ENGINEERING DEVELOPMENT OF COAL-FIRED HIGH-PERFORMANCE POWER SYSTEMS

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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.

This report addresses the areas of technical progress for this quarter. In order to prepare the CETF for the HIPPS char combustion test program, the following three subsystems were designed during this quarter:

1. Flue Gas Recycle System
2. Pulverized Coal Feed System
3. Limestone Feed System

The flue gas recycle system is added to simulate the performance of a commercial char burner fired with gas turbine exhaust. Since synthetically made char will be used for the tests at the CETF, the limestone injection system was added to produce a char more representative of that from an actual pyrolyzer. The pulverized coal system is included to provide a supplemental support fuel if a stable flame can not be maintained with char firing only.

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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^oC (1700^oF) 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 design phase of the CETF continued during this quarter. Figures 1, 2, and 3 depict three alternative arrangements for the HIPPS process. In each configuration, the turbine exhaust stream provides the oxidant for the combustion of char in either a HITAF for a “greenfields” plant, or in an existing boiler in the case of the repowering option. Since the typical gas turbine operates with high excess air, sufficient oxygen remains in the exhaust stream to support the combustion of char. The gas turbine exhaust stream is commonly referred to as “vitiated air” with an oxygen volume concentration of approximately 15%. At the CETF, simulation of the gas turbine exhaust stream will be accomplished by recycling the flue gas from the backend of the existing boiler.

The experimental tests at FWDC’s pilot plant in Livingston, NJ, were performed to gain a better understanding of pyrolyzer behavior. All of the partial gasifier test runs were made with concurrent limestone and coal feed. Since the pyrolyzer operates as a jetting bubbling bed, it was felt that injection of limestone was necessary to prevent agglomeration of the highly caking Pittsburgh #8 coal. In order to simulate the presence of calcined lime with synthetic char for the CETF test campaign, limestone will be mixed with the char. The char and the limestone will be pneumatically conveyed through two separate transport lines, ultimately mixing together in the char burner.

The char, to be fired in the burner, is synthetically produced by McClain Corp. by heat-treating Pittsburgh #8 coal. As a result of this process, virtually all of the volatile matter is liberated from the coal. Although the resulting char is highly porous, it is more difficult to burn because of its lack of volatile matter. The pulverized coal system was incorporated into the test facility to provide a source of supplemental fuel if combustion of the char proves to be too unstable. The pulverized coal is pneumatically conveyed through the char burner and discharges directly into the boiler.

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^{o}C (1400^{o}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^{o}C (2350^{o}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.

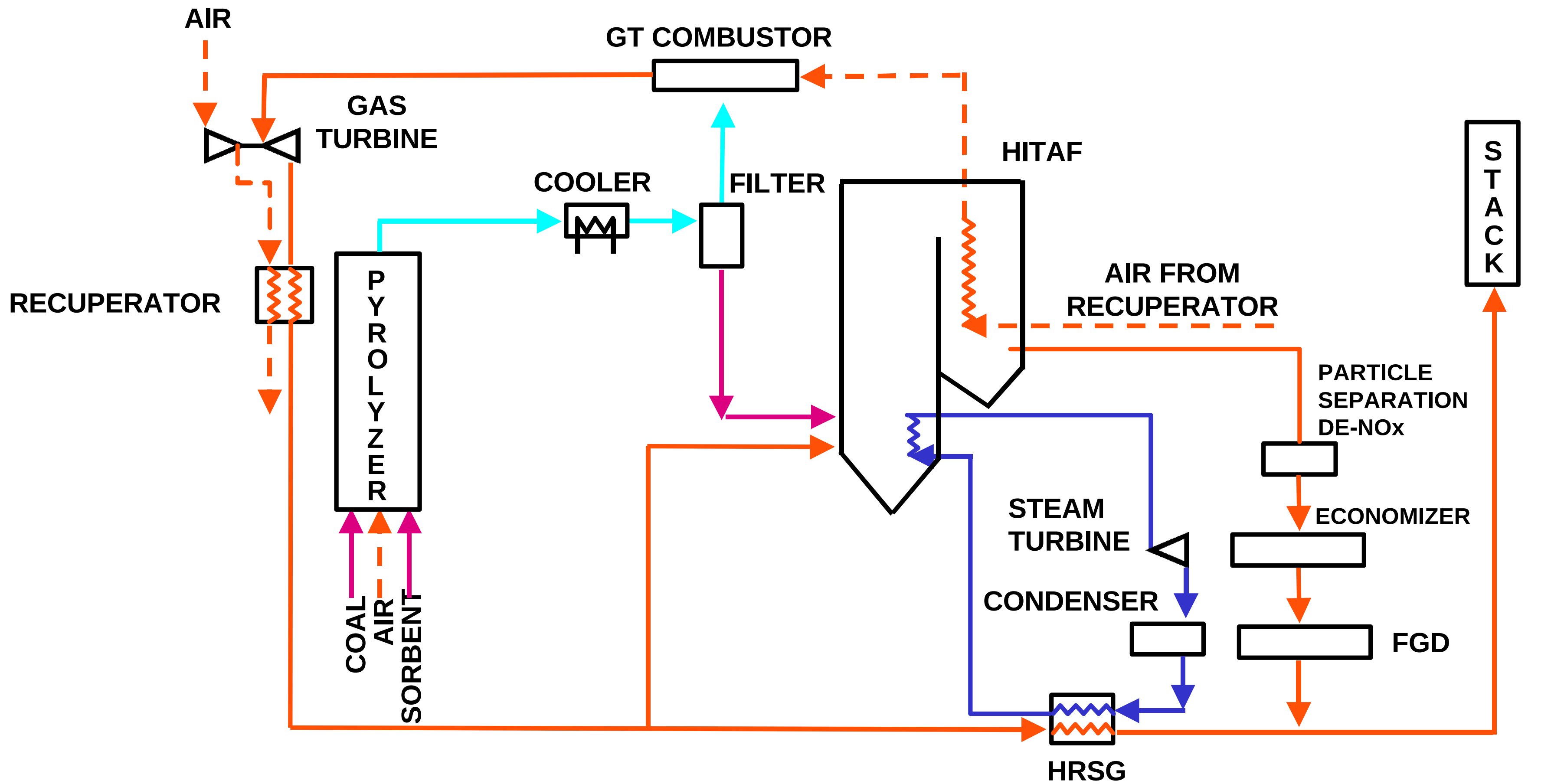

Figure 1 All Coal Fired HIPPS

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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.

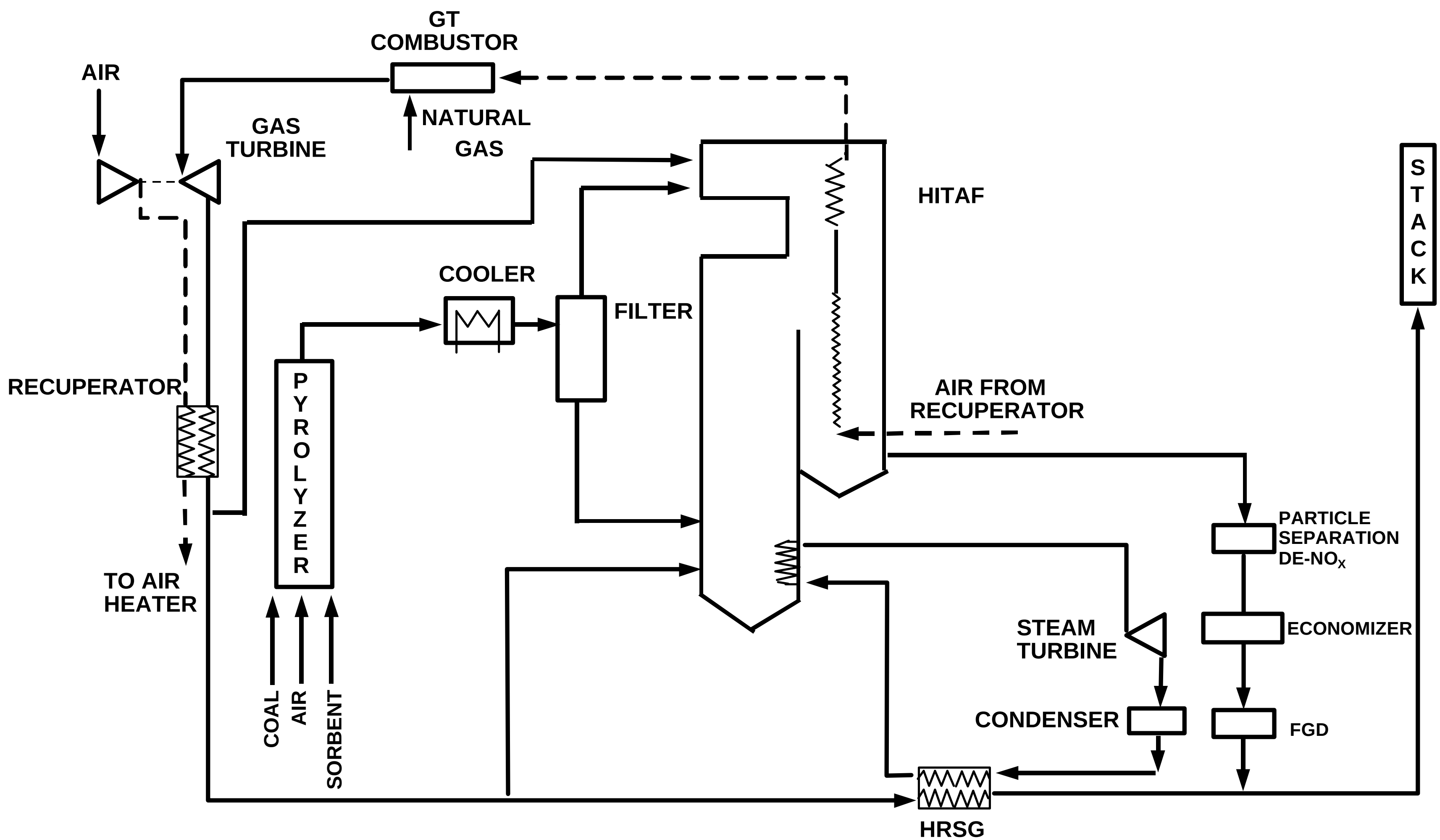

Figure 2 35-Percent Natural Gas HIPPS

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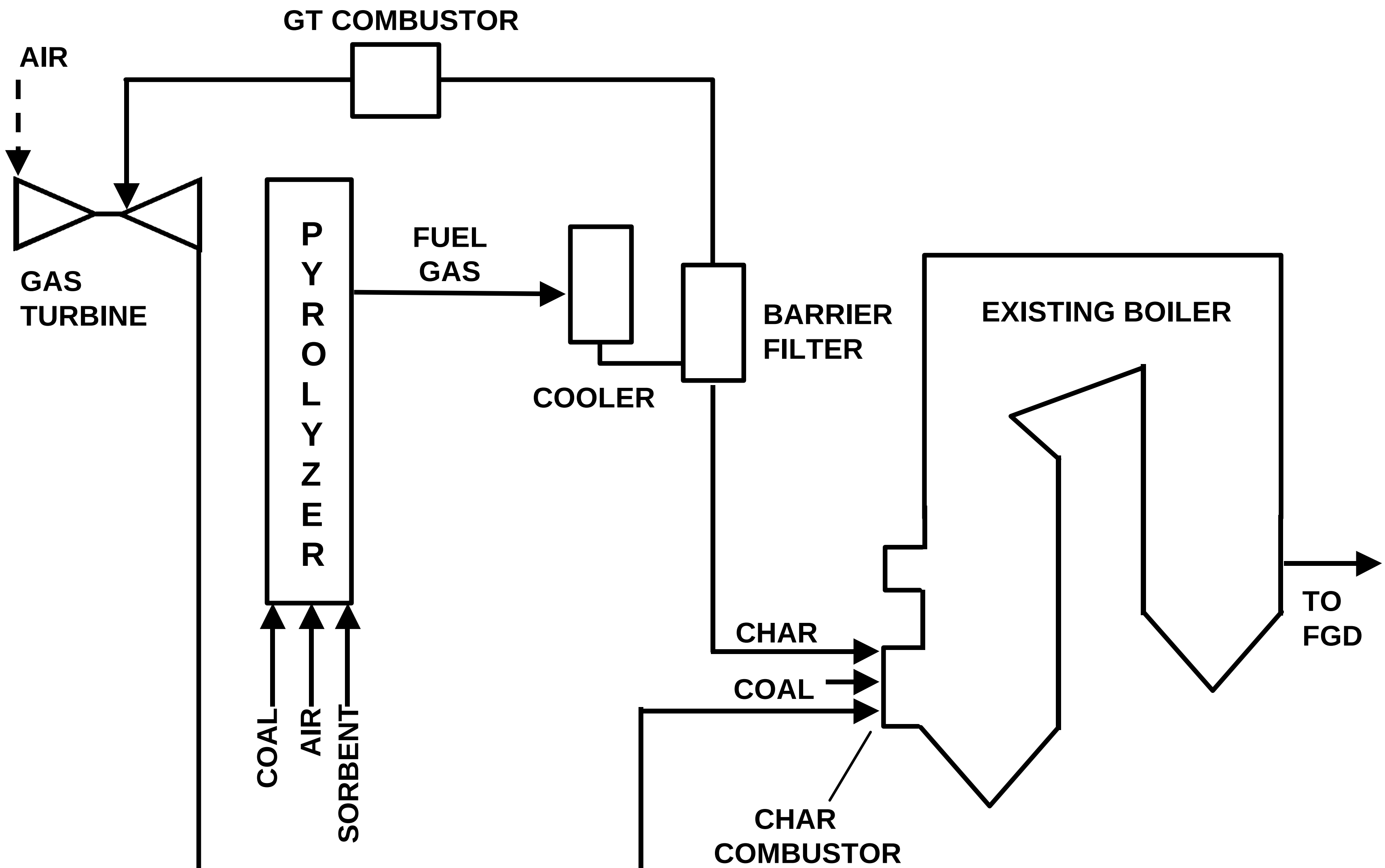


Figure 3 Simplified HIPPS Repowering Process Flow Diagram

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 will be conducted at the Two-Phase Cold Flow Test Facility in Livingston.

Fabrication drawings of the two-phase fuel injector, tertiary air tube, and tertiary air swirler were made and sent to fabricators for quotes and eventual construction. Carbon steel material was chosen for the model because of the need to pass relatively hot air through the injector. (Plastic was not chosen because the temperature of the hot air was above the plastic operating temperature.) The following model fabrication drawings are attached to this report:

1) DWG 972-118 "HIPPS Burner Design for Two-Phase Modeling" (Figure 4.)
2) DWG 974-120 "HIPPS Burner Tertiary Air Tube for Two-Phase Modeling" (Figure 5.)
3) DWG PE-975-66 "Fabricated Outer Swirler for 7.35" Diameter Throat" (Figure 6.)

Test flow rates will be based on achieving momentum and velocity similarities between the prototype field and model conditions. The major parameters that will be varied during the two-phase testing include primary air flow, primary air temperature, tertiary air flow, pumice flow rate, burner model vane position (extended or retracted), and placement of tertiary air swirler. Primary air temperatures and flows will be varied in order to model the changes in the inlet and outlet burner temperatures due to mixing of the hot primary air and the cooler char that occur in the actual unit. Insertion or retraction of the burner model vane will simulate the placement of the prototype vane design which will be tested at CETF. Solids flow and primary air flows will also be varied for low load conditions. It is currently proposed that the char and sorbent will be modeled as pumice entering the burner as one stream. A preliminary test matrix is presented in Table 1.

Measurements will be taken for the determination of model pressure drop, mixing effectiveness of the primary air and pumice within the burner model, and overall system mass and energy balance. In addition, burner model exit velocity distributions will be recorded by observing the orientation of streamers located near the near outlet burner region.

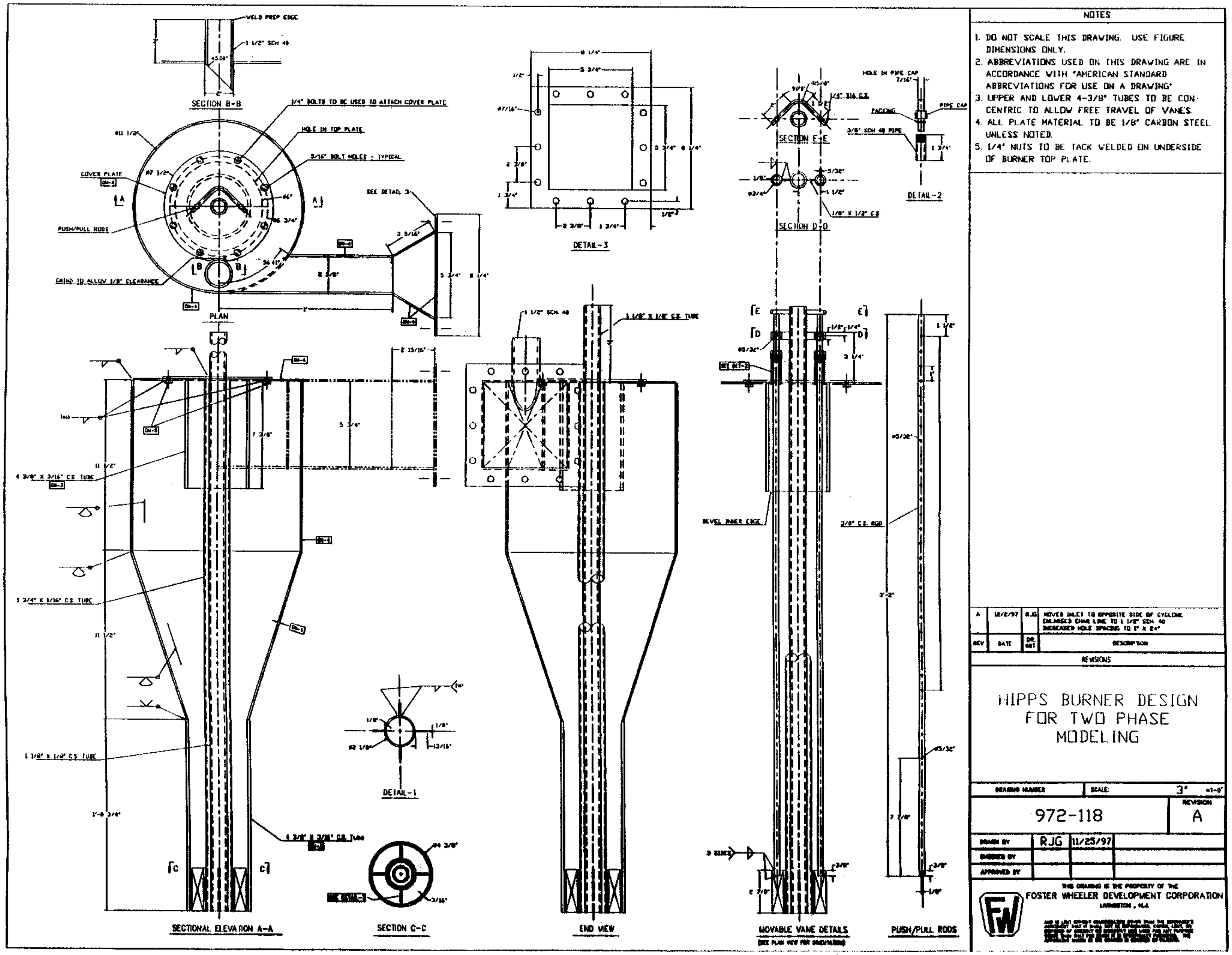


Figure 4 HIPPS Burner Design for Two-Phase Modeling

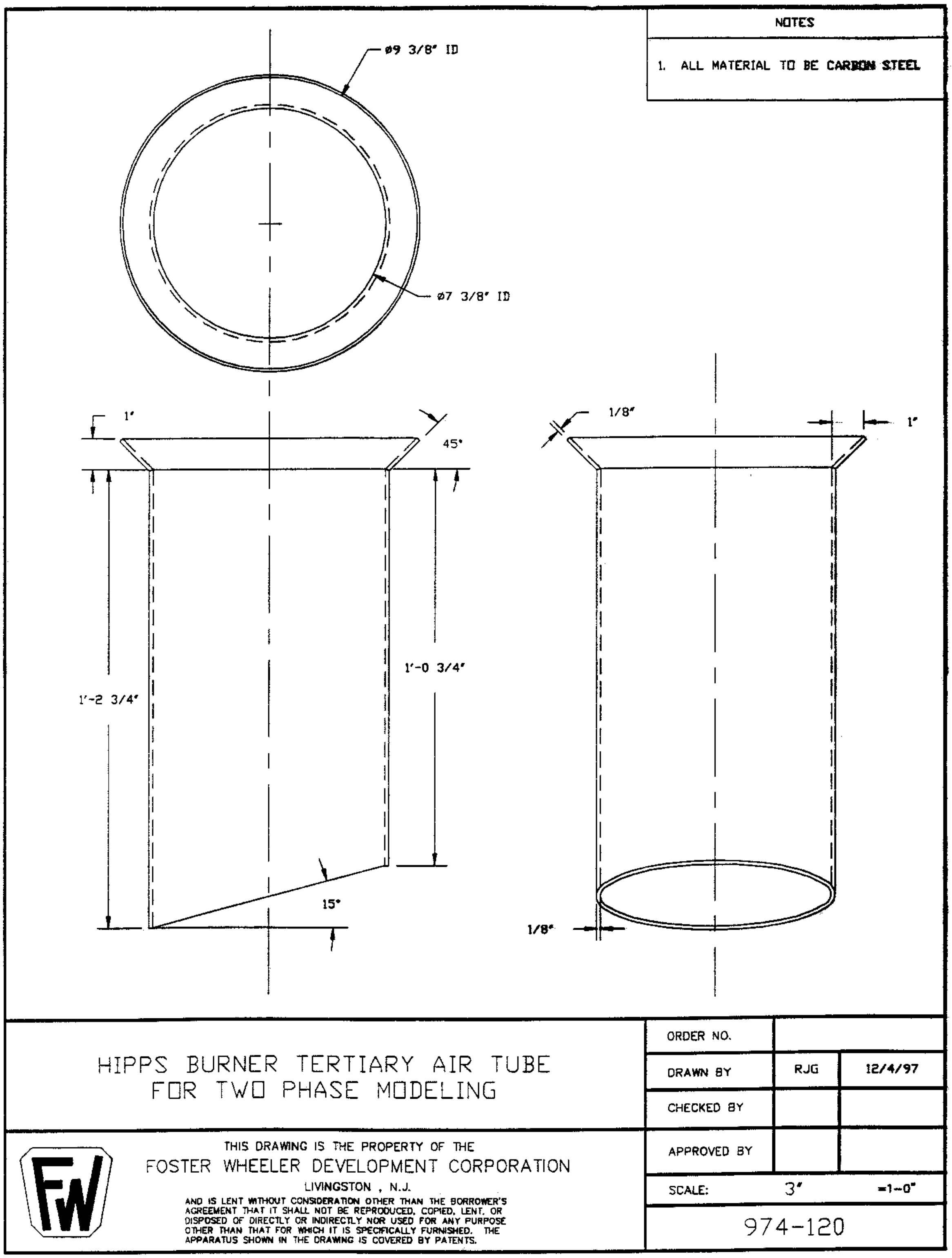


Figure 5 HIPPS Burner Tertiary Air Tube for Two-Phase Modeling

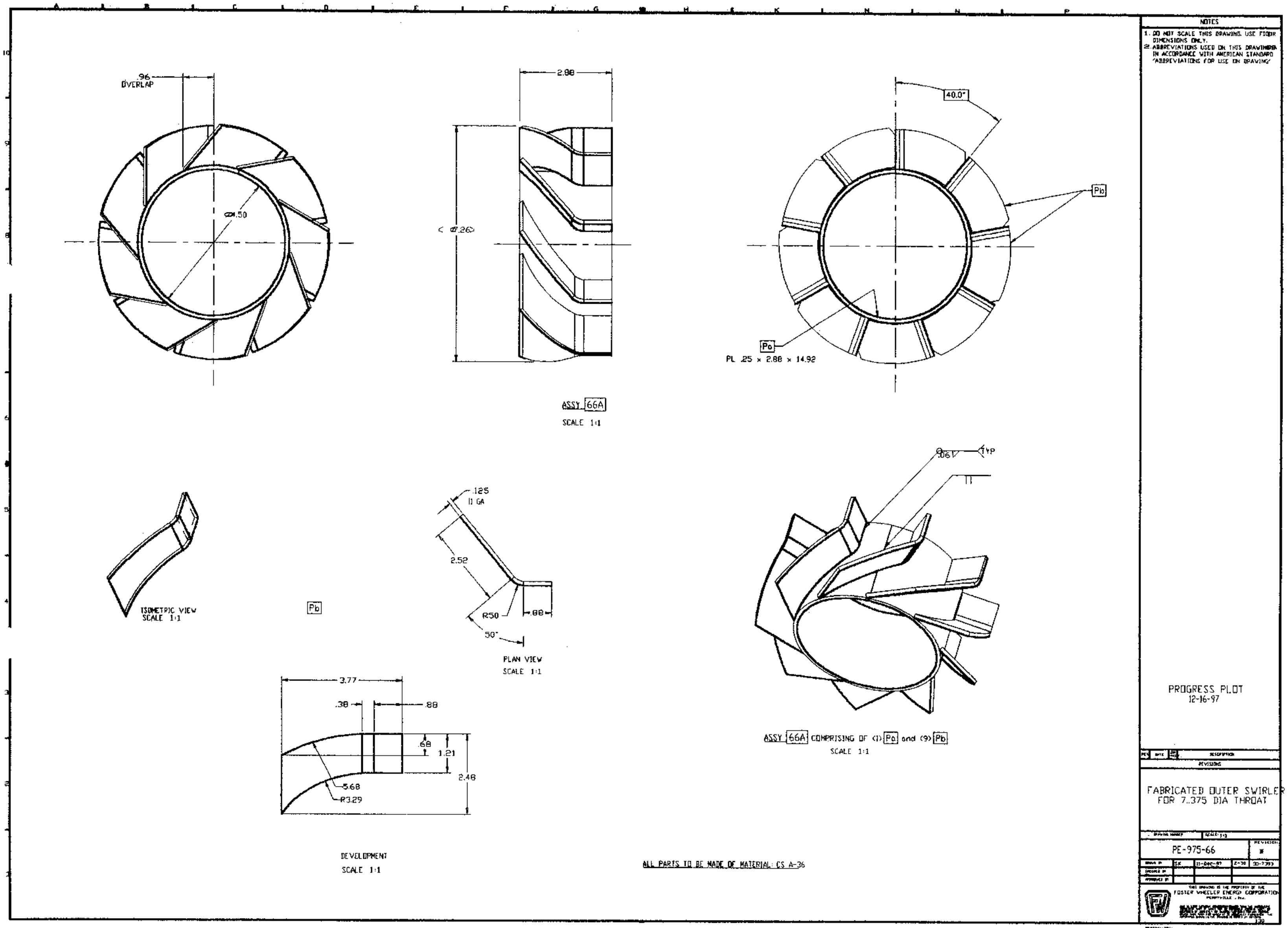


Figure 6 "Fabricated Outer Swirler for 7.35" Diameter Throat"

Table 1 Preliminary Two-Phase HIPPS Model Test Matrix

	Test Designation		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Test Parameter	Units																			
1	Burner Air (tangential) flow	lbm/hr	1100	1000	1575	1200	1190	1075	1190	1100	1000	1575	1200	1190	1075	660	660	820	820	1210	1210
2	Burner Air Temperature	deg F	150	150	150	150	60	60	60	150	150	150	150	60	60	150	150	150	150	150	150
3	Burner Air Swirl	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	No	Yes	No	Yes	No
4	Tertiary Air Flow	lbm/hr	2620	2620	4075	4075	2620	2620	2620	2620	2620	4075	4075	2620	2620	1430	1430	1780	1780	2625	2625
5	Tertiary Air Swirl	-	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	Yes	No
6	Solids Flow Rate	lbm/hr	1020	930	1465	1115	1100	1000	1100	1020	930	1465	1115	1100	1000	610	610	760	760	1120	1120
	Similitude @ Burner inlet		D	-	V	-	D	-	D	D	-	V	-	D	-	-	-	-	-	-	-
	Similitude @ Burner outlet		-	D	-	V	-	D	-	-	D	-	V	-	D	-	-	-	-	-	-

Notes:

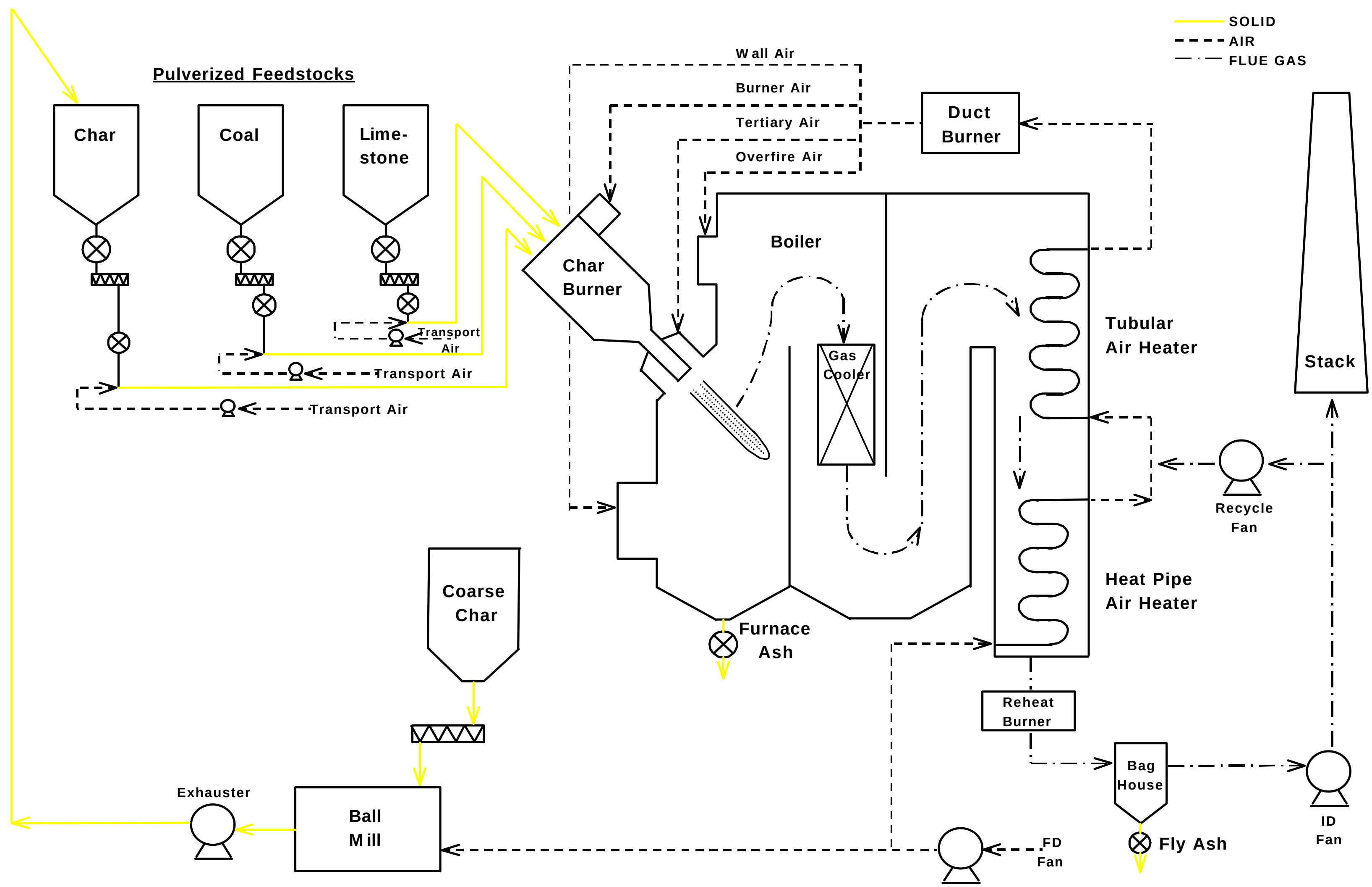
1) Flow/process conditions to be recorded before introduction of solids
2) Burner air swirl condition is produced by retracting straightening vanes. No swirl condition is achieved by inserting straightening vanes.
3) Tertiary air swirl condition is produced by inserting the fixed swirler. No swirl condition is achieved by removing the fixed swirler.
4) Notation: D: Dynamic pressure V: Velocity
5) Test designation does not represent order of testing.
6) Flow rates are calculated based on burner air temperature. Values will be dependent on actual operating temperatures and fan operation.
7) Qualitative observations of flow distribution to be made in the near outlet burner region via tuft screen.
8) Qualitative observations to be made of the solid particle trajectories inside injector via wear patterns of three paint layers.

Task 3 - Subsystem Test Unit Design

Subtask 3.2 - Char Combustion Subsystem Design

A schematic of the Combustion and Environmental Test Facility (CETF) in Dansville, N.Y. is presented in Figure 7. The initial combustion tests will be performed in an arch-fired configuration, as opposed to the more common wall fired system. In the arch arrangement, the burner fires downward into the boiler rather than firing horizontally through the sidewall. Because of the longer particle trajectory, the arch design provides for increased fuel residence time in the boiler, and as a result, tends to enhance overall carbon conversion efficiency. The arch arrangement is typically used for "hard to burn" fuels such as anthracite coals. Since the HIPPS char lacks the volatile matter to promote robust combustion, the CETF was designed for arch firing as a means to reduce unburned carbon. If the arch-fired tests demonstrate acceptable combustion performance coupled with low NOx generation, the overall HIPPS test program will be extended to include performance validation of a wall-fired burner. It should be noted that the wall-fired boiler is less expensive to build than the arch-fired unit, and is therefore preferable from a commercial marketing standpoint.

The design of the pulverized coal unloading station is shown in Figure 8. This system is used to feed support fuel, pulverized Pittsburgh #8 coal, if necessary to support stable combustion of the char. The pulverized coal feed system is designed to provide a flow approximately 10 percent that of the maximum char flow to the burner. Pulverized coal is manually loaded in one ton supersacks onto a shallow hopper within the unloading station. The discharge chute on the supersack is pulled down through the 12" opening in the bottom of the hopper. When the 12" iris valve is closed manually, the operator is then able to cut the internal waterproof seal within the bag through the access door. The contents of the supersack first flow into a discharge hopper (8 cu.ft.), and then into the flights of a 2" screw feeder. The speed of the screw feeder is controlled within the DCS, and is linearly proportional to the coal flowrate. The screw feeder discharges into a smaller hopper (see Figure 9.), and then into a rotary valve before entering the pneumatic transport line. The purpose of the screw feeder is to control the coal flow, while the rotary valve simply serves as a pressure isolation boundary between the supersack and the transport line. A vent sock is outfitted on the lower hopper to relieve the pressurized air pockets as the rotary valve turns. A control valve on the vent line modulates the velocity in the transport line. If more air is required for two-phase flow, the vent valve will be closed – if less air is required, the vent valve will be opened. The pressure drop within the line is expected to be approximately 1.5 psi. The two-phase flow pressure drop calculations are shown in Table 2., and are based on correlations from the Particulate Solids Research Institute (PSRI).



Combustion & Environmental Test Facility (CETF) HIPPS Burner Program

Figure 7

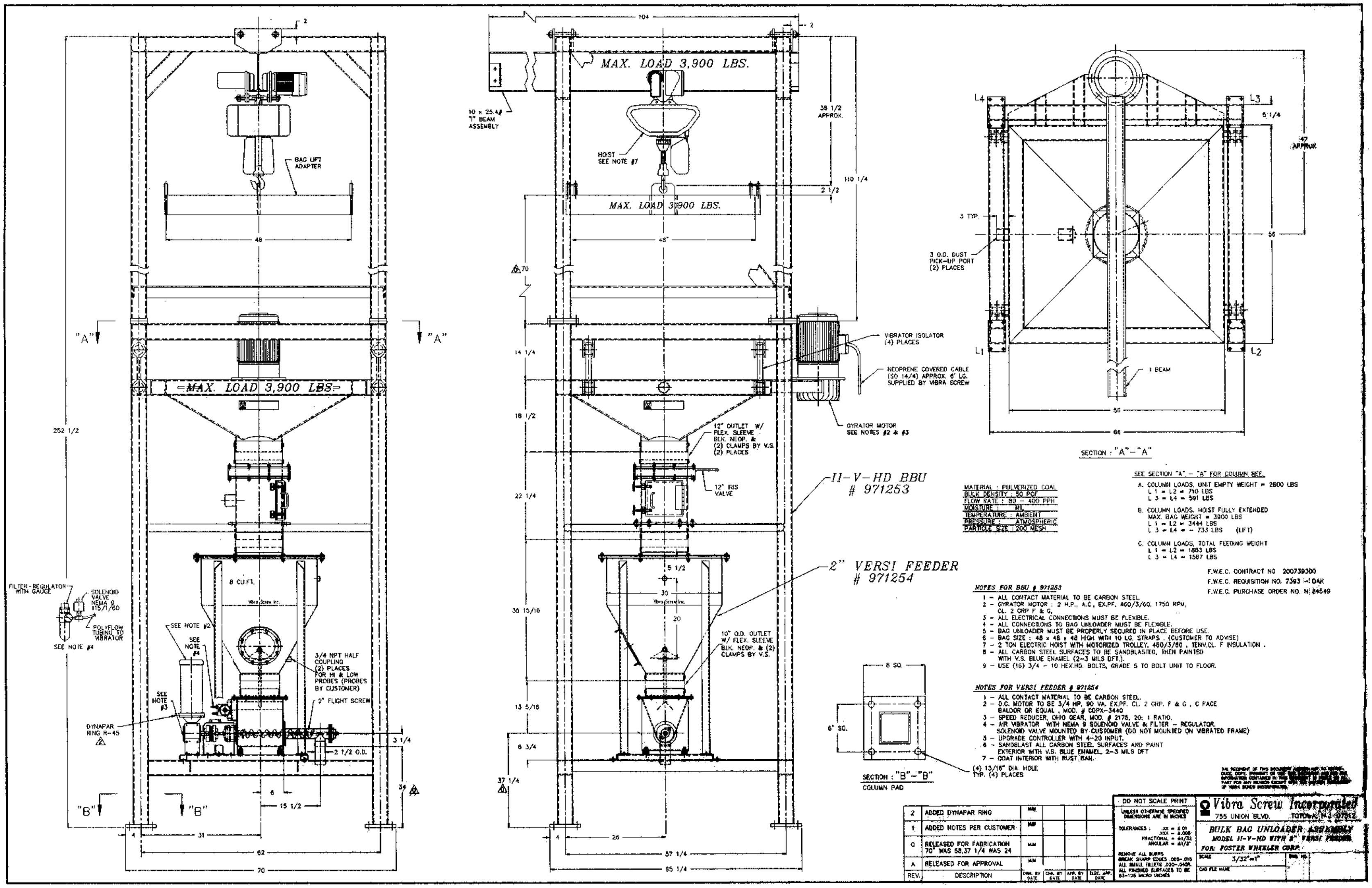


Figure 8 Pulverized Coal Bulk Bag Unloading System

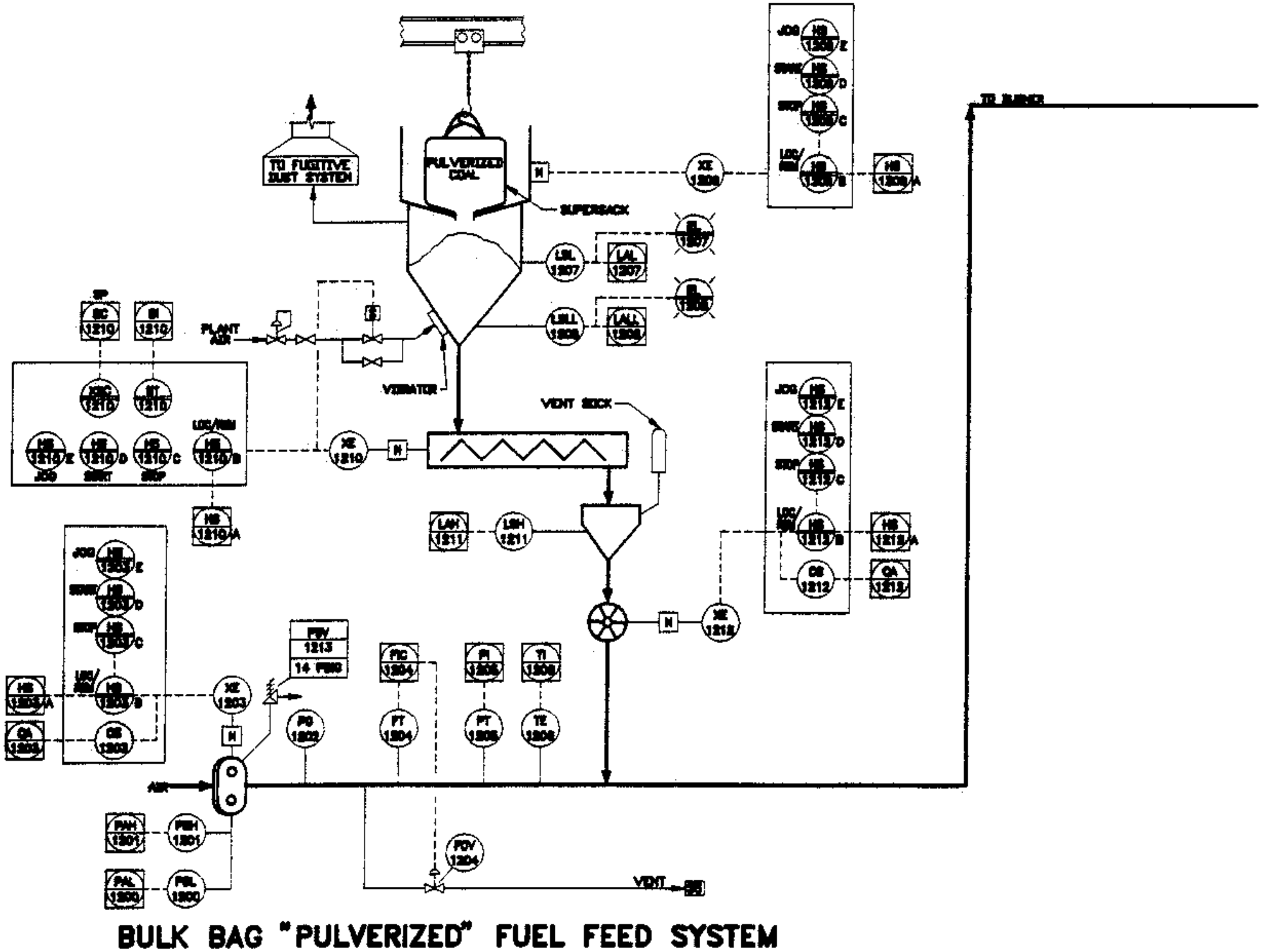


Figure 9 Pulverized Coal Process Flow Diagram

Table 2 Coal and Limestone Transport Line Pressure Drop

CETF-HIPPS Transport Systems
Pressure Drop in Piping with Solids Flow

	Char Transport 2" Sch. 40				*Coal Transport* 1 1/2" Sch. 40				*Limestone Transport* 1 1/2" Sch. 40			
	vertical		horizontal		vertical		horizontal		vertical		horizontal	
D, pipe inner diameter, in	2.067	in	2.067	in	1.61	in	1.61	in	1.61	in	1.61	in
L, length of pipe, ft	30	ft	40	ft	31	ft	107	ft	37	ft	22	ft
f, fanning friction factor	0.022		0.022		0.024		0.024		0.024		0.024	
ms, mass flow of solids, lb/hr	2500	lb/hr	2500	lb/hr	258	lb/hr	258	lb/hr	340	lb/hr	340	lb/hr
Dp, particle size, microns	50	microns	50	microns	50	microns	50	microns	60	microns	60	microns
ρs, particle density, lb/ft³	40	lb/ft³	40	lb/ft³	80	lb/ft³	80	lb/ft³	30	lb/ft³	30	lb/ft³
Qg, gas flow rate, ACFM	110	ACFM	110	ACFM	50	ACFM	50	ACFM	50	ACFM	50	ACFM
Tg, average gas temperature, °F	100	°F	100	°F	100	°F	100	°F	100	°F	100	°F
Pg, average gas pressure, lb/in²	17.8	lb/in²	17.8	lb/in²	15.45	lb/in²	15.45	lb/in²	15.2	lb/in²	15.2	lb/in²
Elbow r/D ratio, LR	12		12		12		12		12		12	
Elbow r/D ratio, SR	6		6		6		6		6		6	
mg, gas mass flow, lb/hr	**566.32**	lb/hr	**566.32**	lb/hr	**223.43**	lb/hr	**223.43**	lb/hr	**219.82**	lb/hr	**219.82**	lb/hr
Solids/Gas Ratio	**4.41**		**4.41**		**1.15**		**1.15**		**1.55**		**1.55**	
Dp, particle size, ft	1.64E-04	ft	1.64E-04	ft	1.64E-04	ft	1.64E-04	ft	1.97E-04	ft	1.97E-04	ft
Gs, solids mass flux, lb/s-ft²	29.801	lb/s-ft²	29.801	lb/s-ft²	5.069	lb/s-ft²	5.069	lb/s-ft²	6.680	lb/s-ft²	6.680	lb/s-ft²
D, pipe diameter, ft	1.72E-01	ft	1.72E-01	ft	1.34E-01	ft	1.34E-01	ft	1.34E-01	ft	1.34E-01	ft
A, pipe cross section area, ft²	2.33E-02	ft²	2.33E-02	ft²	1.41E-02	ft²	1.41E-02	ft²	1.41E-02	ft²	1.41E-02	ft²
ρg, gas density, lb/ft³	8.58E-02	lb/ft³	8.58E-02	lb/ft³	7.45E-02	lb/ft³	7.45E-02	lb/ft³	7.33E-02	lb/ft³	7.33E-02	lb/ft³
μg, gas viscosity, lb*s/ft²	1.26E-05	lb/ft*s	1.26E-05	lb/ft*s	1.26E-05	lb/ft*s	1.26E-05	lb/ft*s	1.26E-05	lb/ft*s	1.26E-05	lb/ft*s
ρmix, mixture density, lb/ft³	4.65E-01	lb/ft³	4.65E-01	lb/ft³	1.60E-01	lb/ft³	1.60E-01	lb/ft³	1.87E-01	lb/ft³	1.87E-01	lb/ft³
Ug, average gas velocity, ft/sec	**78.674**	ft/sec	**78.674**	ft/sec	**58.944**	ft/sec	**58.944**	ft/sec	**58.944**	ft/sec	**58.944**	ft/sec
Usalt, saltation velocity, ft/sec	**48.726**	ft/sec	**48.726**	ft/sec	**30.391**	ft/sec	**30.391**	ft/sec	**32.511**	ft/sec	**32.511**	ft/sec
Re, pipe gas reynolds number	9.22E+04		9.22E+04		4.67E+04		4.67E+04		4.60E+04		4.60E+04	
epsilon/D	8.71E-04		8.71E-04		1.12E-03		1.12E-03		1.12E-03		1.12E-03	
Nhg, gas velocity heads lost, LR	0.272		0.272		0.272		0.272		0.272		0.272	
Nhs, solids velocity heads lost, LR	11.356		11.356		2.759		2.759		3.926		3.926	
Nhg, gas velocity heads lost, SR	0.275		0.275		0.275		0.275		0.275		0.275	
Nhs, solids velocity heads lost, SR	13.044		13.044		3.170		3.170		4.509		4.509	
w, term used to calculate Vs	1.43E+00		1.43E+00		1.98E+00		1.98E+00		1.44E+00		1.44E+00	
delta, term used to calculate Vs	1.03E-04		1.03E-04		8.54E-05		8.54E-05		1.19E-04		1.19E-04	
Vs, solids terminal velocity, ft/sec	0.144	ft/sec	0.144	ft/sec	0.283	ft/sec	0.283	ft/sec	0.155	ft/sec	0.155	ft/sec
pressure drop due to fluid acceleration, " H2O	1.59	" H2O	1.59	" H2O	0.77	" H2O	0.77	" H2O	0.76	" H2O	0.76	" H2O
pressure drop due to solids acceleration, " H2O	13.98	" H2O	13.98	" H2O	1.78	" H2O	1.78	" H2O	2.35	" H2O	2.35	" H2O
fluid-pipe friction pressure drop, " H2O	6.08	" H2O	8.10	" H2O	4.28	" H2O	14.79	" H2O	5.03	" H2O	2.99	" H2O
solids-pipe friction pressure drop, " H2O	4.16	" H2O	5.55	" H2O	0.83	" H2O	2.86	" H2O	1.30	" H2O	0.77	" H2O
pressure drop due to static head of solids, (use only when flowing UP in pipe), " H2O	2.19	" H2O	2.92	" H2O	0.51	" H2O	1.78	" H2O	0.81	" H2O	0.48	" H2O
pressure drop due to static head of gas, (use only at HIGH pressure), " H2O	0.49	" H2O	0.66	" H2O	0.44	" H2O	1.53	" H2O	0.52	" H2O	0.31	" H2O
pressure drop in one Long Radius Elbow, " H2O	18.44	" H2O	18.44	" H2O	2.34	" H2O	2.34	" H2O	3.19	" H2O	3.19	" H2O
pressure drop in one Short Radius Elbow, " H2O	21.12	" H2O	21.12	" H2O	2.66	" H2O	2.66	" H2O	3.64	" H2O	3.64	" H2O
Total System Pressure Drop			**173.2 " H2O** **6.3 psi**	2 SR 4 LR			**40.1 " H2O** **1.4 psi**	0 SR 5 LR			**27.1 " H2O** **1.0 psi**	1 SR 2 LR
HP required (@ 75% efficiency)			**4.0 hp**				**0.4 hp**				**0.3 hp**	
Electricity required (@ 95% efficiency)			**3.1 kW**				**0.3 kW**				**0.2 kW**	

A schematic of the pulverized limestone system is illustrated in Figure 10. This system is equipped with a large outdoor silo for the bulk storage of pulverized limestone. A 3" pneumatic transport line is used for connecting directly with a tanker truck to unload the pulverized limestone. An indoor limestone bin is used for the delivery of material to the burner. The limestone feed system operates the same way as the pulverized coal system, with the exception that the screw feeder is replaced with a weighbelt feeder. The weighbelt feeder outputs a true solids flowrate signal rather than a simple speed signal, because both a tachometer and a weigh cell are incorporated into the controls.

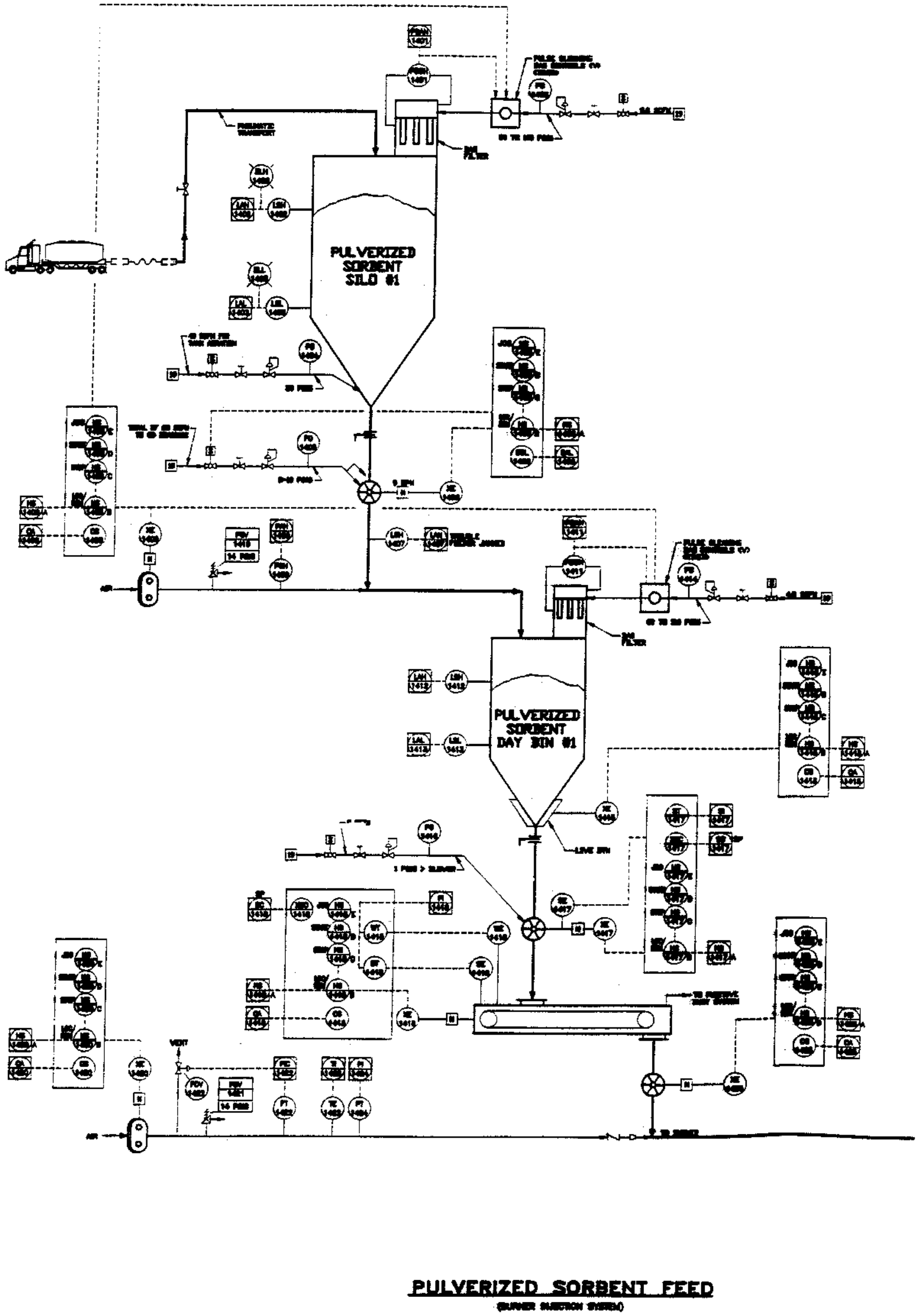


Figure 10 Pulverized Limestone Process Flow Diagram

As identified in Figure 1, the gas turbine exhaust stream is directed into the burner, and provides the total oxygen requirement for complete char combustion. However, since the CETF is not outfitted with a gas turbine, a simulation of this stream is achieved by recycling the flue gas and mixing it with fresh incoming air. The flue gas exhaust stream at the CETF has a typical oxygen concentration of approximately 4 percent by volume, and can be mixed with fresh air (21 percent O2 by volume) to attain burner oxygen concentrations of 15 percent by volume (typical of most gas turbines). Figures 11 and 12 illustrate the flue gas recycle piping layout. The intake for the flue gas recycle fan is connected to the ID fan outlet duct. Under normal operating conditions the ID fan outlet pressure is approximately 4 inches w.c. At the discharge of the recycle fan, the 16" piping splits into two separate lines. One of the lines is connected with the existing air heater and mixes with the incoming secondary air. A static mixer was installed in the air heater to prevent flow stratification, and produce a uniform flow both in terms of mass distribution and chemical composition. An in situ oxygen sensor is installed in the "vitiated air" line to control the proportions of recycle flue gas and air to maintain desired levels into the burner. The additional flue gas recircualtion line is connected to the ball mill. Flexibility was built into the system so that the classifier could be operated either on air or flue gas.

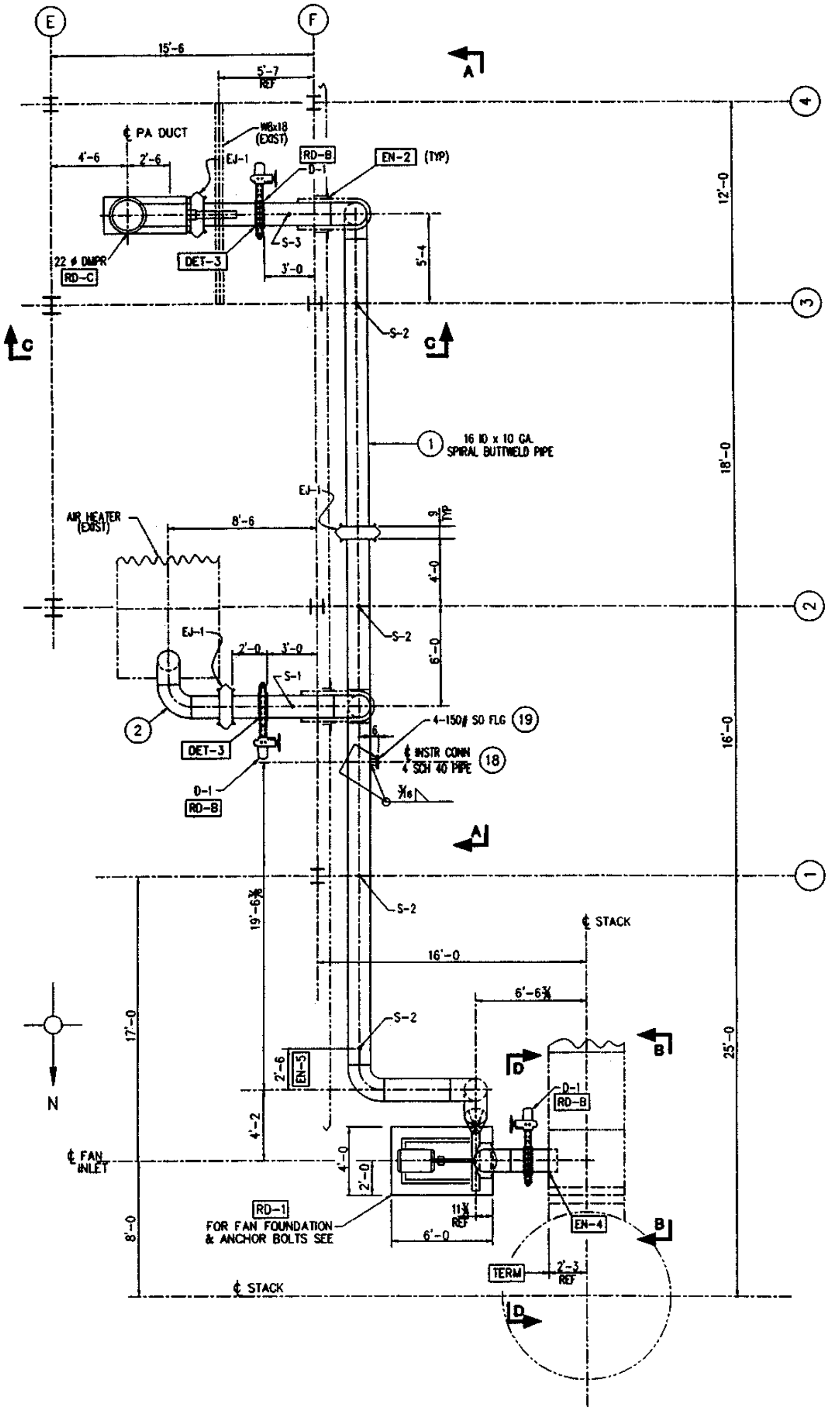


Figure 11 Flue Gas Recycle Piping (Plan View)

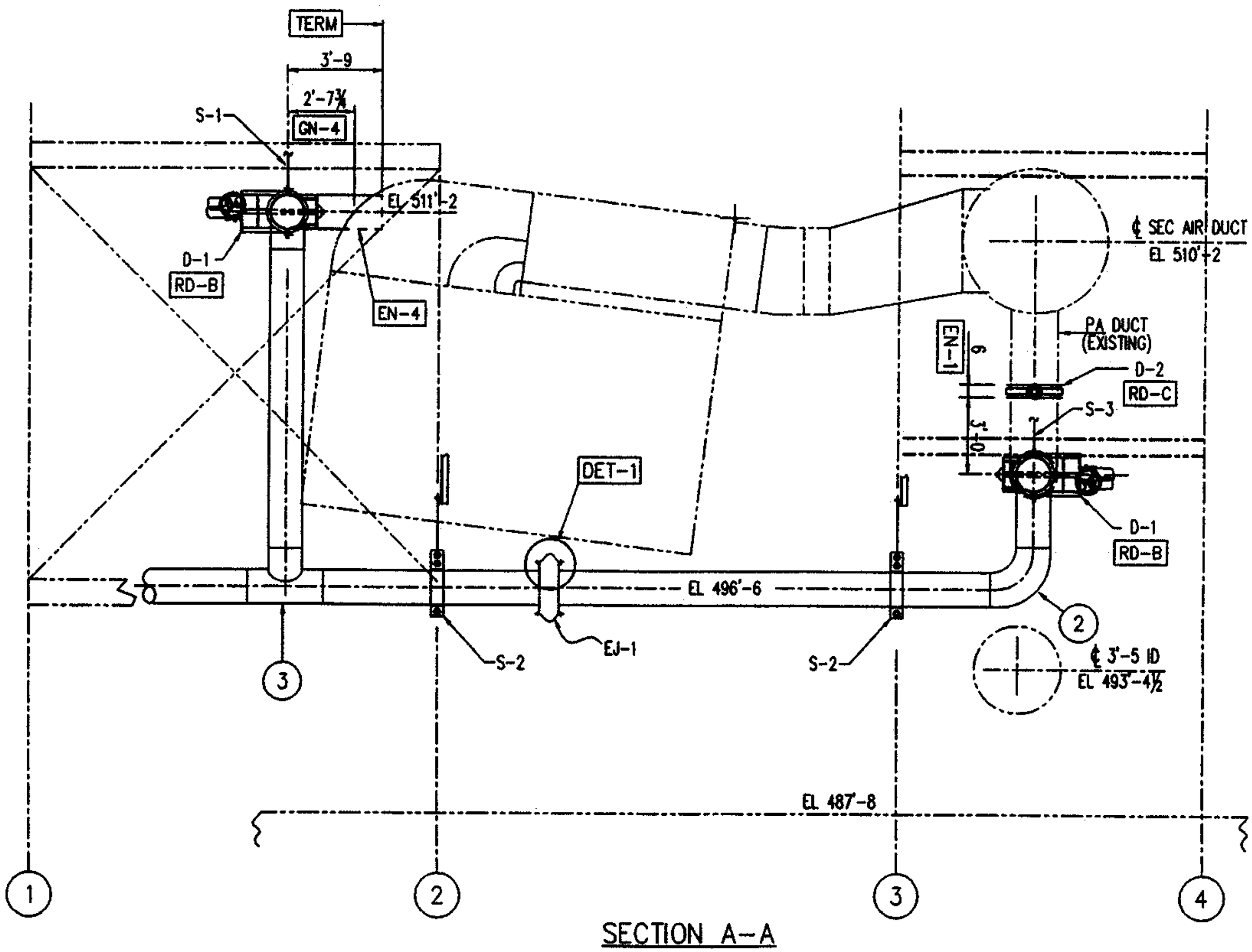


Figure 12 Flue Gas Recycle Piping (Elevation View)

Task 4 - Subsystem Test Unit Construction

Subtask 4.2 - Char Combustion System Test Unit Construction

In order to accommodate the increased I/O loading for all of the new subsystems added in support of the HIPPS test program, the DCS was upgraded to a new Windows NT operating platform. The DCS is a Moore APACS system with an open architecture, and as such, the server was enhanced to support the overall HIPPS I/O communication requirements.

Task 5 - Subsystem Test Unit Testing

No experimental testing was performed during this quarter.