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ENGINEERING DEVELOPMENT OF COAL-FIRED HIGH-PERFORMANCE POWER SYSTEMS

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TECHNICAL PROGRESS REPORT 3
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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:

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

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

- Total station efficiency of at least 47 percent on a higher heating value basis.
- Emissions:
  NO_x < 0.06 lb/MMBtu
  SO_x < 0.06 lb/MMBtu
  Particulates < 0.003 lb/MMBtu
- All solid wastes must be benign with regard to disposal.
- Over 95 percent of the total heat input is ultimately from coal, with initial systems capable of using coal for at least 65 percent of the heat input.
- Ten percent lower cost of electricity (COE) relative to a modern coal-fired plant conforming to NSPS.

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

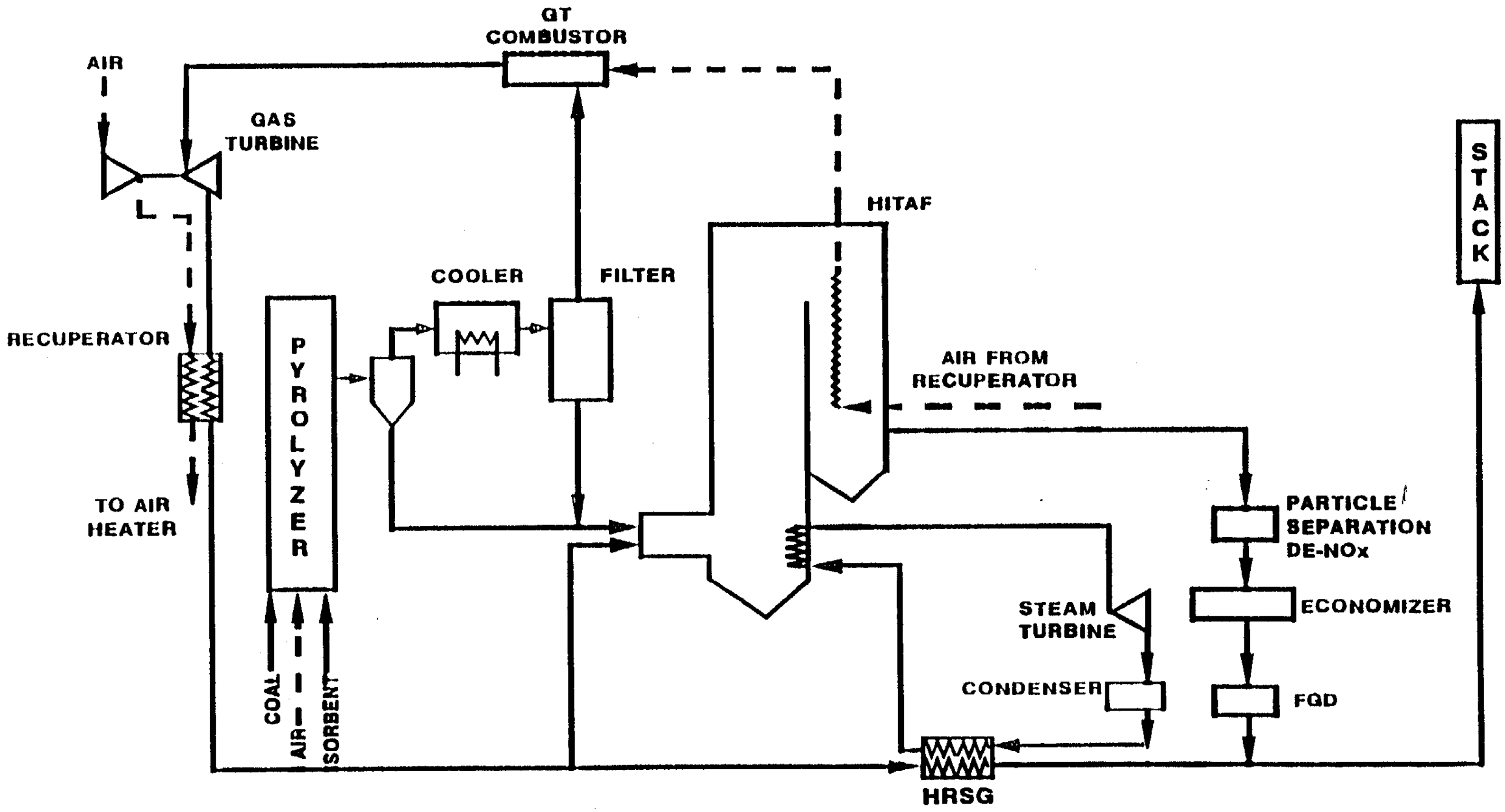

Figure 1 All Coal-Fired HIPPS

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 to1288°C (2350°F). In addition to the HITAF, steam duty is achieved in with a heat recovery steam generator (HRSG) in the gas turbine exhaust stream and economizers in the HITAF flue gas exhaust stream.

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

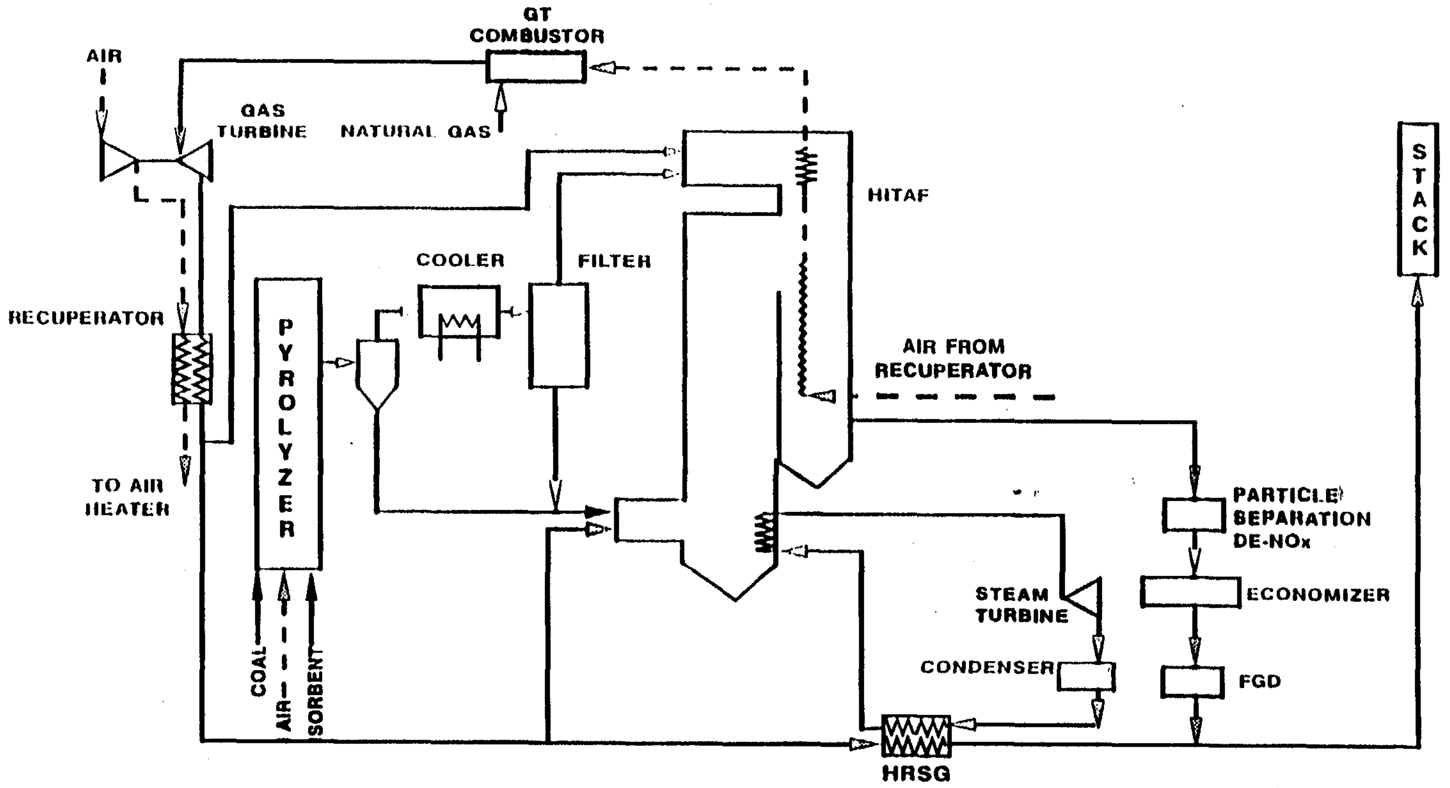

Figure 2 35 Percent Natural Gas HIPPS

TECHNICAL PROGRESS

Task 1 - Project Planning and Management

The project is proceeding in accordance with the Project Plan. A Progress Review Meeting was held during this quarter.

Part of the Task 1 effort is an updating of the Commercial Plant design that was developed in Phase 1. During this reporting period, Bechtel continued the work initiated in the previous quarter which investigated the impact on the performance of the conceptual commercial plant when the pyrolyzer coal feed system is changed from a wet to a dry feed system [1]. This work is part of the Phase 2 overall task objective of improving the design, operability, and performance of the commercial plant by analyzing and comparing various plant component and configuration options.

In the previous period it was reported that for a dry coal feed system water can generally be added before and/or after the pyrolysis reaction has taken place, as steam to the pyrolyzer or as quench water injected in the pyrolysis gas, respectively. Plant performance results were reported for two dry feed cases: one with moderate amount of steam injected into the pyrolyzer and one without. In both cases, no further addition of water through fuel gas quench was used. The results have shown that the net plant efficiency improves and the size of the bottoming cycle decreases with the addition of steam to the pyrolyzer. The plant efficiencies for both dry feed cases were, however, lower than that achieved when using a wet paste feed.

In this reporting period, Bechtel assessed the dry feed option further by analyzing the plant performance for four more pyrolyzer dry feed cases for which Foster Wheeler provided the respective heat and mass balances. In three of these cases, the amount of steam fed to the pyrolyzer was steadily increased. In the fourth case, water quench was used to cool the fuel gas to 593°C (1100°F) in addition to pyrolyzer steam injection. Direct quench is being considered for fuel gas cooling in lieu of indirect cooling with steam because it potentially offers a simpler, generally more reliable, and less costly design option. Only two of these cases were, however, analyzed in detail. Table 1 lists the total water introduced in the pyrolysis system for the two new dry feed cases and for the three pyrolyzer feed cases reported previously. For the five analyzed pyrolyzer feed cases, the total amount of injected steam and/or water ranges from about 3 to 103 kg per 100 kg of moisture-free feed coal.

Table 2 summarizes the major process design and performance parameters determined for the five pyrolyzer feed cases, and Figures 3 through 6 graphically show the variation in some of the process and performance parameters as the amount of water introduced in the pyrolysis system is increased in going from the Dry Feed Case (DF) to the Dry Feed

Table 1
Specification of Pyrolyzer Feed and Quench Cases

Description	Total Injected Water kg/100 kg mf coal	Case Designation
Paste Feed	37	PF
Dry Feed	2.6 *	DF
Dry Feed & Low Steam Injection	19.2	DF-LS
Dry Feed & High Steam Injection	46.8	DF-HS
Dry Feed & High Steam Injection Plus Quench	103.3	DF-HSQ

* Moisture in feed coal

Table 2
Process and Performance Parameters For Pyrolyzer Feed and Quench Cases

	Pyrolyzer Feed Case				
Parameter	**DF**	**DF-LS**	**PF**	**DF-HS**	**DF-HSQ**
Topping Cycle					
Coal flow to pyrolyzer, *as received basis* (kg/h)	88,891	80,355	74,551	69,082	83,892
Moisture in coal feed to pyrolyzer (wt %)	2.5	2.5	27	25	2.5
Total injected water/steam (kg/100 kg mf coal)	2.5	19.2	37	46.8	103.3
Fuel gas flow to GT combustor (kg/h)	172,002	197,812	264,667	233,786	283,905
Moisture in fuel gas to GT combustor (wt %)	2.72	5.51	7.39	8.48	19.9
Fuel gas high heating value (kJ/Nm^3)	6755	6062	4901	5377	4653
Total fuel heat input to GT combustor (GJ/h)	1099	1143	1203	1204	1265
Fraction of coal energy that goes to fuel gas (%)	43.4	49.7	56.1	60.6	60.6
Bottoming Cycle					
Char flow to slagging combustor (kg/h)	49,943	40,299	30,692	27,315	33,171
Fraction of coal energy that goes to char (%)	42.5	35.7	23.6	28.6	28.6
Flue gas flow to HITAF economizer (kg/h)	982,018	754,506	540,959	471,745	620,383
GT exhaust flow to HRSG (kg/h)	643,330	865,409	1,072,546	1,140,245	1,017,848
Steam to HP steam turbine (kg/h)	568,889	474,172	381,201	357,404	387,075
Heat duty relative to that for the DF Case (%):					
HITAF economizer	100	62	33	26	33
GT exhaust HRSG	100	149	204	216	197
Performance					
Gas turbine generator output (MW)	147.6	149.1	153.6	154.7	164.5
Steam turbine generator output (MW)	256.2	210.7	173.1	155.4	168.9
Total auxiliary power (MW)	19.9	17.5	15.7	14.4	16.5
Net plant power output (MW)	383.9	342.3	311.1	295.7	316.9
Net plant efficiency HHV basis (%)	46.34	46.65	47.16	48.4	42.4

Table 2A
Process and Performance Parameters For Pyrolyzer Feed and Quench Cases (English Units)

Parameter	Pyrolyzer Case				
	DF	DF-LS	PF	DF-HS	DF-HSQ
Topping Cycle					
Coal flow to pyrolyzer, as received basis (lb/h)	195,970	177,152	164,357	152,300	184,951
Moisture in coal feed to pyrolyzer (wt%)	2.5	2.5	27	2.5	2.5
Total injected water/steam (lb/100 lb mf coal)	2.5	19.2	37	46.8	103.3
Fuel gas flow to GT combustor (lb/h)	379,200	436,100	583,490	515,410	625,904
Moisture in fuel gas to GT combustor (wt%)	2.72	5.51	7.39	8.48	19.9
Fuel gas high heating value (Btu/scf)	171.6	154	124.5	136.6	118.2
Total fuel heat input to GT combustor (MMBtu/h)	1042	1083	1140	1142	1142
Fraction of coal energy that goes to fuel gas (%)	43.4	49.7	56.1	60.6	60.6
Bottoming Cycle					
Char flow to slagging combustor (lb/h)	110,106	88,843	67,664	60,219	73,129
Fraction of coal energy that goes to char (%)	42.5	35.7	23.6	28.6	28.6
Flue gas flow to HITAF economizer (lb/h)	2,164,980	1,663,400	1,192,610	1,040,020	1,367,710
GT exhaust flow to HRSG (lb/h)	1,418,300	1,907,900	2,364,560	2,513,810	2,243,970
Steam to HP steam turbine (lb/h)	1,254,185	1,045,370	840,405	787,940	853,354
Heat duties relative to that for the DF Case (%):					
HITAF economizer	100	62	33	26	33
GT exhaust HRSG	100	149	204	216	197
Performance					
Gas turbine generator output (MW)	147.6	149.1	153.6	154.7	164.5
Steam turbine generator output (MW)	256.2	210.7	173.1	155.4	168.9
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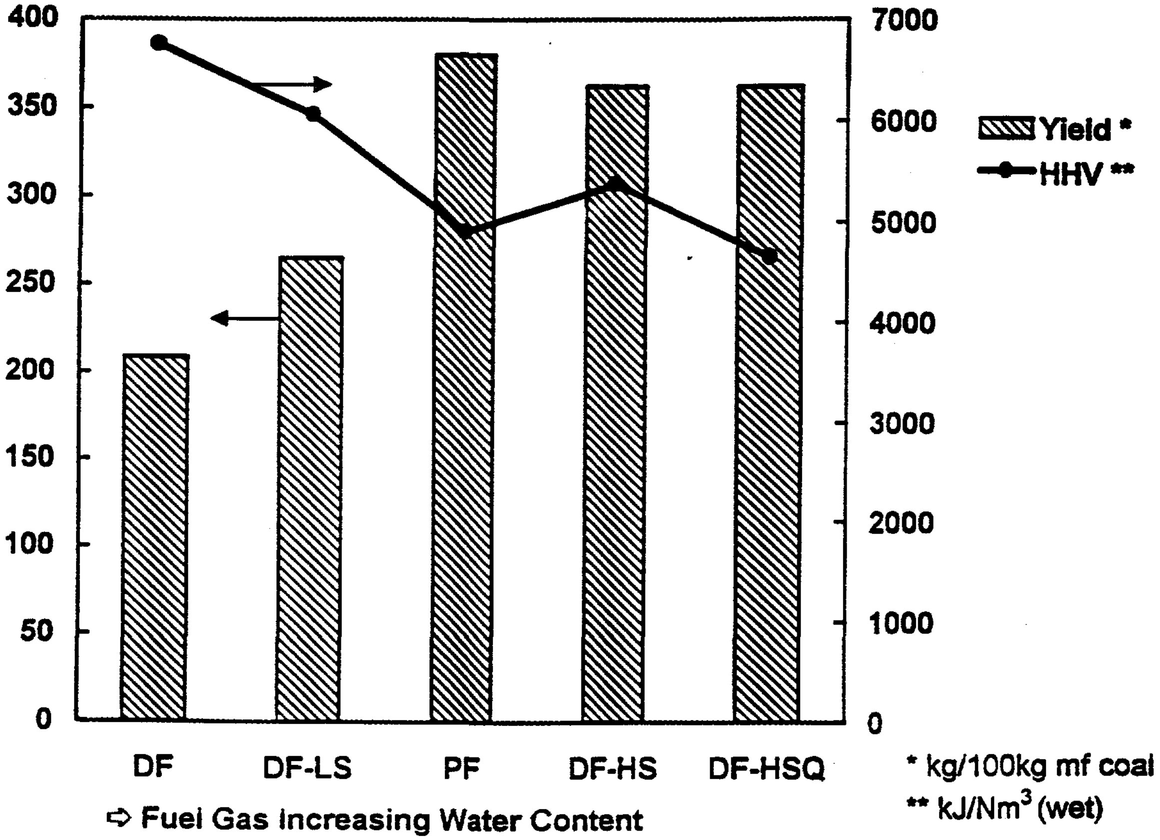

Figure 3
Fuel Gas Yield and Heating Value

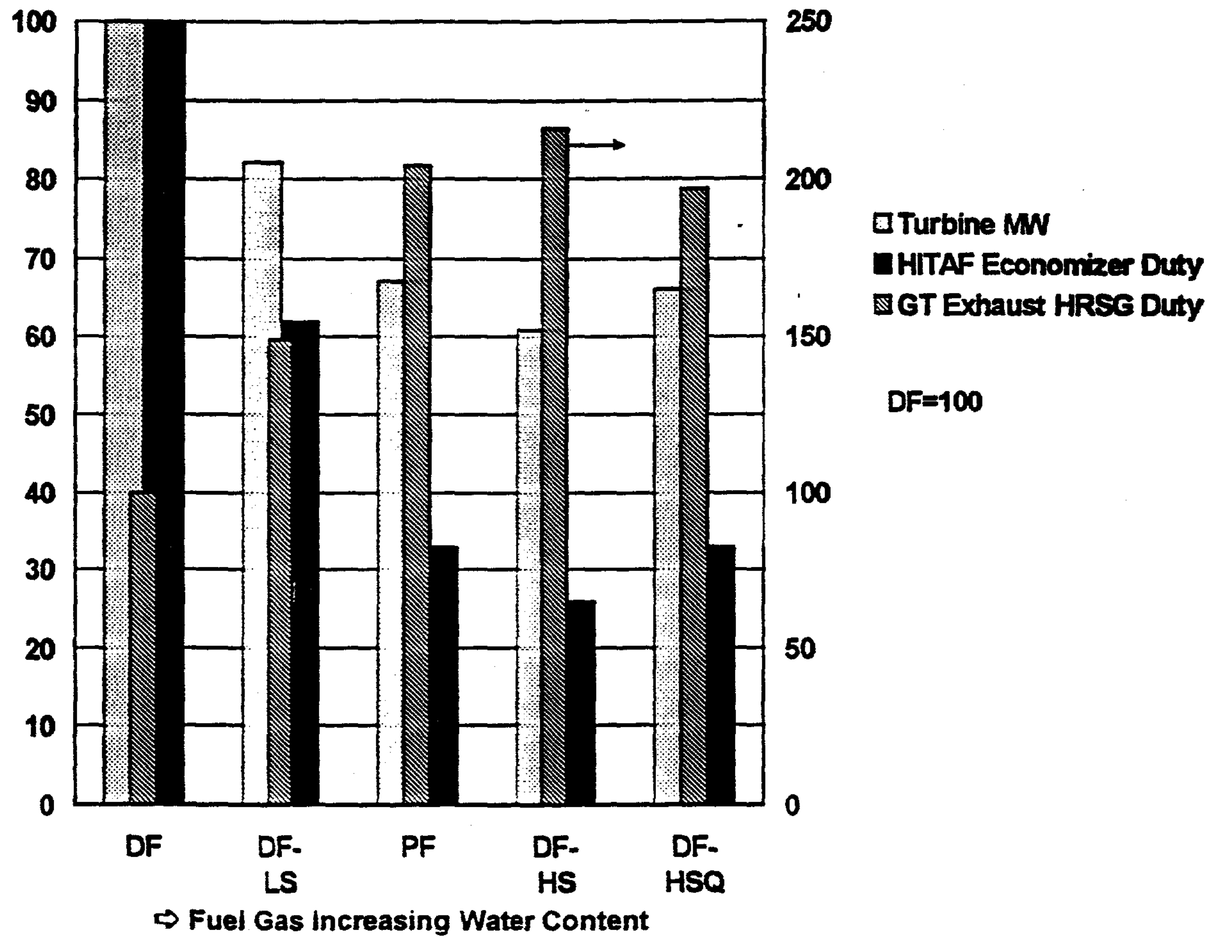

Figure 4
Bottoming Cycle Parameters
(Relative to the Dry Feed Case)

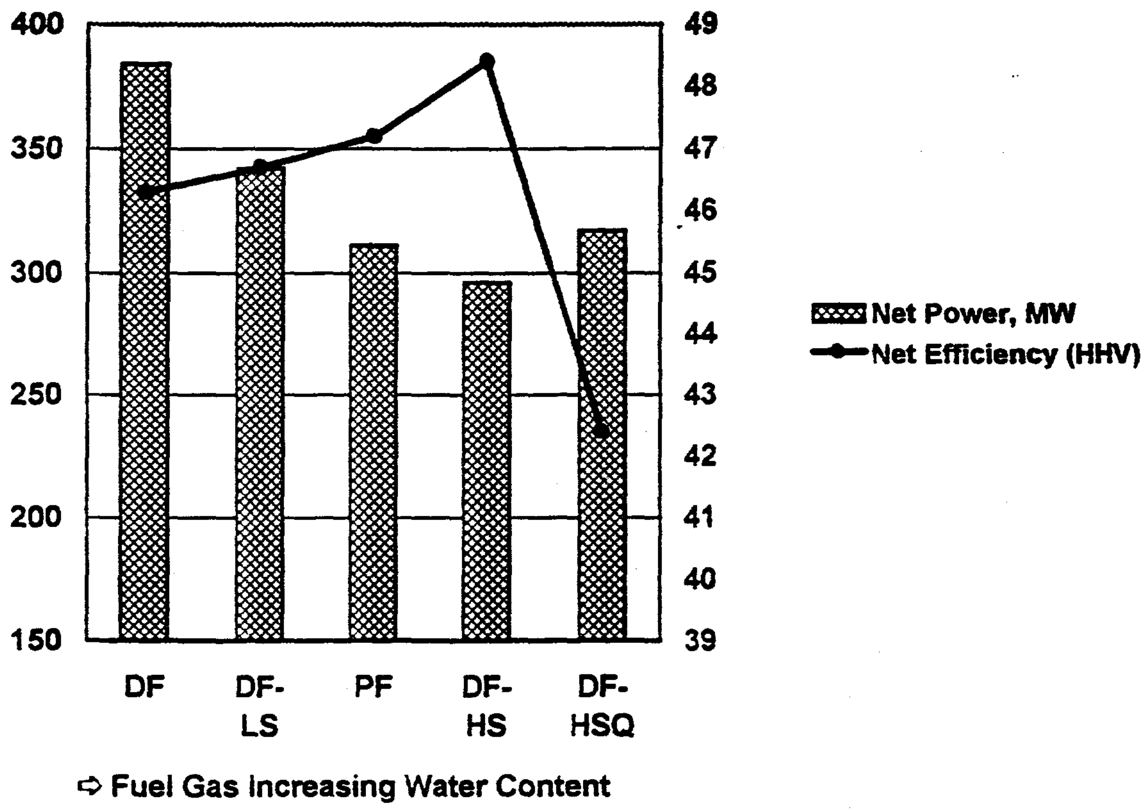

Figure 5
Variation in Net Plant Power and Efficiency

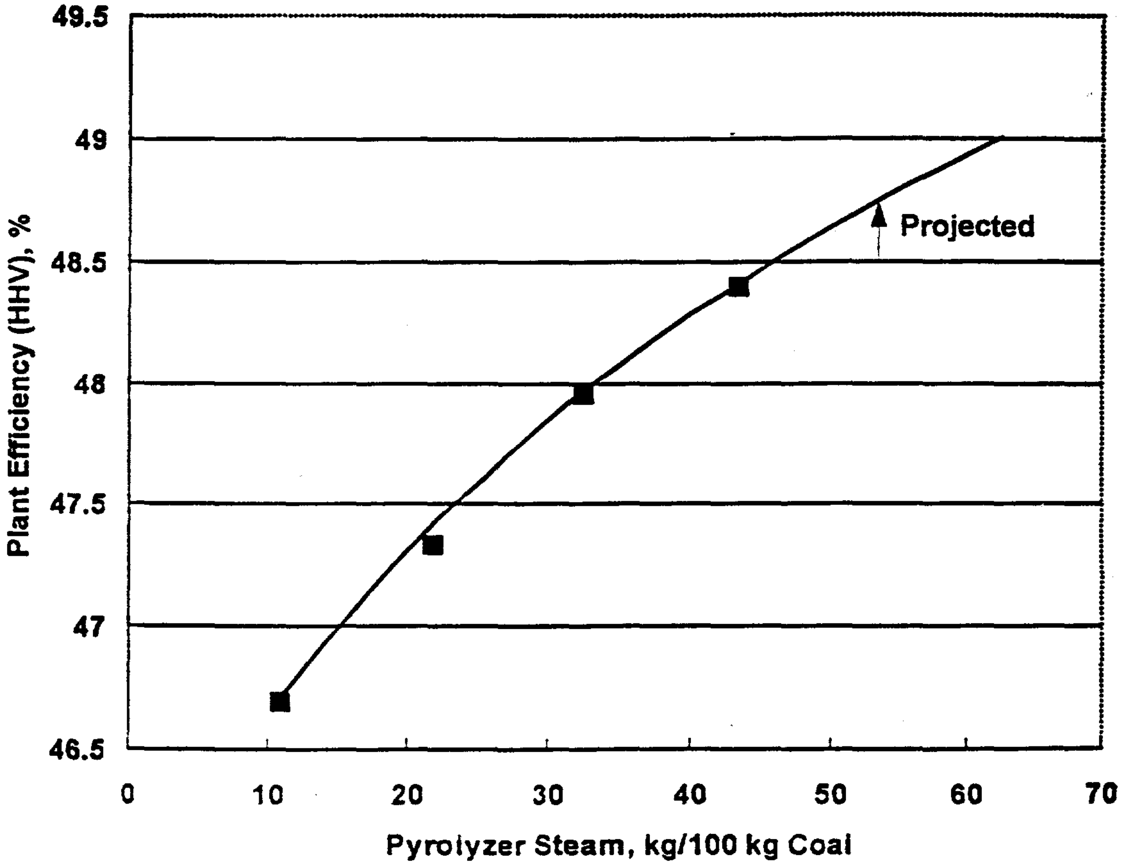

Figure 6
Effect of Pyrolyzer Steam Injection on Plant Efficiency

with High Steam Plus Quench case (DF-HSQ). The following paragraphs discuss the results from the two new dry feed cases (Case DF-HS and DF-HSQ) and compare them with those from the three previous dry and paste feed cases. The discussion specifically addresses the impact on various process parameters affecting the design (and ultimately the cost) of plant components/systems as well as the impact on overall plant performance.

Impact on Plant Component Design

For all the non-quench pyrolyzer feed cases, a consistent correlation appears to exist between the total amount of water/steam injected in the pyrolyzer and several process design parameters affecting both the topping and bottoming cycles of the HIPPS commercial plant. For the single dry feed quench case (DF-HSQ), where considerable water is added downstream of the pyrolyzer, the above correlation does not quite hold because additional secondary factors are introduced.

Fuel Gas Yield and Heating Value. As the amount of water/steam introduced in the pyrolyzer increases, the gas production increases while the char production decreases. In contrast, the heating value of the produced gas generally tends to go down because of the increased moisture content of the gas, as Table 2 and Figure 3 indicate. This heating value downtrend is consistent for the dry feed cases. The paste feed case introduces additional decline in the fuel gas heating value because of the extra carbon dioxide generated from combustion of the coal to evaporate the paste water. Thus, the heating value of the fuel gas produced in the PF case ends up being lower than that in the DF-HS case, although the fuel gas in the latter case has a higher moisture content. The fuel gas from the quench case contains the most moisture and ends up, accordingly, with the lowest heating value of all cases. The fuel gas heating values obtained for all cases, however, fall within the operating limits of the Westinghouse topping combustor being considered for the commercial HIPPS design.

Pyrolyzer Coal Feed Rate. In the commercial plant design, the heat input to the topping cycle remains roughly fixed because the air flow to the turbine is kept constant. Accordingly, the total fuel heat input to the gas turbine combustor increases only slightly in going from the DF to the DF-HSQ case to account for heating the added moisture in the fuel gas. The topping combustor heat input depends on both the fuel gas flow and its heating value, and it turns out that the drop in heating value is more than offset by the rise in fuel gas yield as water/steam injection in the pyrolyzer increases. All this leads to lowering the pyrolyzer coal feed rate in going from the DF to DF-HS case, with the DF-HS case showing a drop in the pyrolyzer coal feed rate of about 22 percent. The quench case does not follow this coal feed reduction trend because the significant amount of moisture added to the fuel gas through quench cooling requires that additional fuel gas be produced without a corresponding reduction in char. This ultimately leads to a higher coal feed requirement than all but that for the DF case.

Char Combustor Feed Rate. As Table 2 shows, less of the feed coal goes to char as the pyrolyzer water/steam injection is increased. In addition, injecting water rather than steam, as in the paste feed case, yields even less char per unit mass of feed coal since more of the coal is combusted to evaporate the water. This decrease in char yield coupled with the decrease in the total coal feed rate to the pyrolyzer will result in significantly reducing the amount of char fed to the bottoming cycle when going from the DF to the DF-HS case. Consequently, the char burners, HITAF furnace, and downstream equipment will get smaller. Although the total furnace size will be reduced, the part of the furnace containing the air heater must remain relatively unchanged since the air flow to the topping cycle compressor remains constant. An increase in char amount is encountered when quench is added to the DF-HS case. This extra char amount results from the higher pyrolyzer coal feed rate, as discussed above.

Steam to HP Steam Turbine. The total amount of high-pressure, superheated steam generated and fed to the steam turbine decreases in proportion to the char fed to the combustor in going from the DF to the DF-HS case, and the steam turbine size and output follows suit. The drop in steam turbine output is significant compared to the corresponding increase in gas turbine output for each of the feed cases. On the average, a one percent gain in the gas turbine output is accompanied by about 11 percent drop in the steam turbine output, for all the non-quench feed cases, while for the quench case the corresponding drop in steam turbine output is about 3 percent.

Bottoming Cycle Heat Duty. The results in Table 2 and Figure 4 indicate that the relative duty, and hence the size, of the HITAF economizer (dirty economizer) and the gas turbine exhaust HRSG (clean HRSG) tend to change in opposite direction but that their combined duty tends to go up as the amount of water/steam injected in the pyrolyzer is increased. The size of the dirty economizer train, including the heat transfer surface as well as the SCR and particulate removal units, gets smaller as the amount of char fed to the furnace combustor drops while the clean HRSG size gets bigger as the amount of vitiated air diverted away from the furnace to the HRSG rises. The drop in duty/size of the dirty economizer is more dramatic than the rise in duty/size of the clean HRSG. For example, the dirty economizer duty drops by a factor of almost four while the clean HRSG duty increases by a factor of almost two, when comparing the DF-HS case to the DF case.

Although the work reported here does not include a cost analysis, it appears likely that the reduction in size of the dirty economizer train coupled with reduction in size of the steam turbine will result in cost savings significant enough to offset the rise in size/cost of the clean HRSG, and this should lead ultimately to net cost savings for the bottoming cycle.

Impact on Plant Performance

Thermodynamic cycle analyses done so far (in both Phase 1 and Phase 2) for the HIPPS commercial plant have indicated that, in general, the overall thermal efficiency of the plant benefits more from improvement in the gas turbine topping cycle than from equivalent improvement in the steam bottoming cycle because of the intrinsic higher efficiency of the topping cycle. The results in Table 2 show that more of the energy in the feed coal is utilized in the topping cycle as fuel gas and less of it is utilized in the bottoming cycle as char as the amount of water/steam injected in the pyrolyzer is steadily increased in going from the DF to the DF-HS case, with the latter case showing about 61 percent coal utilization in the topping cycle. Increasing the moisture content of the fuel gas has the added benefit of increasing the gas turbine power output as well as increasing the gas turbine exhaust temperature.

As a result of the above two effects, the gas turbine output increases while the steam turbine output decreases in going from the DF to the DF-HS case. The increase in gas turbine output is modest while the drop in steam turbine output is more dramatic and this ultimately leads to a decrease in the net plant power output, with the DF-HS case showing about 23 percent drop in plant output compared to the DF case. This can be seen in Figure 5. Although the plant total power output is reduced, the increase in the percentage of power generated by the more efficient gas turbine topping cycle results in a net increase in overall plant efficiency. Of the four non-quench feed cases, the paste-feed and the high-steam, dry-feed cases both achieve efficiencies higher than 47 percent, with the high-steam, dry-feed case gaining more than 1 percentage point over the paste-feed case.

The quench case performed poorly achieving an overall plant efficiency of only 42.4 percent. Compared to the DF-HS case, the quench case achieves about 6 percent higher topping cycle power output, but it also requires that 21 percent more coal be fed to the pyrolyzer to produce enough fuel gas to heat the moisture added through quench, as explained earlier. Only about 61 percent of this extra feed coal is utilized in the topping cycle and about 29 percent is utilized as char in the less efficient bottoming cycle. Cycle analysis has shown that the extra char energy expended in the bottoming cycle ends up more than offsetting the power benefits gained in the topping cycle, with the net result of reducing the overall plant efficiency. The dramatic hit taken on plant efficiency is directly related to the massive amount of quench water required to cool the fuel gas from 927°C (1700°F) to 593°C (1100°F).

Figure 6 illustrates the upward trend in the overall plant efficiency for the non-quench dry feed cases as the pyrolyzer steam injection rate is increased. The upper and lower points on the plot represent the low-steam and high-steam cases, DF-LS and DF-HS, given in Table 2. The two intermediate points represent two other dry feed cases for which the plant performance was estimated based on less detailed cycle analysis using pyrolyzer data provided by Foster Wheeler. The figure suggests that further improvement in plant efficiency may be achieved by adding more steam to the pyrolyzer, and the potential for plant efficiency gain of 0.6 to 1 percentage point is there. The slope of the plot indicates that each small gain in efficiency will require a significant addition of steam to the pyrolyzer which will lead to a significant drop in char production.

The present analysis does not include a design study of the HITAF. A point will be reached where the amount of produced char will be too small to provide heat for the topping cycle (air heating in the furnace) while producing sufficient steam to drive a utility-scale steam cycle. We plan to verify the possibility or limitation of attaining this higher efficiency as part of our update of the commercial plant design.

Future Work

Future work will evaluate the performance, cost, as well as operational implications of several commercial plant configuration options that may include modifying some of the present plant components and/or arrangements in both the topping and bottoming cycles.

Task 2 - Engineering Research and Development

Subtask 2.2 - Restrictive Pipe Discharge (RPD) System Cold Model

A restricted pipe discharge (RPD) system was designed to depressurize and cool the char generated in the PCTT pyrolyzer. A simplified schematic of this system is shown in Figure 7. In initial tests all the char will be collected in the candle filter vessel which will also act as a surge vessel for the RPD system. The RPD pipe will be steam jacketed to cool the char as it is being depressurized. In addition to steam jacket cooling, nitrogen injection into the candle filter above the RPD pipe and water cooled coils in the solids/gas disengaging hopper below the RPD pipe will ensure a maximum char temperature of 232°C (450°F) at the screw feeder inlet.

In order to verify the operational concept of the RPD system, tests were conducted by the Institute of Gas Technology (IGT) on a cold flow model of the same scale and geometry as the Livingston pilot plant RPD system. Samples of the actual char (from the Second Generation PFB testing) of three different size distributions were used for the cold flow tests. The size distributions of the three different char sizes, designated "C" (coarse), "M" (medium), and "F" (fine), are shown in Figure 8. A schematic of the cold flow test rig is shown in Figure 9. The cold flow tests showed that the RPDS worked smoothly and reliably with the coarse and medium size char. The measured pressure profiles and gas flow rates were in accordance with predicted values from the Ergun equation. Figures 10 and 11 show, respectively, the pressure profiles and gas flow rates measured in the cold flow tests.

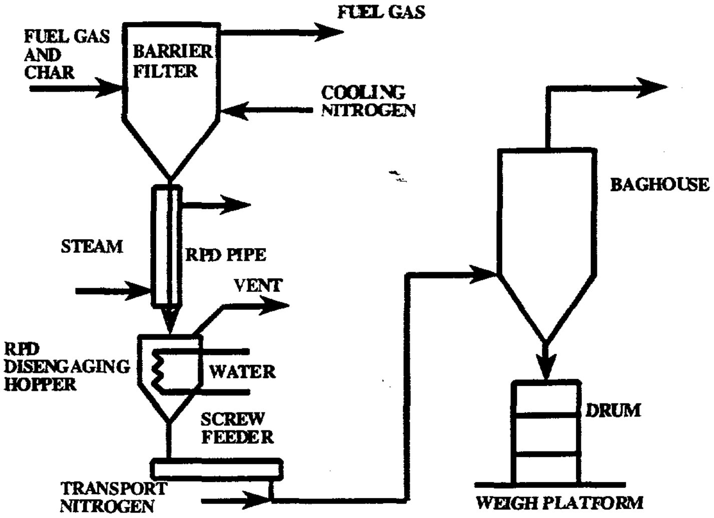

Figure 7. RPD System Schematic

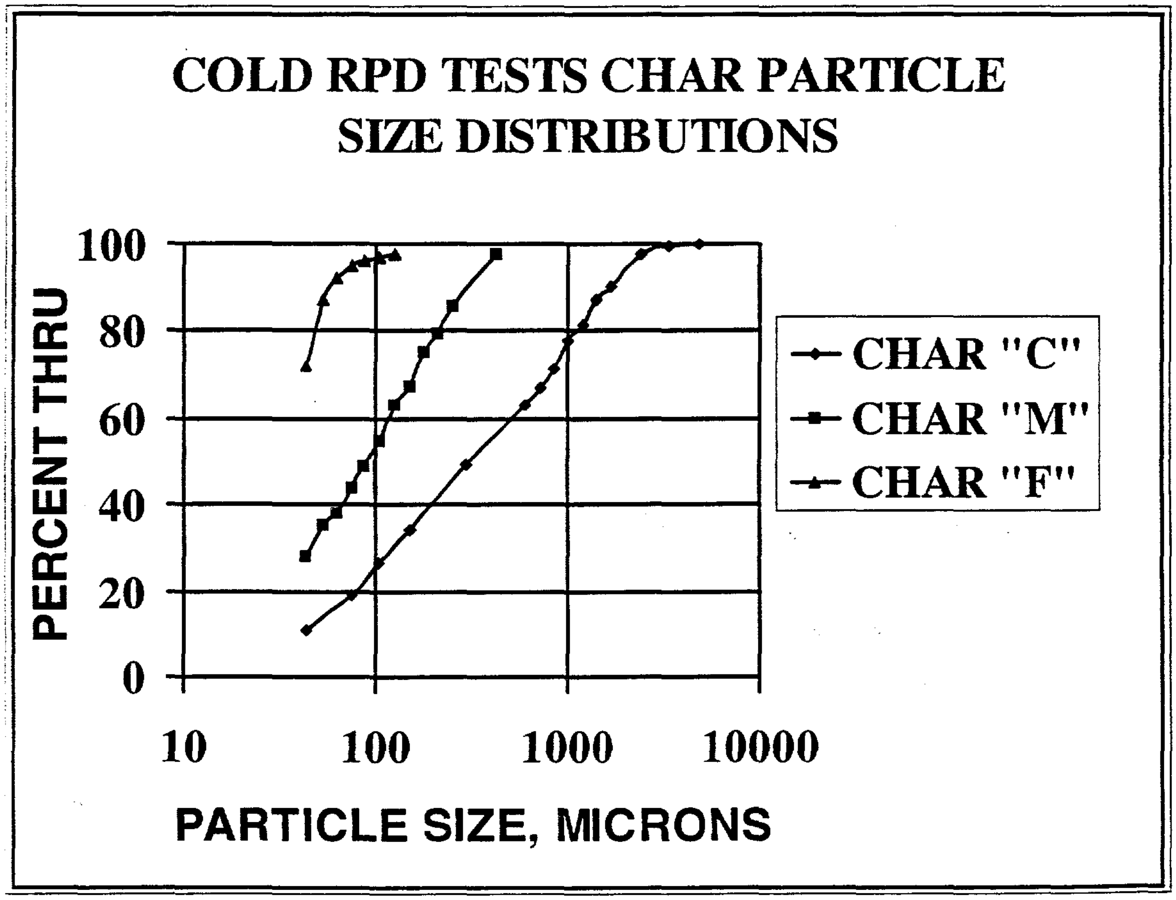

Figure 8. Char Particle Size Distributions

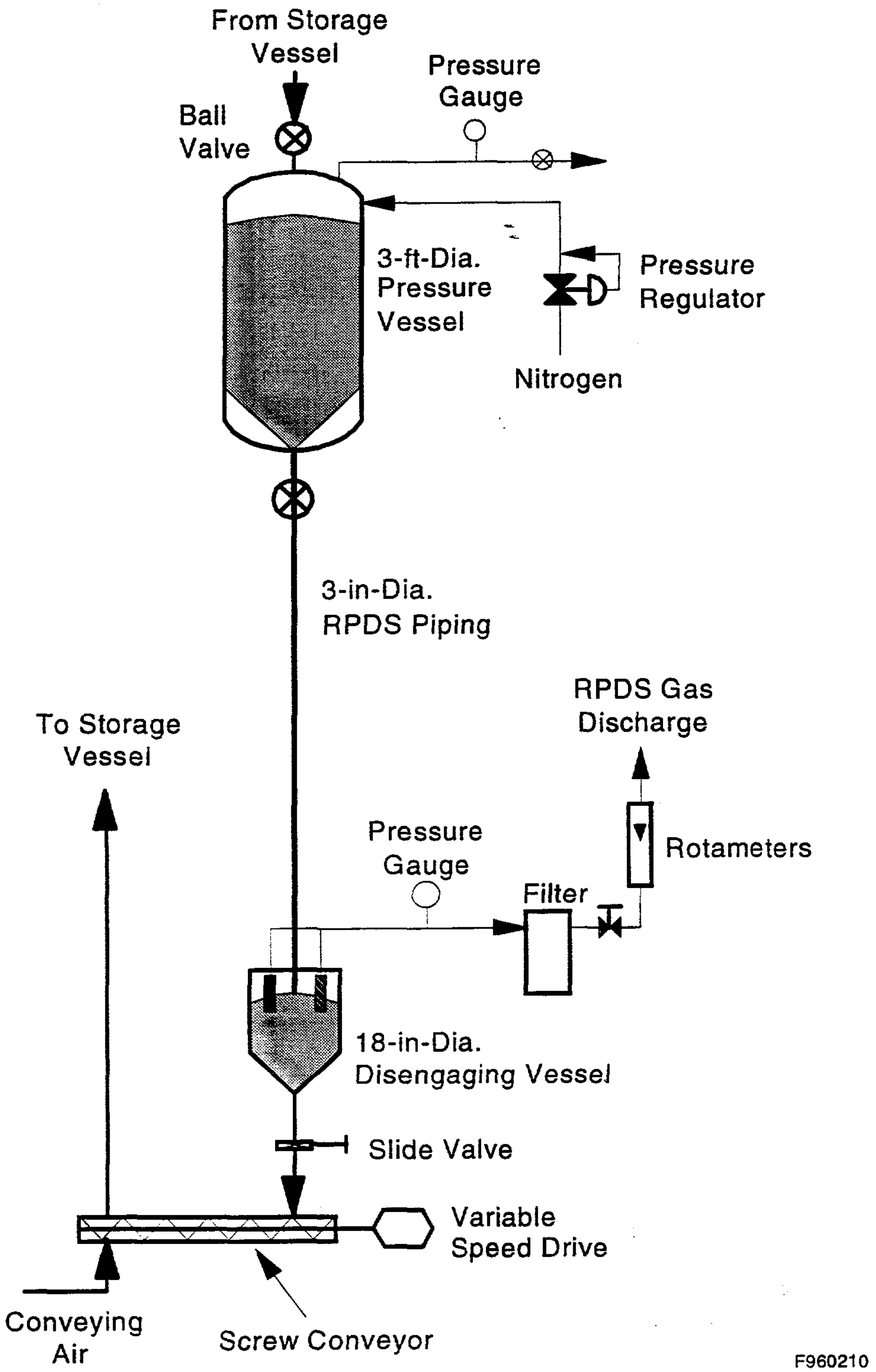

Figure 9. Schematic of the RPDS Cold Flow Model.

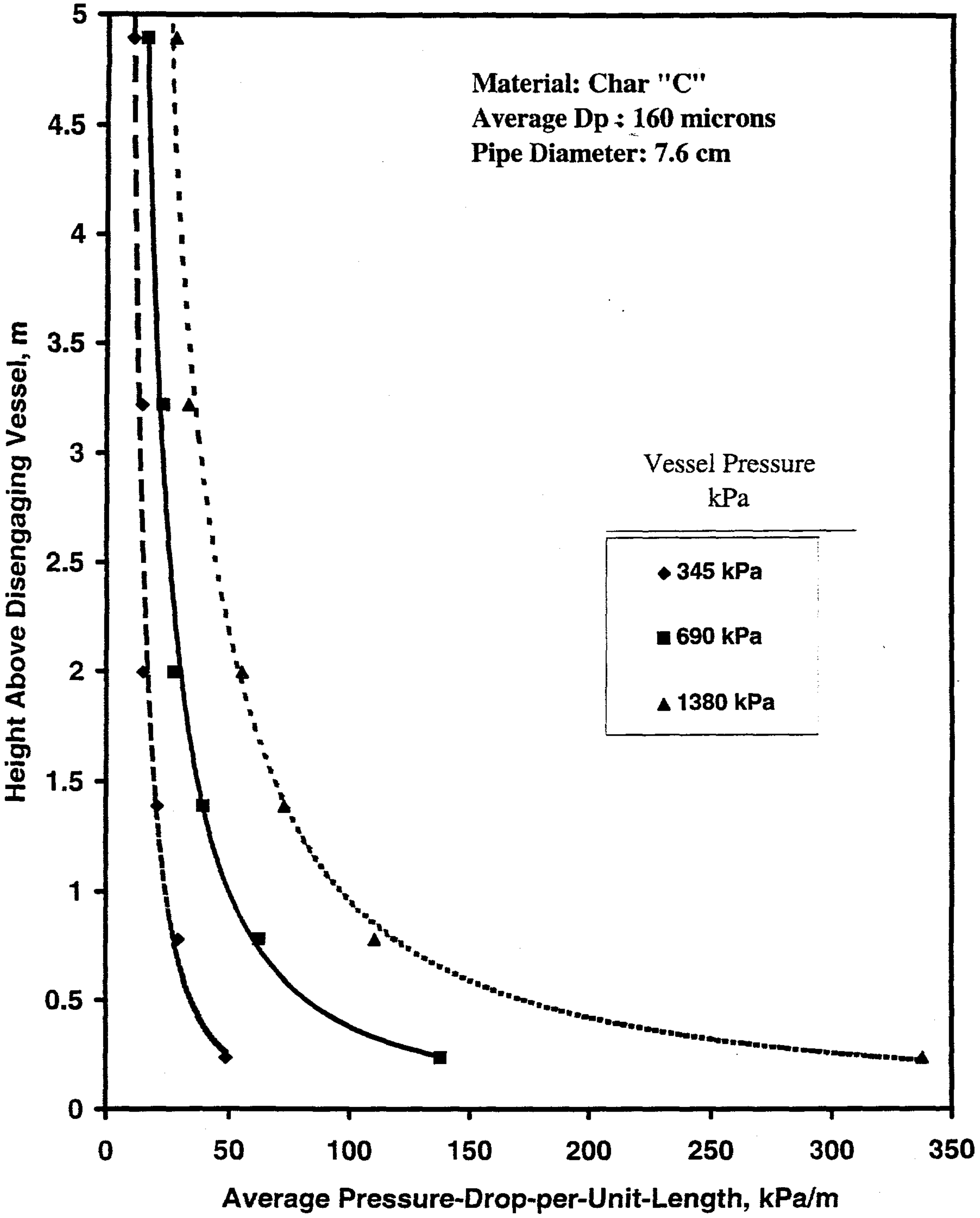

Figure 10. Pressure Gradient Profiles for Char "C".

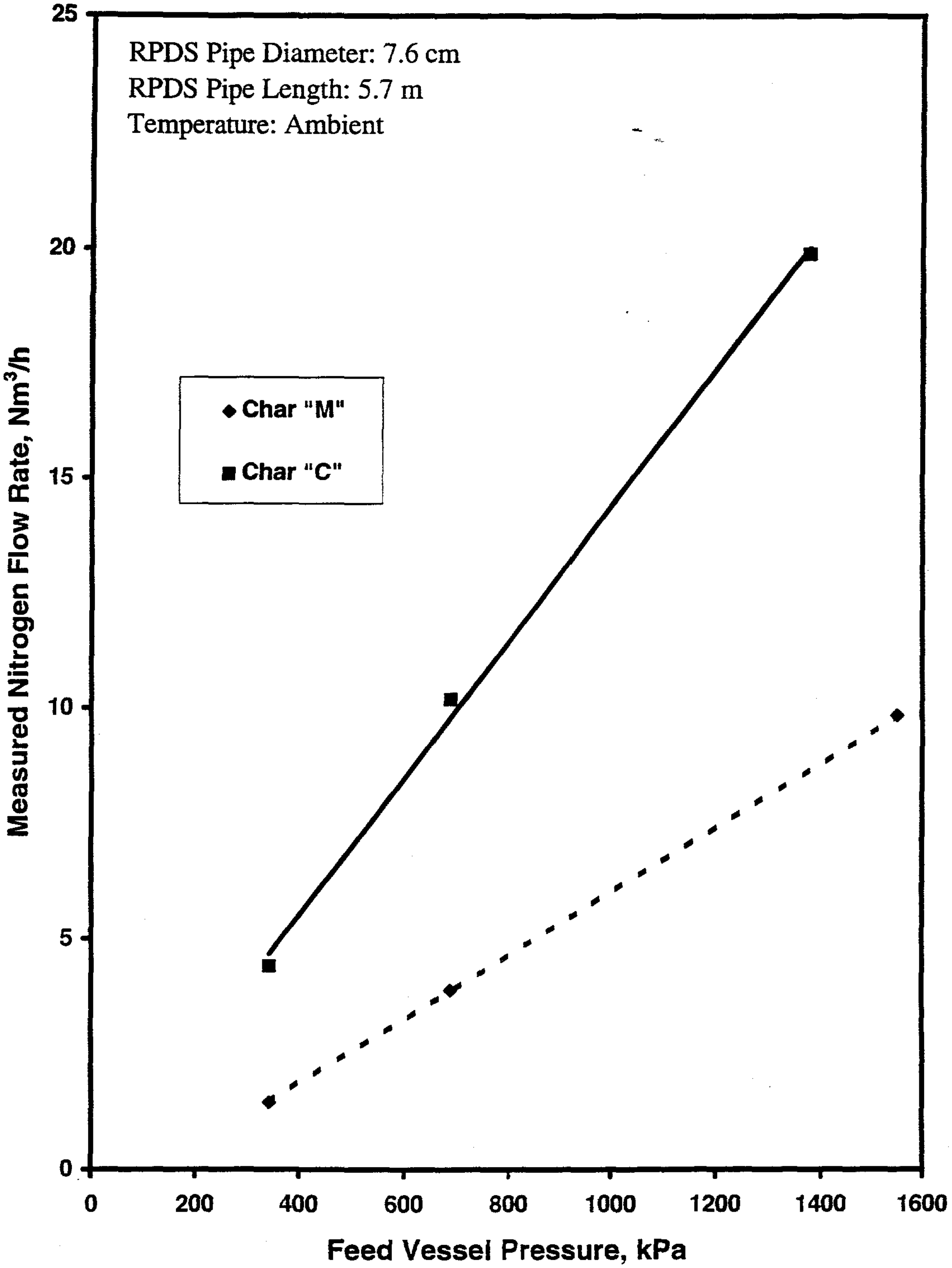

Figure 11. The Effect of Vessel Pressure on the Required Depressurization Gas Flow Rate

Tests with the fine char (30 µm Sauter mean size) proved more difficult. Problems were encountered in getting the char to flow out of the surge hopper and the pressure profiles were not steady, leading to surges in the char flow through the RPD pipe. The possibility of re-designing the RPD system and running additional tests for the fine material is currently being considered. This will depend on the size distribution requirement dictated by the char burner.

Task 3 - Subsystem Test Unit Design

Subtask 3.1 - Pyrolyzer/Char Transport Test Design

The design of the PCTT and the test matrix were presented in the Quarterly Report 2 [2]. During the current quarter the detailed drawings of the pressure vessels were completed and bid packages were sent to vendors. The bids will be received in mid April. The design of the instrumentation and controls is also proceeding. The piping and instrumentation drawings are complete, and an instrument list has been made to identify all the components that will be reused and those that will purchased.

The supply and handling of the fine coal that will be needed for the PCTT is being investigated. In previous test at the Livingston facility the coal has been coarser. Normally it has been received in sacks which were hand loaded into a bucket conveyor. The bucket conveyor feeds a silo, and the coal is then transported with a Z-belt conveyor up to the lock hopper system. We are considering pulverizing the coal at the University of Tennessee Space Institute (UTSI) and transporting the coal to Livingston in a modified dry cement tanker truck. The truck would hold a sufficient quantity of coal for a test run. It would also serve as storage on site since the silos do not have capacity for a full run. The coal would be pneumatically transported from the truck to the silo with nitrogen.

A meeting will be held in April to review the PCTT design and test plan. This meeting will include FWDC personnel and representatives of Foster Wheeler commercial divisions.

Subtask 3.3 - Integrated System Test Design (IST)

A kick-off meeting for the IST was held with FWDC and UTSI personnel in attendance. UTSI is doing preliminary work to prepare for the Integrated System Test (IST) that will be done at the Coal-Fired Flow Facility (CFFF). UTSI examined design activity schedules and identified that insufficient time was planned for approval of long lead time equipment purchases to allow installation by scheduled dates. After discussions with FWDC, UTSI has revised their schedule advancing items as needed. One item is the development of specifications for the IST distributed control system, which could not have been procured in time to be ready for testing by July 1998. UTSI has begun identifying requirements for this distributed control system, and is coordinating that effort with FWDC to account for control requirements for the pyrolyzer and the char combustor as well as test display and data archiving requirements. UTSI also initiated a survey of vendors and pricing for this distributed control system. The joint UTSI-FWDC effort to compile specifications for this system will continue, so that appropriate hardware and software is procured in time to complete all instrumentation and controls installation and checkout.

To help coordinate mechanical interfaces for the IST, UTSI began preparing packages of drawings of the CFFF's mechanical systems for FWDC. Design details for the furnace, superheater and air heater, downstream pollution control equipment, and major support systems will be provided. To assist in this effort FWDC is preparing heat and mass balance flows, temperatures and pressure requirements of the IST for UTSI. In addition, UTSI and FWDC agreed to use AutoCAD Release 12 as the common software interface for drafting and mechanical design. All hardware designs, facility support systems, and schematics of mechanical systems for the CFFF since 1985 have been documented in AutoCAD. These drawings are archived on computer disks and all drawings are compatible with the AutoCAD Release 12 format.

One change from the original IST planning is that we now intend to use dry feed to the pyrolyzer. Bechtel analysis of the cycle indicates that steam should be added to the pyrolyzer with dry feed. This type of operation will result in higher cycle efficiencies. UTSI is reviewing alternatives for supplying high pressure steam to the pyrolyzer and feeding sorbent to the pyrolyzer. The CFFF's current steam capability is 1.03 MPa (150 psig) steam, which is insufficient for pyrolyzer operation. Required steam pressure is expected to be about 1.72 MPa (250 psig). Budgetary cost estimates for new and used boilers, boiler rental, and a steam booster compressor are being obtained. Another alternative would be to approximate the desired pyrolyzer conditions by injecting water instead of steam.

It has been determined that the CFFF coal lock hopper system has sufficient pressure rating to be used for the HIPPS pyrolyzer. It has a design pressure of 5.34 MPa (775 psia). A sorbent lock hopper system will have to be added.

An audit of the CFFF by the Tennessee Air Pollution Division was completed during the quarter with no violations noted. The Air Pollution Control Division appears to be in the process of issuing TSI permit(s) under Title V of the CAAA as "conditional major", thus allowing the CFFF to be classified as a "pilot plant" and "insignificant emission unit". This will place the CFFF in a categorically exempt status and would allow testing to proceed without extensive application procedures and only limited air permit oversight. However, UTSI is continuing plans for IST SO_2 control on a "good neighbor" basis.

REFERENCES

1. Foster Wheeler Development Corporation, "Engineering Development of Coal-Fired High Performance Power Systems- Technical Progress Report 2 (October through December 1995)", DOE PETC under contract DE-AC22-95PC95143, February 1996, pp 5-11.

2. Foster Wheeler Development Corporation, "Engineering Development of Coal-Fired High Performance Power Systems- Technical Progress Report 2 (October through December 1995)", DOE PETC under contract DE-AC22-95PC95143, February 1996, pp 18-30.