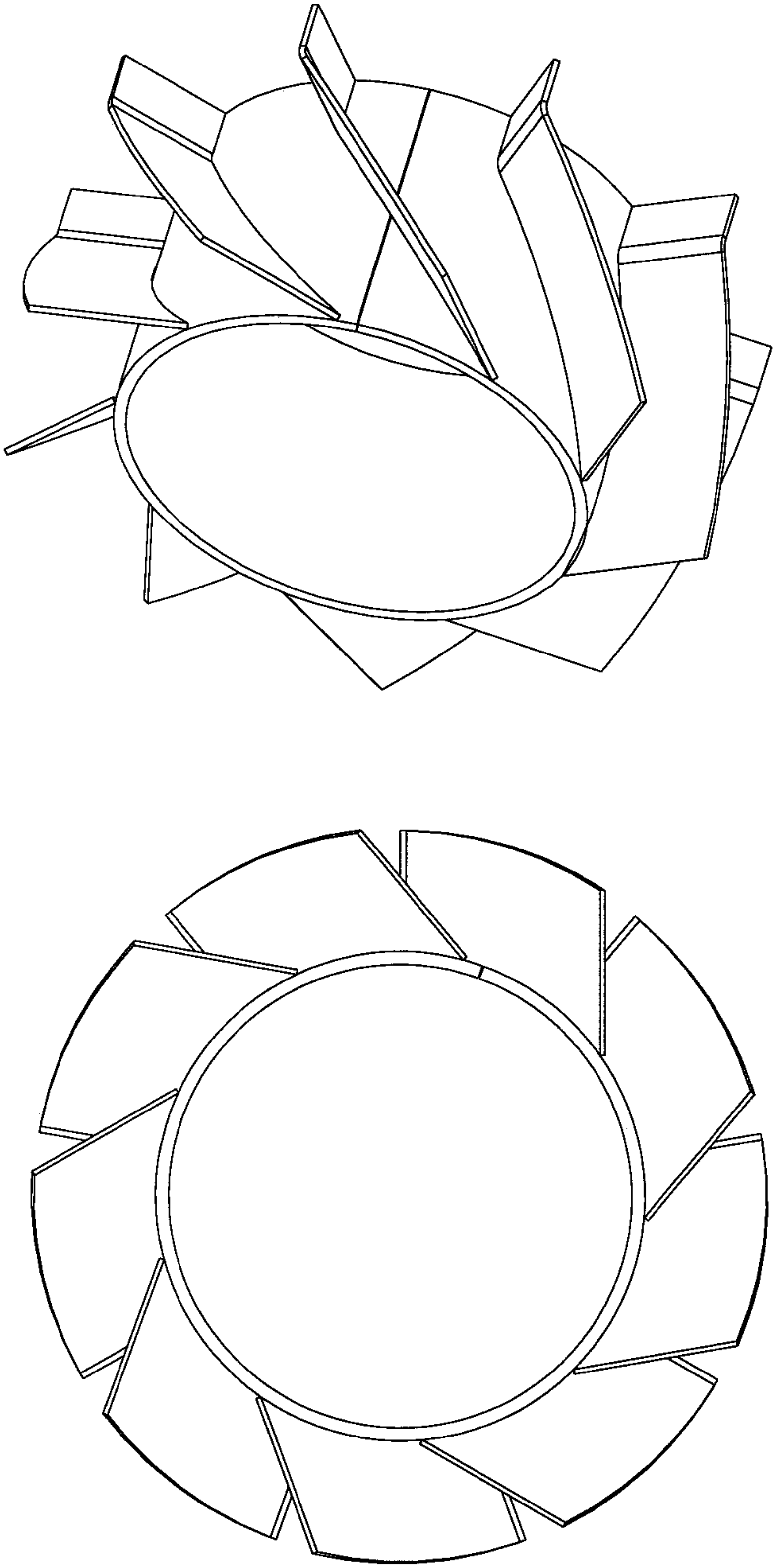

Figure 7  Tertiary Air Swirler

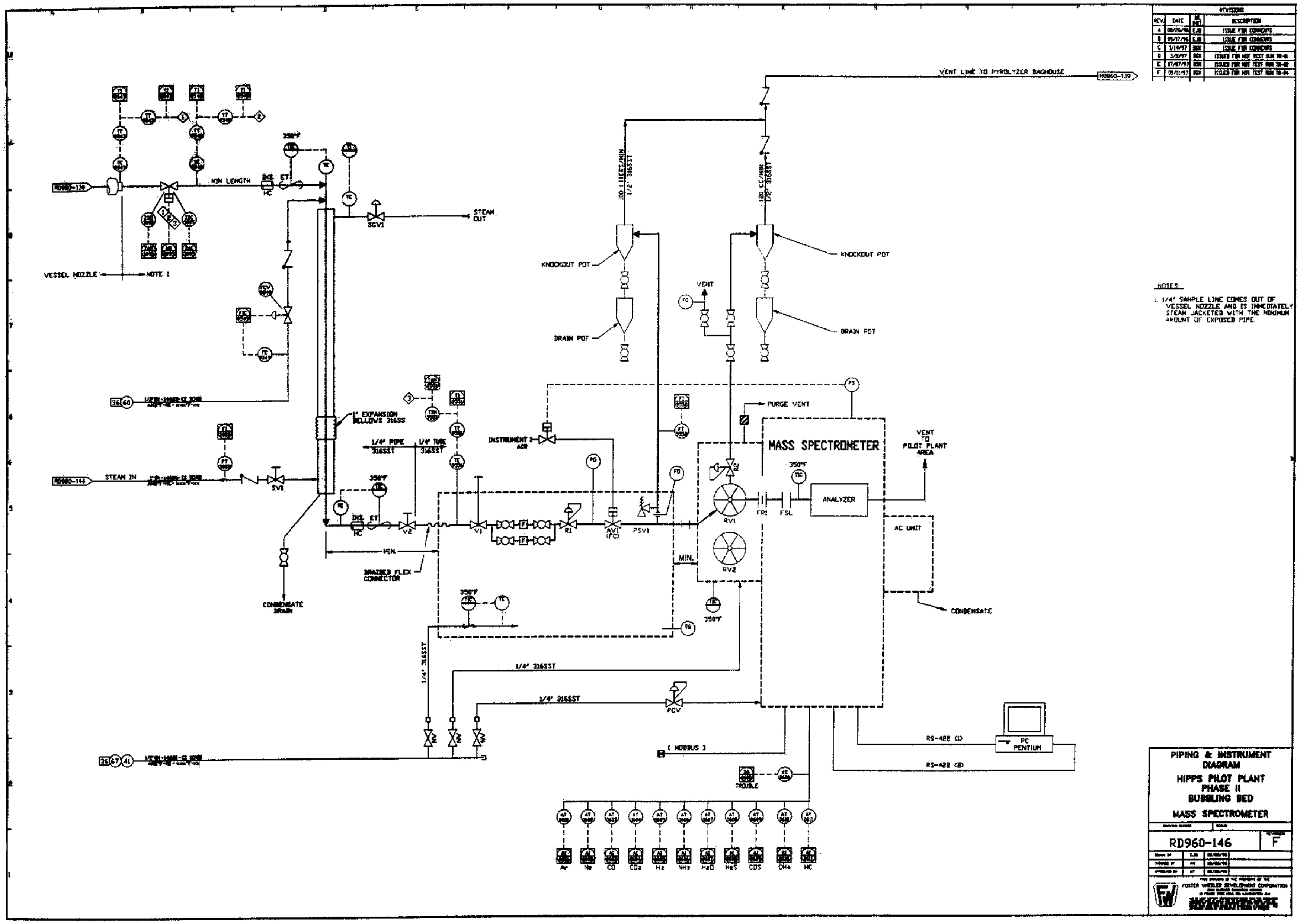

Figure 8  Mass Spectrometer Process Schematic

## Task 4 - Subsystem Test Unit Construction

### Subtask 4.2 - Char Combustion System Test Unit Construction

The construction effort continued at the CETF during this quarter. The following subsystems were installed:

1. Char Storage System (Figure 9 & 10)
2. Reheat Burner (Figure 11)
3. Flue Gas Recycle Piping (Figure 12)
4. Pulverized Coal Feed System (Figure 13)

The design and operation of these subsystems was described in the previous quarterly report.

**Figure 9  Char Storage Silo**

Figure 10  Char Feed Hopper Skirt

**Figure 11 Reheat Burner**

Figure 12  Flue Gas Recycle Piping

**Figure 13 Pulverized Coal Unloading System**

## Task 5 - Subsystem Test Unit Testing

### Subtask 5.1 – Char Combustor Test Plan

The fifteen variables, identified in Table 2 have been selected as the important parameters to be investigated during the HIPPS burner test program. Exploration of variables 1 to 8 (which include burner and furnace air flow rates, distribution, and swirl) will allow optimization of the burner and burner operation. are the burner variables. Studying variables 9 to 15 will investigate the boundaries of the “optimum” burner design by varying the HIPPS system parameters such as vitiated air temperature, char fineness, and char flow rate. The major test criteria are combustion stability (determined by both visual observation and flame scanner measurements taken throughout the furnace), NOx emission, and carbon conversion (analyzed by loss of ignition (LOI) tests of actual bottom ash and flyash samples). The “optimal” burner design will be selected as the combination of burner and furnace flow rates which produce the best combustion and flame stability and the lowest Nox generation.

# Table 2 - Major Variables and Parameters for HIPPS Testing at CETF

| **Variable Name** | **Units** | **Ranges/Levels** | | |
|---|---|---|---|---|
| | | **Low** | **Mid-point** | **High** |
| .. Vitiated Air $O_2$ | % wt. wet. | 13 | 15 | 18 |
| 2. Flue Gas Outlet $O_2$ | % vol. wet. | 2.0 | 3.5 | 4.5 |
| . Burner Air Flow Rate | Lbs/hr | 2,000 | 3,430 | max |
| . Tertiary Air Flow Rate | Lbs/hr | 4,400 | 6,600 | max |
| 5. OFA Flow Rate | % Total Flow | 0 | 10 | max |
| 6. Air Wall Flow Bias | % (top mid.,bot.) | 1st set<br>100, 100, 20 | 2nd set<br>50, 50, 30 | 3rd set<br>10, 30, 60 |
| 7. Support Fuel Flow Rate | lb/hr | 0 | 258 | 130 |
| 8. Straightening Vanes Location | Relative Position | In | Middle | Out |
| 9. Vitiated Air Temperature | °F | | 800 | maximum |
| 10. Char Fineness | % through 200 mesh | 70 | 80 | 90 |
| 11. Tertiary Air Swirl | Relative Position | No | Yes | |
| 12. Nozzle Length | | Short | Long | |
| 13. Sorbent Injection Flow Rate | lb/hr | 0 | 340 | maximum |
| 14. Char Flow Rate | Lbs/hr | 2,000 | 2,500 | 3,000 |
| 15. Char Fuel Type | Origin | Pyrolyzer | McLain | |

### Subtask 5.2 - Char Combustion System Test Unit Testing

The pulverized coal feed system is designed to provide support fuel for the burner. Coal is metered through a screw feeder into a rotary valve. The rotary valve provides a pressure boundary between the pneumatic transport line and the coal supersack, while the screw feeder speed is varied to control coal flow. The screw feeder is not equipped with a load cell, and therefore only the speed, not the coal feedrate, is output to the DCS. The screw feeder was calibrated during this quarter, and the relationship between speed and flow is defined in Table 3.

**Table 3. Coal Screw Feeder Calibration**

| SCREW RPM | LBS COLLECTED | TIME (MIN) | LB/HR |
|---|---|---|---|
| 4.5 | 9.8 | 20.0 | 29.4 |
| 14.6 | 18.6 | 12.0 | 93.0 |
| 23.0 | 21.6 | 9.0 | 144.0 |
| 34.6 | 21.8 | 6.0 | 218.0 |
| 44.3 | 19.2 | 4.0 | 288.0 |
| 56.1 | 18.2 | 3.0 | 364.0 |
| 62.6 | 20.2 | 3.0 | 404.0 |
| 6.1 | 10.4 | 15.0 | 41.6 |
| 19.2 | 20.2 | 10.0 | 121.2 |
| 29.4 | 23.4 | 7.5 | 187.2 |
| 39.6 | 17.0 | 4.0 | 255.0 |
| 48.6 | 15.8 | 3.0 | 316.0 |
| 59.7 | 19.6 | 3.0 | 392.0 |