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Pilot Plant Test Results and Demonstration of the Ahlstrom Pyroflow Pressurized CFB Technology

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PILOT PLANT TEST RESULTS & DEMONSTRATION OF THE AHLSTROM PYROFLOW® PRESSURIZED CFB TECHNOLOGY

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ABSTRACT:

Ahlstrom Pyropower initiated development of PCFB technology in 1986 after a detailed analysis of competing advanced coal utilization technologies. A 10 MWth pilot plant was started up in 1989 and has produced very promising test results which are highly competitive with coal gasification. This led to a successful application for demonstration of the technology under round III of the DOE Clean Coal Technology Program. The resulting project is Iowa Power's DMEC-1 PCFB Repowering Project. The project is currently in the preliminary engineering phase with supporting pilot plant testing being performed in parallel. Successful demonstration of PCFB technology will provide utilities with a cost effective option for repowering older power stations to comply with the requirements of the 1990 Clean Air Act Amendment in the near term and a clean and high efficiency new plant option in the longer term. This paper will present recent pilot plant test results and review the major technical features of the DMEC-1 project.

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DEVELOPMENT HISTORY

Ahlstrom Pyropower began development of atmospheric circulating fluid bed (ACFB) boilers in the mid 1970's and by the end of the decade had the first commercial unit in operation. Demand for AHLSTROM PYROFLOW® technology expanded rapidly and today there are over 100 atmospheric Pyroflow CFB units in operation or under construction around the world.

At the same time that the first ACFB Pyroflow boiler was put into commercial operation, Ahlstrom Pyropower considered extending Pyroflow technology into the area of gasification. This was driven primarily by the opportunity foreseen for replacing oil fired lime kilns in pulp mill plants with gas firing. The gas would be generated by gasified biomass which is a waste product from the pulping process. In 1982, an atmospheric Pyroflow gasification pilot plant was started up and in 1983 a 35 MW_t Pyroflow gasifier was delivered to a pulp mill in Finland[1].

Five atmospheric Pyroflow biomass gasifiers are now in operation in Europe and the first integrated pressurized biomass gasification combined cycle plant is under construction in Sweden for the Swedish utility, Sydkraft.

In the mid 1980's, Ahlstrom Pyropower began considering development of an advanced coal based power generation technology. Feasibility studies and cost estimates were performed on a variety of advanced coal technologies including gasification and pressurized circulating fluidized bed (PCFB) combustion technologies. These studies concluded that PCFB technology would provide the lowest cost and simplest option for high efficiency power generation with superior emission performance. However, there were two key areas that required detailed component testing prior to further development of the technology. Consequently, small scale testing of the fuel feed system and hot gas clean-up system were initiated at atmospheric conditions. Over 1000 hours of ceramic filter testing was conducted under both oxidizing and reducing conditions. Based upon the successful results from these tests, a decision was made to construct a 10 MW_t Pyroflow PCFB pilot plant utilizing a coal paste feed system and a ceramic barrier filter.

PYROFLOW PCFB PILOT PLANT

Figure 1 provides a flow schematic of the pilot plant that was started up in the spring of 1989 at Ahlstrom Pyropower's research center in Karhula, Finland. Major design parameters for the pilot plant are shown in Table 1.

Crushed coal and ground limestone are mixed with water to provide about 25% surface moisture and are pumped into the combustion chamber utilizing a paste feed pump. This type of pump has been used successfully for many years in the construction industry to pump concrete.

Pressurized air is introduced into the combustion chamber via a four stage radial compressor and is injected through the grid at the base of the combustion chamber and at various levels above the grid to provide staged combustion as is typical in ACFB boilers. In a commercial plant, the combustion air would be supplied from the compressor section of the gas turbine.

The combustion chamber and hot cyclone are of conventional atmospheric design and are enclosed in an insulated steel pressure vessel which is approximately 12 feet in diameter and 55 feet high.

Hot pressurized flue gas leaves the cyclones at about 1600°F and enters a ceramic tube filter . The filter is enclosed in a 8 foot diameter vessel which is approximately 40 feet high. The dirty gas flows down the inside of the ceramic tubes and diffuses through the tube wall leaving the ash on the inside of the tube wall. Periodically, the unit is back pulsed with compressed air in much the same manner as a baghouse in order to dislodge the accumulated ash into the ash hopper at the bottom of the vessel.

At this point in the process, the hot clean gas would be expanded through a gas turbine to generate power in a commercial plant. In the pilot plant, the hot gas is first quenched and then depressured before being vented to the stack.

Ash is removed from both the bottom of the combustion chamber and the ceramic filter and is cooled in a watercooled screws before being depressured in lock hoppers.

The heat removal circuit for the pilot plant uses water as the cooling medium but the construction of the heat removal surfaces is identical to that which would be employed in a commercial plant. The combustion chamber walls are fabricated from membrane tube panels. Double omega tube panels are located in the upper combustion chamber where superheater surface would be normally be placed.

TECHNOLOGY DEMONSTRATION

In August, 1991 a Cooperative Agreement was executed by the U.S. Department of Energy and the DMEC-1 Limited Partnership (General Partner - Iowa Power) under round 3 of the Clean Coal Technology program covering the repowering of Iowa Power's mothballed Des Moines Power Station. The No. 6 steam turbine at the site will be repowered with an Ahlstrom Pyropower PCFB boiler. Other project participants include Black & Veatch as the Architect/Engineer and Dairyland Power as the Limited Partner in the partnership. The power station has been renamed the Des Moines Energy Center (DMEC).

This project will represent the first commercial demonstration of Ahlstrom Pyropower's PCFB technology. The plant will employ so-called "first generation" PCFB technology where hot clean combustion gases from the PCFB boiler are expanded through an un-fired gas turbine. This technology is intended as a stepping stone to second generation PCFB designs which involves raising the inlet temperature to the gas turbine to current state of the art levels by firing coal generated "syngas" into the PCFB exhaust (topping), prior to entry into the gas turbine. This syngas is generated in a carbonizer with the resulting char being fed to the PCFB boiler.

Complete details of the DMEC-1 project objectives, schedule and structure have been discussed in detail in a number of other papers[2,3,4] and will not be repeated here. This paper will focus primarily on the results of the pilot plant testing that has been carried out in support of the project and on the major technical features of the project.

PILOT PLANT TEST RESULTS

To date the pilot plant has been operated for over 3000 hours on a variety of different fuels. Analyses of three of the coals tested are shown in Table 2 including Illinois No. 6 and Western sub-bituminous coal (Powder River Basin) which are planned for use in the Iowa Power DMEC-1 Project. These two coals were procured and shipped to the pilot plant by EPRI.

Ceramic Filter Testing

A key feature of the pilot plant testing has been and will continue to be the testing of ceramic barrier filtration technologies including the Asahi Advanced Ceramic Tube Filter (ACTF)[5] technology and Westinghouse's Candle Filter Technology[6]. At the time that this paper was prepared, testing had been completed on the Asahi ACTF filter and the filter pressure vessel was in the process of being modified to accommodate a Westinghouse candle cluster. A detailed report on the results of the Asahi ACTF testing was still under preparation for submittal to EPRI who co-funded the testing. No detailed results of the filter testing will therefore be presented until the EPRI report has been submitted. In general terms, the Asahi design was successful in reducing the outlet dust loading to the level required by gas turbine manufacturers but certain problems were encountered which led to some premature ceramic tube failures.

Carbon Conversion Efficiency

Figure 2 shows a plot of carbon conversion efficiency versus load for Illinois No. 6 (high sulfur coal) and low sulfur coal (Newlands and Rawhide). The data indicates conversion efficiencies between 99.8 and 100% from approximately 40 - 100% load. Combustion temperature ranged from 1500° - 1600°F with excess air levels of 4 - 30%. This excellent performance is attributable to the high partial pressure of oxygen inside the combustion chamber which leads to accelerated and improved combustion of the coal particles under pressurized conditions. The results compare favorably with coal gasification and contribute to the high cycle efficiency of the PCFB.

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SO2 Removal

Figure 3 shows a graph of SO_2 removal efficiency versus Ca/S molar ratio for both the high sulfur and low sulfur coals. In order to achieve 90% removal, a Ca/S molar ratio of approximately 1.1 is required for the high sulfur coal while the low sulfur coal requires a Ca/S molar ratio of about 1.4. At slightly higher calcium sulfur ratios, 98 to 99% removal was demonstrated. The SO_2 emission results are equivalent to or surpass the capabilities of coal gasification while the calcium utilization results are superior to ACFB performance due to the different nature of the chemical reactions that take place.

In ACFB's, limestone is first calcined to calcium oxide before it reacts with SO_2 to form calcium sulfate. The sulfation reaction is prevented from going to completion by the relatively impervious layer of calcium sulfate that forms around the unreacted particles of calcium oxide. This layer impedes the diffusion of SO_2 through to the unreacted core of the particle.

Under PCFB conditions, the chemical reactions are quite different[3]. The high partial pressure of CO_2 in the combustion chamber inhibits the calcination reaction from proceeding. The calcium carbonate is converted directly to calcium sulphate without an intermediate step by the following reaction:

$$CaCO_3 + SO_2 + \tfrac{1}{2}O_2 \rightarrow CaSO_4 + CO_2$$

CO_2 is expelled from the individual limestone particles in parallel with the diffusion of SO_2 and O_2 into the particle. This reaction mechanism maintains the porous nature of the particle and the sulphation reaction proceeds further towards completion than in the case of ACFB's thus providing lower Ca/S molar ratios for the same given SO_2 removal requirement.

NOx Emissions

Figure 4 presents results of NO_x emissions as a function of load for the low sulfur coal indicating that the resulting emissions are well below current Federal standards. Ahlstrom Pyropower has also successfully used ammonia injection to provide non-catalytic reduction of NO_x emissions in ACFB boilers where very low NO_x emissions are required (≈0.1 lb/MMBTU or lower). This same technique has also been shown to be very effective for pressurized conditions and emissions as low as 0.04 lb/MMBTU have been demonstrated in the pilot plant.

CO Emissions

Figure 5 shows CO emissions as a function of load. The data points measured before the filter indicate the effect of gas residence time. While the test data are excellent, even better results would be expected in a commercial size plant due to the greater gas residence time that would be present.

N_2O Emissions

N_2O emissions have also been measured in the pilot plant. While N_2O emissions are not currently being regulated by the EPA or state and county pollution control agencies, there is considerable test work being performed on operating units to determine what levels are being generated with various combustion technologies. Measurements to date in the pilot plant indicates N_2O levels of less than 0.03 lb/MMBTU being formed in a PCFB boiler at combustor temperatures of 1540°-1600°F.

DMEC-1 PROJECT DESCRIPTION

Process Flow Diagram

Figure 6 shows the preliminary process flow diagram for the PCFB system that will repower the existing No. 6 steam turbine at the DMEC site. Almost all the major components are indistinguishable in nature from those described previously for the PCFB pilot plant. Key differences are the substitution of the gas turbine for the air compressor, gas cooling and pressure letdown system used in the pilot plant; and the use of a 1300 psig, 955°F steam cycle for heat removal.

The gas turbine is a standard single shaft, cold end drive industrial machine that has had the center section of the turbine modified to eliminate the conventional combustors. A scroll section has been added to allow for the removal of compressor discharge air from the machine for external firing in the PCFB combustor and to allow for the introduction of hot clean gas back into the expander section. (This air outlet/gas inlet design is commonly used in recuperative gas turbine cycles.) The 1600°F gas inlet temperature allows for a simplified turbine shaft and blade cooling system that only consumes approximately 8% of the total air relative to the 18-20% required for higher inlet temperatures. This means a greater quantity of air is available for firing coal to generate steam in the PCFB combustor .

The boiler layout is different from a conventional ACFB boiler in that there is no convective pass. All evaporative duty and all the superheater duty is accomplished by heat removal from the combustion chamber. The type of surface used to accomplish this has been demonstrated successfully in numerous Pyroflow ACFB applications as well as in the PCFB pilot plant. All the economizer surface is located in a heat recovery unit which is after the gas turbine exhaust. The heat recovery unit is of conventional finned tube design .

Scale-up

The scale-up factor for the DMEC-1 PCFB "hot loop" relative to the pilot plant is approximately 17 based on fuel heat input. While at first glance, this appears considerable, a comparison of the DMEC-1 combustion chamber and cyclone size with a ACFB boiler of comparable size (Table 3) indicates that due to the effect of pressure, the PCFB components are considerably smaller in cross sectional area than their demonstrated atmospheric counterparts.

Plant Performance

Table 4 presents a comparison of predicted PCFB plant performance for DMEC-1 relative to the previous PC boiler plant performance. The PCFB repowering will result in a 32% increase in power output. Despite the limitations on efficiency imposed by the existing steam cycle heat rate, the PCFB repowering is expected to provide a heat rate improvement of up to 15% over that of the previous PC boiler (without a scrubber) while providing considerably better environmental performance. Second generation PCFB technology will provide a further improvement in heat rate as discussed later.

Fuel Flexibility

The DMEC-1 facility is being designed with the capability to fire a wide range of different coals including Illinois No. 6, Western sub-bituminous and Iowa coal. The primary long term fuel is expected to be Western coal but performance on other coals will be proven during the two year demonstration period immediately following the construction phase. The requirement to design for these differing coals translates into wide ranges of operation at full load for the PCFB and all the material handling systems as shown in Table 5.

FUTURE PCFB APPLICATIONS

Between now and the end of the decade, the utility repowering market is expected to be the primary application of PCFB technology. This will provide a cost effective and efficient means of compliance with the 1990 Clean Air Act provisions and for life extensions of existing power plants. Furthermore, given the capability of the technology to achieve emission control well below current regulatory requirements, an opportunity will exist to create pollution credits for assistance in environmental compliance of a utility's total generating capacity or for trading on the emerging market.

In addition to the repowering market, a new plant market is expected to develop in the 150 - 500 MW size range. These plants are expected to achieve efficiencies in the 44-47% (7580-7260 BTU/kWh) range using second generation PCFB technology.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the U.S. Department of Energy for its partial funding of the DMEC-1 PCFB Repowering Project and its role together with American Electric Power (AEP) in co-funding the design, engineering and manufacturing of a Westinghouse candle cluster to be tested at Ahlstrom Pyropower's pilot plant in Karhula Finland. This "proof of concept" testing of Coors mullite candles is in support of AEP's hot gas filtration work at the Tidd plant in Ohio.

REFERENCES

1. M. Siro. "First Finnish Pulp and Paper Mill Independent of Oil as an Energy Source." In Proceedings of 1984 TAPPI Pulping Conference, book 3, pp 591-595

2. S. J. Provol. "Ahlstrom Pyroflow PCFB Technology, Technical Development Status and Preparation for Commercial Demonstration." In Proceedings of 11th International Conference of Fluid Bed Combustion,

3. S. Ambrose, G. Kruempel, N. Kennebeck. "Des Moines Energy Center PCFB Repowering Project." In Proceedings of 1991 International Power Generation Conference, 91-JPGC-PWR-51

4. S. Provol, G. Kruempel, S. Ambrose. "The Iowa Power PCFB Demonstration Project." In Proceedings of American Power Conference, vol 54-I, pp 776-783

5. N. Oda. "New Ceramics Tube Filter Technology for Hot Gas Cleaning." In Proceedings of 1988 EPRI Conference on PFBC.

6. T. Lippert. EPRI Workshop on Filtration of Dust from Coal Gas at High Temperature. Palo Alto, California, November, 1989

Table 1

PCFB PILOT PLANT DESIGN PARAMETERS

Heat Input	10 MW_t	34 MMBtu/hr
Fuel Feedrate	2.0 kg/s	15,200 lb/hr
Air Flowrate	5.5 kg/s	43,700 lb/hr
Combustion Temperature	880°C	1615°F
Operating Pressure (max)	16 bar	232 psia

Table 2

COALS TESTED IN PCFB PILOT PLANT

Weight %(dry)	Rawhide	Illinois #6	Newlands
Carbon	69.5	68.0	73.1
Hydrogen	4.9	4.7	4.1
Sulfur	0.5	3.7	0.5
Nitrogen	1.1	1.2	1.5
Oxygen	17.2	7.5	5.9
Ash	6.8	14.9	14.9
Total	100.0	100.0	100.0
Moisture	30.9	9.4	8.0
HHV, BTU/lb	7760	10,960	11,230

Table 3

SCALE-UP COMPARISON

	DMEC-1	Comparable ACFI
Combustion Chamber	15'x 6'	29'x 18'
Cyclone Diameter	6'	17'

Table 4

DMEC-1 PLANT PERFORMANCE

	Original	DMEC-1
Steam Turbine, MW	66.1	64.2
Gas Turbine, MW	N/A	20.5
House Load, MW	4.9	4.2
Net Power, MW	61.1	80.5

Table 5

COMPARISON OF DESIGN REQUIREMENTS FOR VARIOUS FUELS

	Western (lb/hr)	Illinois #6 (lb/hr)	Iowa (lb/hr)
Coal to Paste System	107,700	73,600	86,300
Limestone	3,200	10,700	16,100
Ash	8,900	20,300	33,200

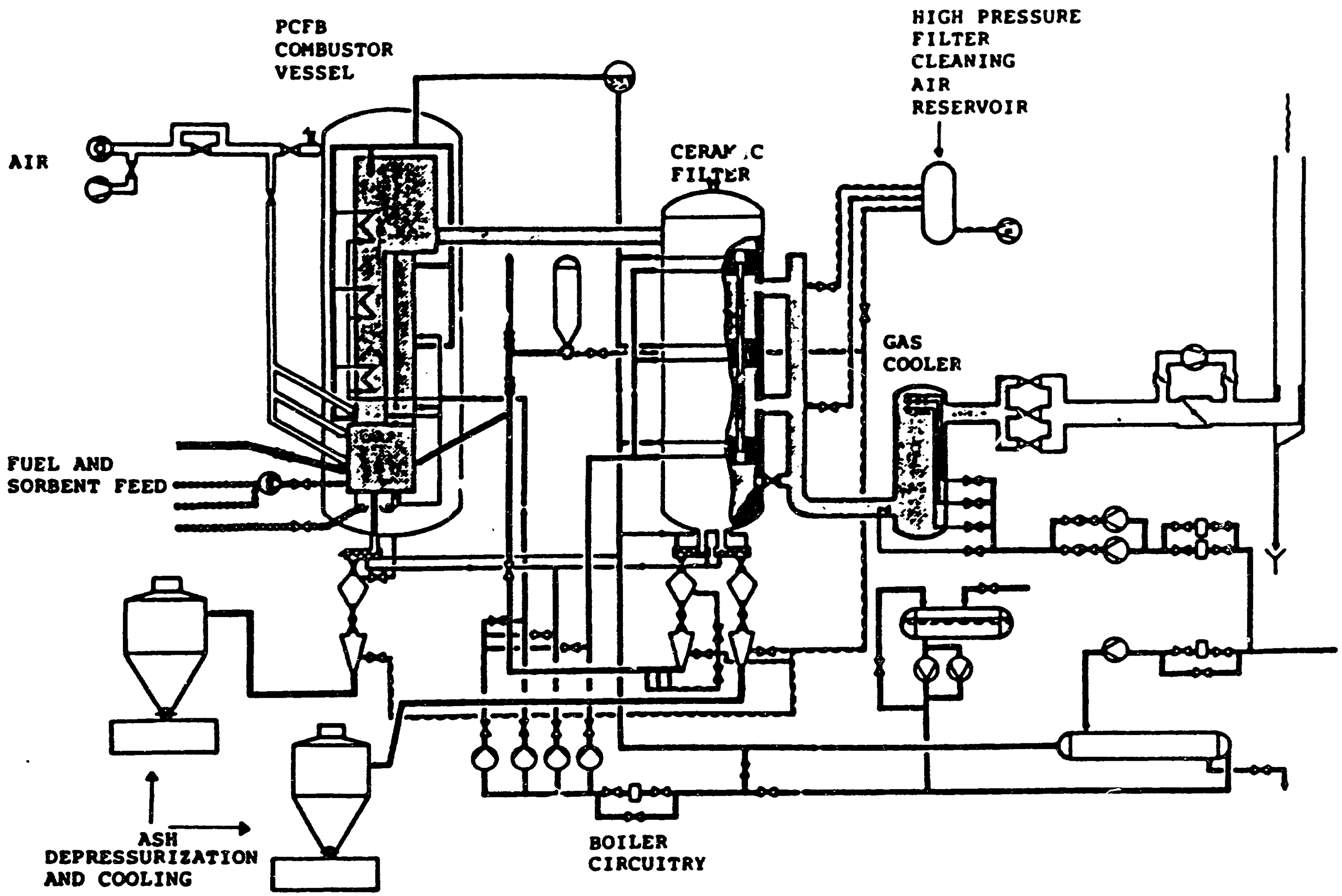

Figure 1 - Karhula Pilot Plant Schematic

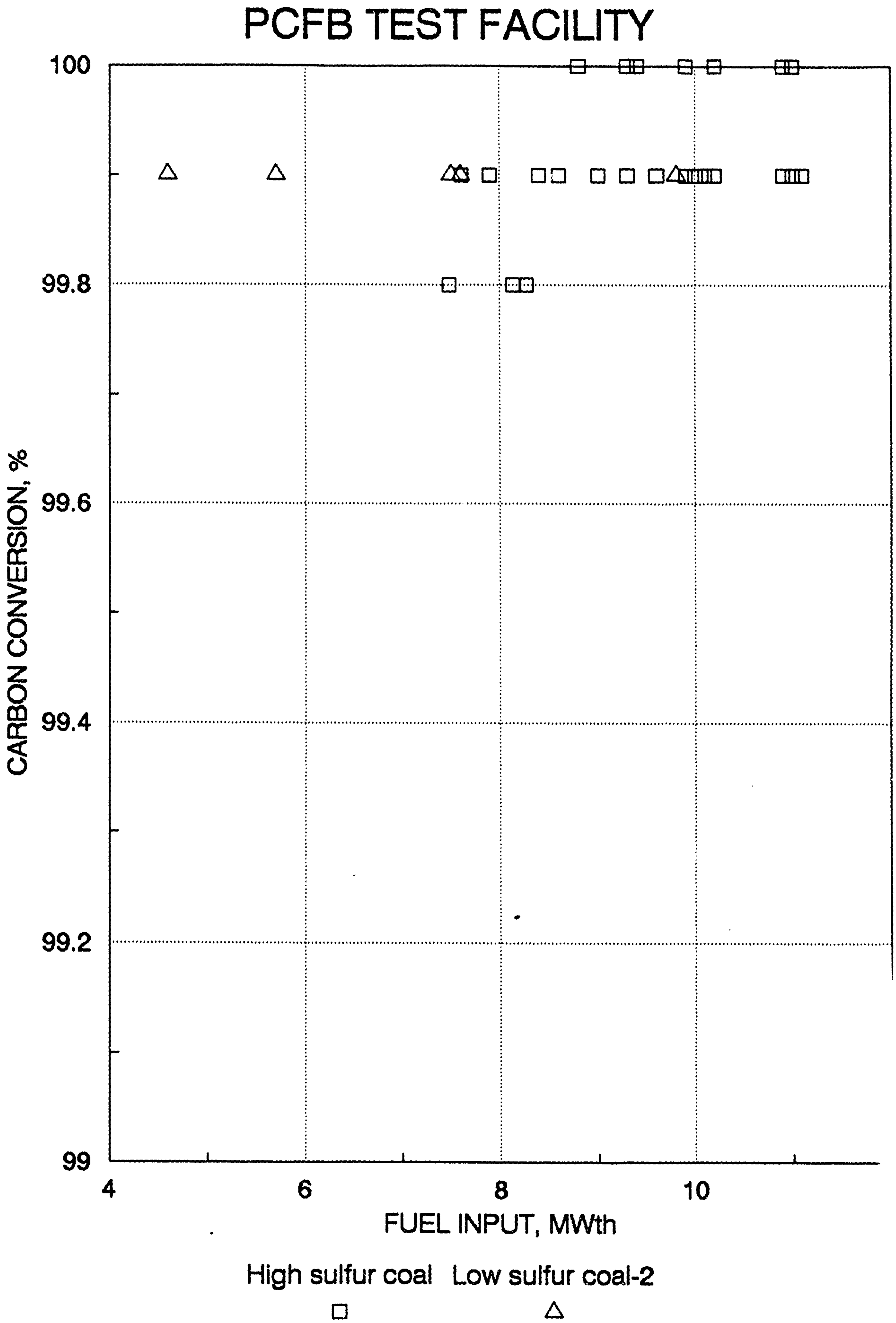

Figure 2 - Combustion Efficiency

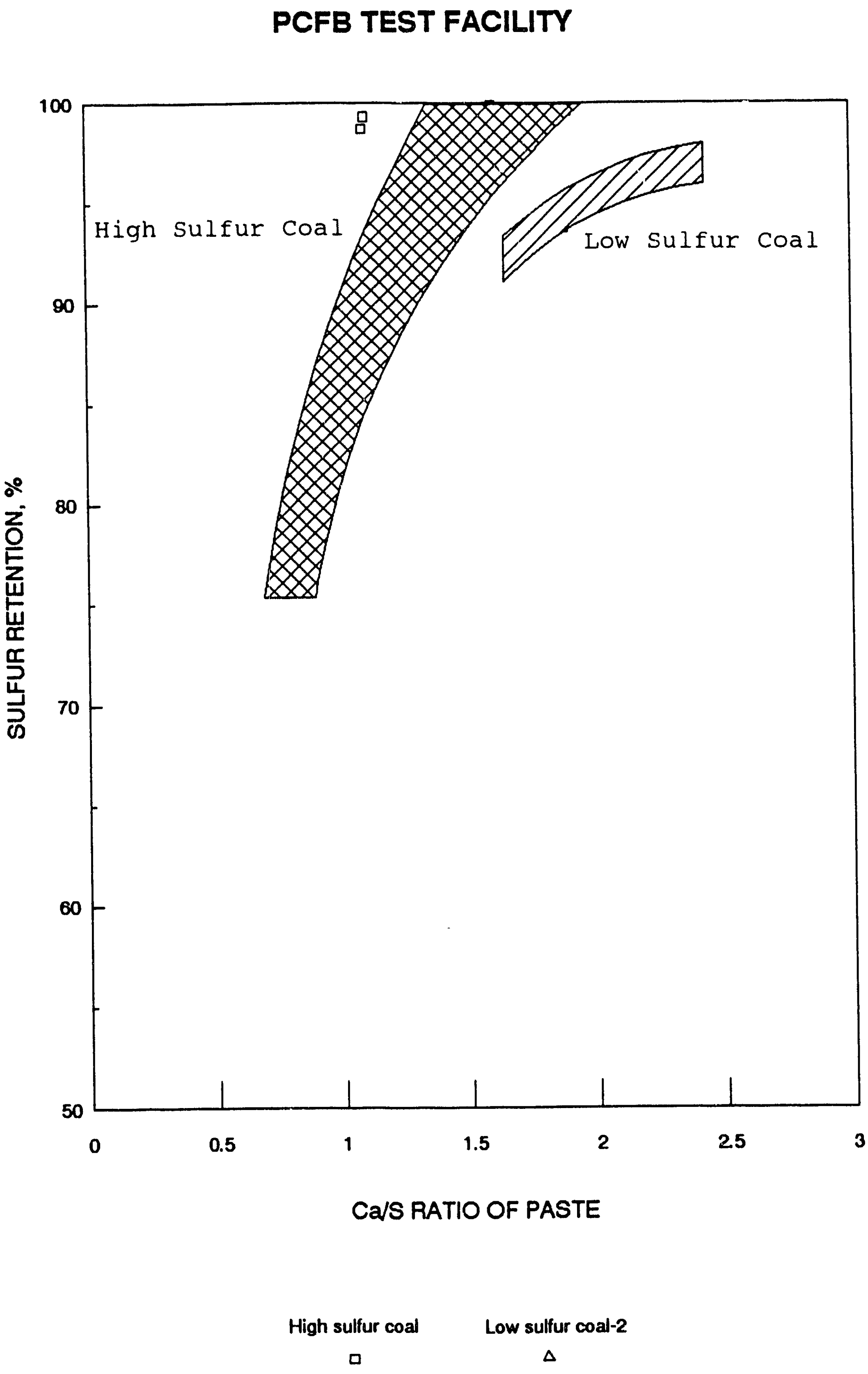

Figure 3 - SO_2 Removal vs. Ca/S Molar Ratio

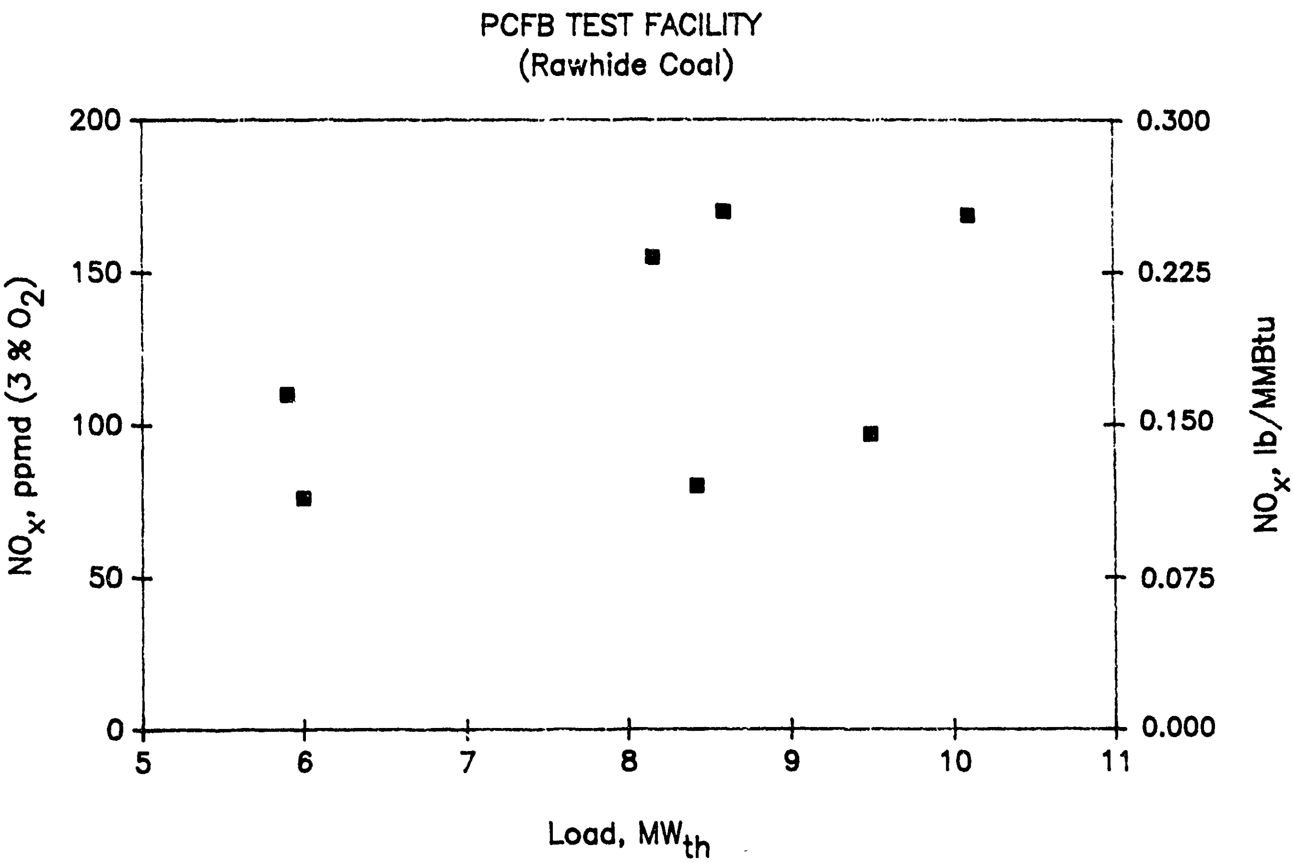

Figure 4 - NO_x Emissions vs. NH_3 Molar Ratio

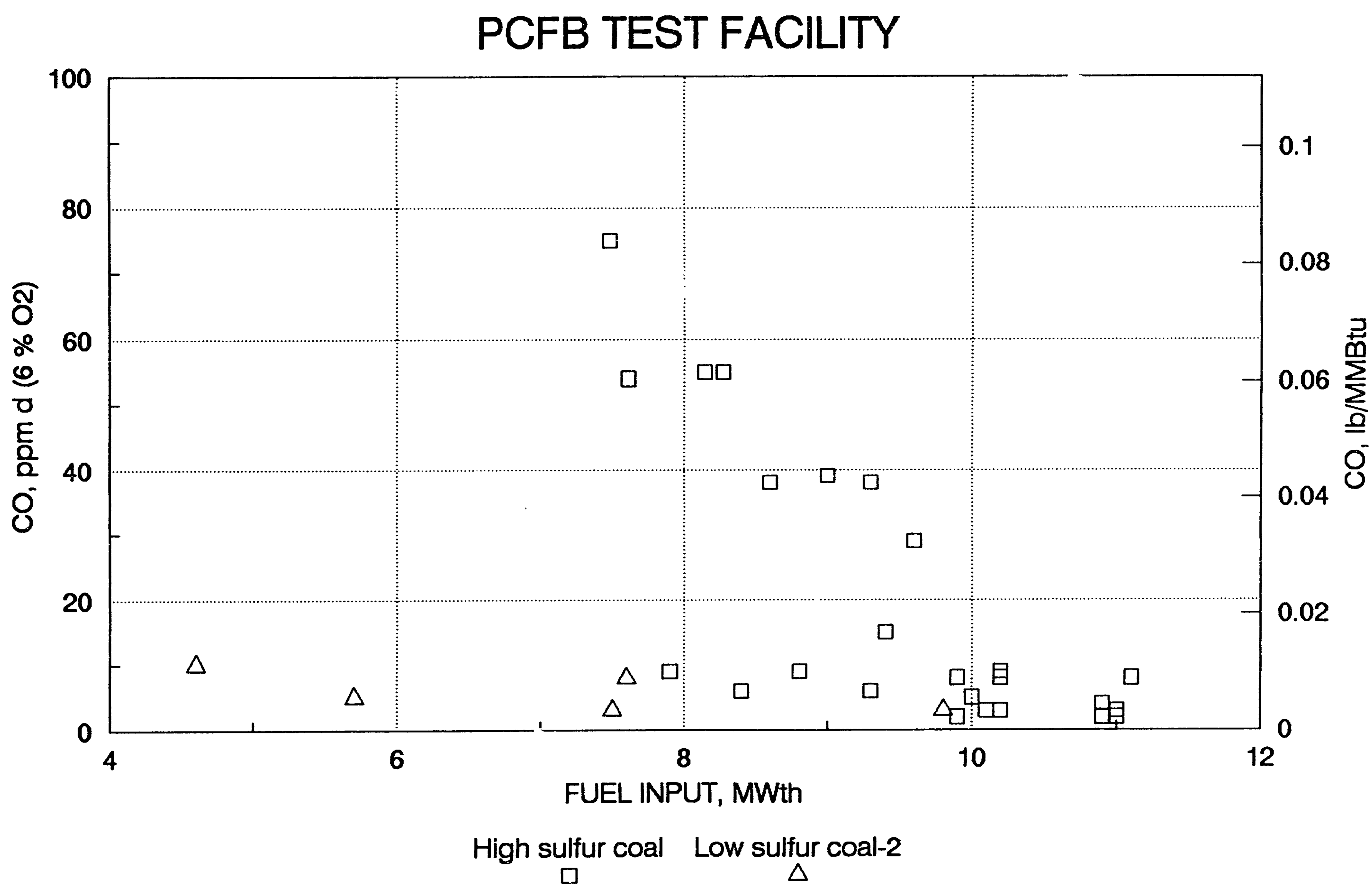

Figure 5 - CO Emissions

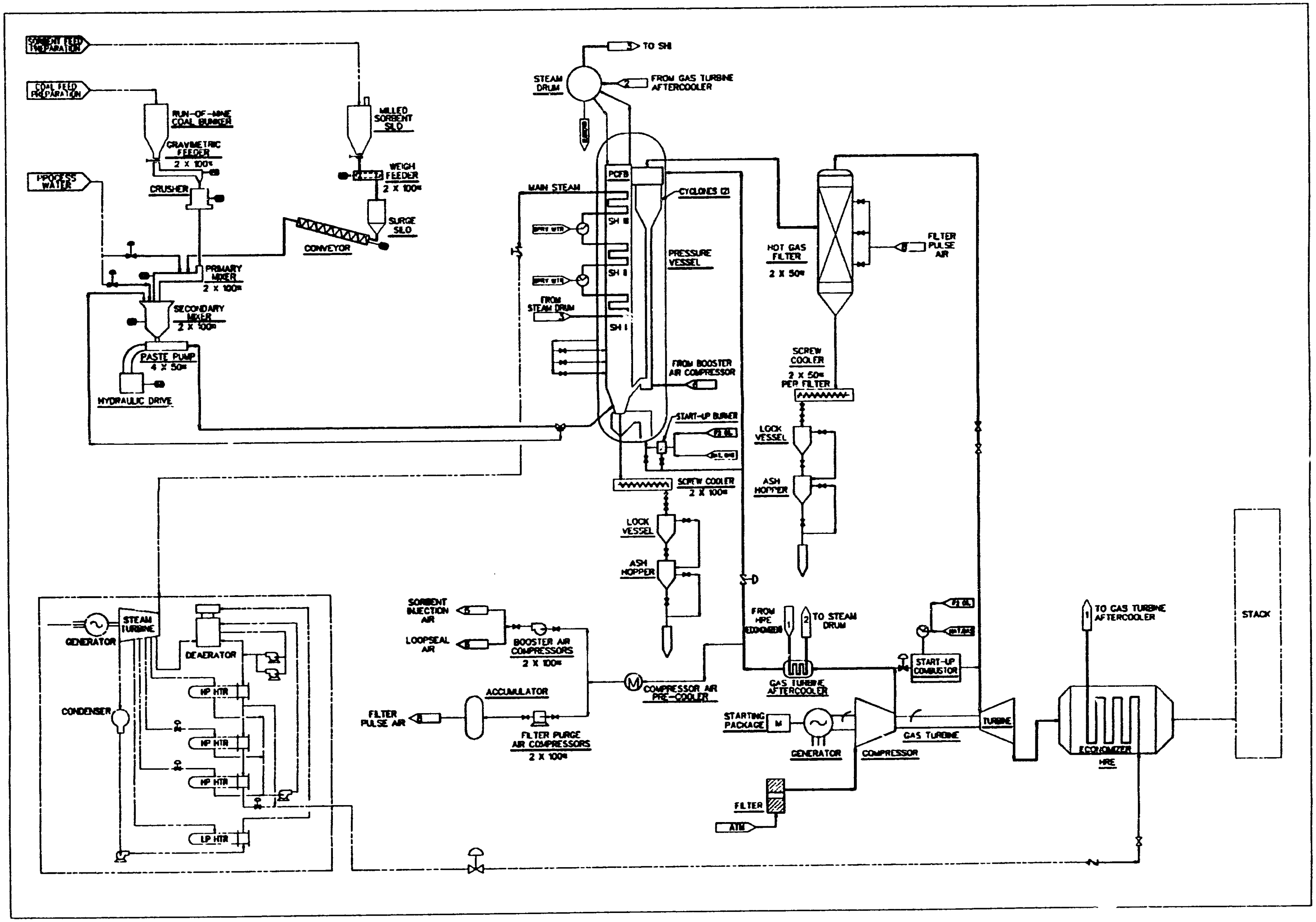

Figure 6 - Process Flow Diagram

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