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Initial Operation of the Tidd PFBC HGCU Test Facility

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DISCLAIMER

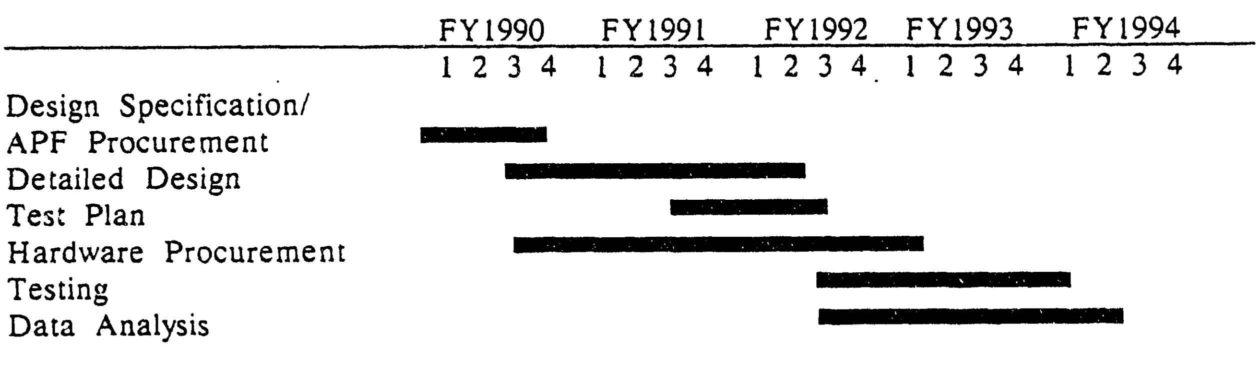
Initial Operation of the Tidd PFBC HGCU Test Facility

CONTRACT INFORMATION

Contract Number	DE-FC21-89MC26042
Contractor	Ohio Power Company c\o American Electric Power Service Corporation 1 Riverside Plaza Columbus, Ohio 43220 (614) 223-1745
Contractor Project Manager	M. J. Mudd
Principal Investigator	J. D. Hoffman
METC Project Manager	R. A. Dennis
Period of Performance	August 2, 1989 to June 30, 1994

Schedule and Milestones

Program Schedule



OBJECTIVES

The objective of this program is to evaluate the design and obtain operating experience for up to two advanced particle filter (APF) systems through long-term testing on a slip stream at Ohio Power Company's Tidd PFBC Demonstration Plant. Performance and reliability of commercial-scale filter modules will be monitored to aid in an assessment of the readiness and economic viability of this technology for commercial PFBC applications.

BACKGROUND INFORMATION

The 70 MWe Tidd PFBC Demonstration Plant in Brilliant, Ohio was completed in late 1990, and is currently in a three-year test program as part of the Department of Energy's Clean Coal Technology Program. Provisions were included as part of the original design to install a slip stream on the PFBC exhaust gases between the fluidized bed and the gas turbine to test an APF system. In November, 1988, AEP submitted a proposal to the DOE for the HGCU Program, and in August, 1989, a Cooperative Agreement was signed. In July, 1990 AEP awarded a contract to Westinghouse Science and Technology Center to provide a candle-based APF. Installation of the slip stream began in December, 1991, and the filter will be commissioned in October, 1992.

PROJECT DESCRIPTION

In the original design, the Tidd PFBC Demonstration Plant utilized seven strings of primary and secondary cyclones to remove 98% of the particulate matter from the gases between the fluidized bed and the gas turbine. The full load gas flow of the unit is 700,000 #/hr at 1580F, and 185 psia. The HGCU slip stream replaces one of the seven secondary cyclones by taking 100,000 #/hr of gas from the discharge of one of the primary cyclones, to outside of the combustor vessel, and into the APF.

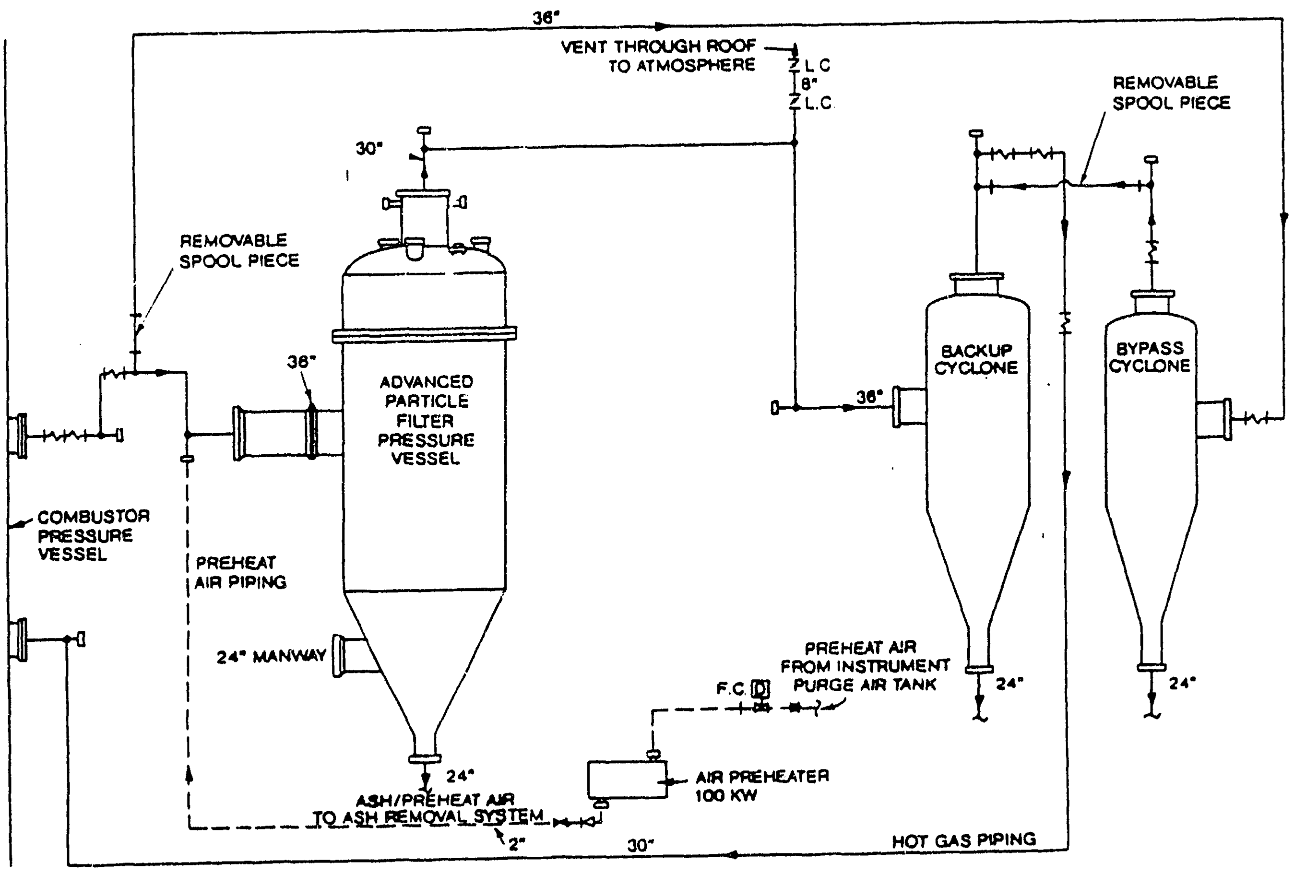


Figure 1. HGCU System Schematic

The gas flows through a back-up cyclone, and then returns to the combustor vessel, where the slip stream flow rejoins the combustor gas at the discharge of the other six cyclone strings.

Figure 1 provides a simplified schematic of the APF system, and Figure 2 shows an isometric view of the system.

Gas at 150 psig, 1550F flows into the filter at 7600 acfm with a dust loading of approximately 600 ppmw. Ash collected in the APF is discharged to a screw cooler and into lockhoppers which feed a vacuum pneumatic ash transport system. A backup cyclone downstream of the filter is installed to clean the gas in case of a filter malfunction, and to balance the pressure drop of the slip stream with the other six cyclone strings.

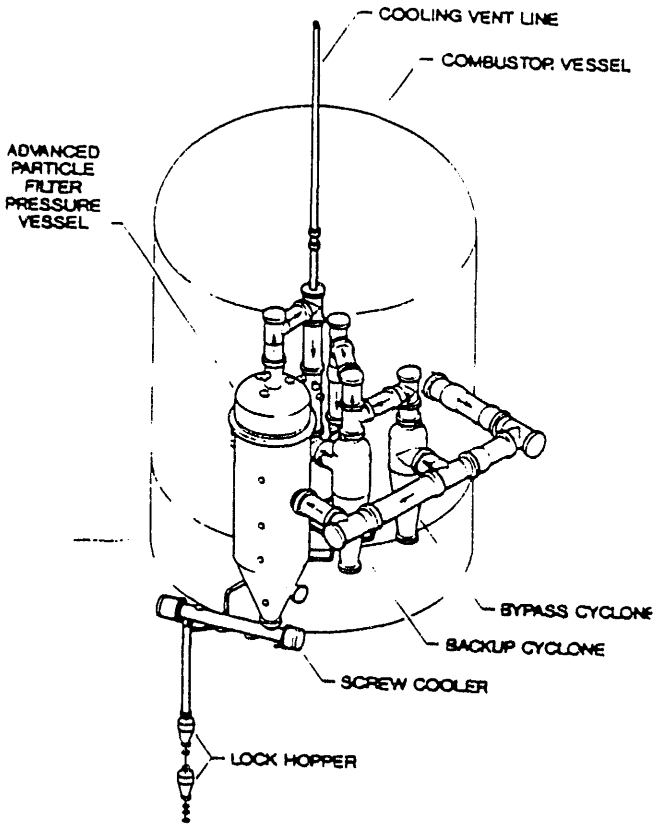


Figure 2. Isometric View of HGCU Slipstream

An air preheating system is used to warm up the system to approximately 350F for start up of the unit. A vent line is provided to facilitate cooling of the filter internals after a shut down.

Table 1 provides the design basis of the APF system.

TABLE 1
APF DESIGN BASIS

Maximum Temperature	1670F
Operating Temperature	1550F
Operating Pressure	164 psia
Gas Flow Rate	100,700 lb/hr
Inlet Dust Loading	5000 - 500 ppm
Outlet Dust Loading	<15 ppm
Average Particle Size	1.5 microns
Temperature Drop	5F
Pressure Drop	3 psi

Filter Vessel. The filter vessel is 10 ft. in diameter, and 44 ft. long. It is internally insulated with alumina-silica ceramic insulation, with an internal 310 stainless steel liner to protect the insulation from erosion. The hot gas enters the side of the vessel radially, flows through the candle elements, through the tube sheet, and exits from the top of the vessel head. The exterior of the APF vessel is not insulated, and is coated with temperature sensitive paint.

Filter Internals. The filter, shown in Figure 3, contains 384 candle filter elements, arranged in three clusters, spaced 120° apart. Each cluster holds three plenums, each arranged vertically, with 38 candles in each of the upper and middle clusters, and 52 candles in each of the lower clusters. The candles are attached to the tube sheets in each plenum by bolted collars and high temperature gaskets.

The candles are Schumacher Dia-Schumalith F40 candles consisting of a clay-bonded sintered silicon carbide support matrix that is coated by an aluminosilicate fibrous membrane. Each candle is 2.36 in. OD (10mm) and 4.92 ft. (1.5m) long.

The 2 in. thick tube sheet is made of RA-333 alloy, and is supported from an inverted "V" expansion cone.

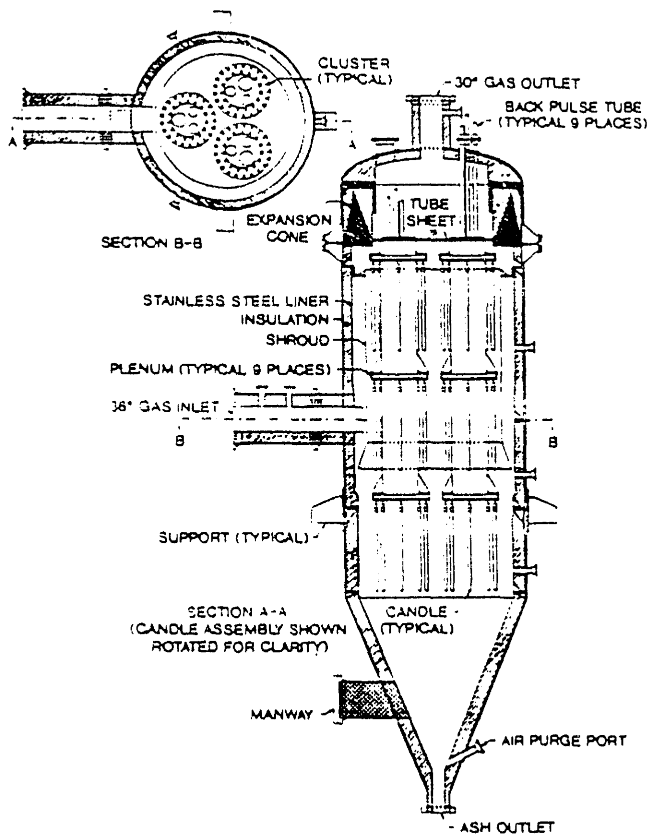


Figure 3. Arrangement of Advanced Particle Filter

Back Pulse System. The back pulse system receives high-pressure back pulse air from a Norwalk reciprocating compressor rated at 282 scfm and 1500 psig. The air discharges from the compressor to an air dryer, and to a primary air accumulator. The air is then directed to a back pulse skid installed near the APF, which comprises of secondary accumulators, and the back pulse valves. The back pulse valves are fast acting (200 to 700 msec stroke time) 2 inch pilot-operated Atkomatic solenoid valves. There are three strings of back pulse valves, with redundant valves on each string. The back pulse pressure will be set at 800 psig.

Hot Gas Piping. The hot gas piping was originally designed with an outer carbon steel A-53 pressure-retaining shell, an inner 310 stainless steel liner, and alumina-silica ceramic fiber blanket insulation between the liner and the shell. The inside of the carbon steel pipe shell was coated with Plasite 4300 for corrosion protection. Table 2 provides design parameters of the piping. Cast refractory rings were used at the ends of each pipe section to support the inner liners, which were designed to allow for thermal expansion at each connection. The system also requires eight expansion joints to allow for thermal expansion and relative movement between the combustor vessel and the HGCU components. The expansion joint bellows were made of 321 stainless steel.

The piping and expansion joints have been redesigned as is discussed later in this paper.

TABLE 2

HOT GAS PIPING DESIGN

	UPSTREAM OF FILTER	DOWNSTREAM OF FILTER
Gas Velocity	60 fps	75 fps
Outer Pipe	36 in. OD	30 in. OD
Inner Liner	20 in. OD	18 in. OD

Ash Removal System. The ash from the APF is discharged through a Denver Hollow-Flight Screw Cooler, which is designed to cool 1000 #/hr of ash from 1670F to 400F. From the screw cooler, the ash discharges to an upper surge hopper and a lower lock hopper, which then discharge into the pneumatic vacuum fly ash removal system which serves the Tidd electrostatic precipitator. The ash is removed from the cyclones by means of a pressurized pneumatic transport system which conveys the ash to the precipitator inlet.

RESULTS

Proof of Concept Tests. During the design phase of the APF system, Westinghouse conducted proof-of-concept testing to verify the design basis of various system components. Test results are as follows:

Thermal Transient Tests. Both candle and cross-flow filters were subjected to thermal transient tests, which imposed a transient of 1550F to 1370F in 200 seconds, followed by a transient of 1370F to 1300F in 400 seconds. These transients simulated expected Tidd trip conditions. After 10 cycles, one cross-flow filter delaminated. Ninety start-up simulations were then conducted, and an additional filter failed. Three of the remaining cross-flow filters were subjected to a 600 hour durability test with no additional failures.

Three Schumacher candles were subjected to 10 trips, 90 start ups, and 1000 blow back cycles with no visible degradation or failures.

HTHP Array Back Pulse Tests. Eleven candles were tested with PFBC ash for 368 hours at a face velocity of 3.4 fpm, for 47 cycles; cleaning was excellent. Five candles were tested for 51 hours at a face velocity of 5.7 fpm for 58 cycles; cleaning was also excellent. Three candles were tested with Tidd ash with a 1/2" back-pulse nozzle; the baseline pressure drop increased from 22" to 45" at 500 psig back pulse pressure. The nozzle size was increased to 3/4". With the larger nozzle size, the baseline pressure drop remained below 35" at 500 psig back pulse pressure.

Alkali Attack. The silicon carbide ceramic media was subjected to 400 hours of exposure to gas-phase alkali in the presence of steam at temperatures of 1550F to 1600F. No physical degradation of the material was observed, however, the hot strength of the material was reduced to less than 30% of its original design value.

Pulse Valve Testing. An Atkomatic pulse valve was subjected to 101,000 cycles without any degradation in performance. The performance declined during the next 5000 pulses. This life well exceeds the cycle life specified for the Tidd APF system.

Cold Flow Modelling. Cold model tests were conducted on an 18 candle array to provide input to the APF vessel design. The cold flow testing also provided a verification of the selection of a radial inlet to the APF compared to a tangential inlet. Cold model testing of a 52 candle array showed less than 10% variation in the back pulse flow distribution.

Gasket Tests. The fibrous ceramic material used for gaskets at the connection between the candles and the tube sheet were subjected to 15,000 cold-gas pulses at

1550F for 50 days, 1800F for 8 days, and cycled from ambient to 1800F for 15 days. No degradation was observed.

Filter Cake Properties. Filter cake properties were checked for three types of ash. Table 3 provides a summary of those results.

Alternative Candle Material Testing. Westinghouse is currently conducting tests of candles made of alumina/mullite. The results of those tests will determine their suitablilty for installation at Tidd for the second APF tests.

TABLE 3

PFBC ASH PROPERTIES

Ash Source	Cake Density gm/cc	Flow Resistance (Relative)	Mean Particle Size (um)	Cleaning Intensity Required (Relative)
Coarse PFB Ash	0.4	1	7.8	Lowest
Grimethorpe Ash(1)	0.6	1.8	5.3	Medium
Tidd Ash	0.3	2.7	3.5	High
Grimethorpe Ash(2)	0.2	6.8	4.0	Highest

(1) With Limestone as sorbent
(2) With Dolomite as sorbent

Initial Commissioning of the Slip stream.

Initial operation of the system using the bypass cyclone occurred during May 21-23, 1992. The APF was not connected to the system for this initial test. The performance of the bypass cyclone, and the operation of the ash removal system from the bypass cyclone was satisfactory. However, several hot spots developed on the piping system, expansion joints, and cyclone as unit load was increased.

On May 23, 1992, an expansion joint bellow ruptured, forcing the unit to be shut down. Another expansion joint bellows was found to have pinhole leaks on the bottom side of some convolutions. The failures were determined to be due to stress corrosion in the 321 stainless steel bellows due to chlorides in an aqueous solution of sulfuric acid. The solution formed from condensation of the moisture in the flue gas on the inside of the bellows.

Following the expansion joint failure, a complete engineering review of the system was undertaken. As a result of this review, several enhancements were made to the system.

From observations made during and after initial operation of the system, certain deficiencies became evident in the design of the hot gas piping system, as listed below:

1. Hot spots appeared at various points in the system, indicating that the insulation was not packed tightly enough in those areas or that a gas leak path into the piping annulus had formed.

2. Several expansion joint bellows exhibited elevated temperatures (250F to 670F) during operation, again indicating inadequate insulation or gas flow into the piping annulus.

3. Corrosion of Type 321 stainless steel expansion joint bellows was evident upon disassembly of the joints. The failure of one joint was attributed to stress corrosion cracking, while the pinholes found in another bellows was due to pitting corrosion. Chlorides were found in the condensed flue gas in the insulation material.

4. Corrosion was also found on carbon

steel surfaces that did not have the Plasite (epoxy) coating which was applied to the inside of the outer pipe. These areas included flange faces inside the gasket area, various nozzles on the cyclones, and the top edges of the damper valves. This corrosion is believed to be from sulfuric acid formed from the flue gas condensation.

System Modifications

After reviewing the above problems and lengthy discussions with other users of hot gas piping systems, consultants, and others, the following piping modifications were decided upon:

1. The expansion joint bellows material was changed from 321 SS to Hastelloy C-22. This is a high nickel alloy that is claimed to have outstanding resistance to pitting, crevice corrosion, and stress corrosion cracking in the presence of oxidizing agents and chlorides.

2. A 2-ply expansion joint bellows was used with pressure monitoring capability between the plies. The inner ply is 0.038" thick and the outer ply is 0.062" thick. Failure of the inner ply will not result in failure of the joint and can be detected with local pressure gauges.

3. The ceramic fiber insulation was replaced with a cast insulating refractory. It was concluded that a cast refractory would present a superior barrier to prevent gas from flowing behind the inner liner in the annulus compared to the ceramic fiber blanket insulation. It was further decided to retain the inner liner (except in two instrument spools) to preclude the possibility of refractory spalling off and getting carried into the gas turbine. As additional enhancement, 1/4" thick ceramic fiber rollboard insulation was used on the ID of the cast refractory for expansion and cushioning.

   The refractory selected has a density of 50 lbs/ft^3 and a thermal conductivity which should keep the outer pipe temperature below 250F.

4. It was decided to clad the inside surfaces of all piping and flange faces with Hastelloy C-22 material. The cladding is 16 gauge (1/16" thick) and was applied to the pipe ID by plug welding. The function of this inner liner is to protect the inside of the outer pipe from the possibility of corrosion from condensed acid.

5. The liner end connection collars were modified where possible to minimize gas leaking behind the liner. One end of the collar was seal welded to the liner where possible.

6. The liners in the expansion joint assemblies were modified to include a bellows at the same location as the bellows in the outer pipe. This was necessary to allow the outer pipe, refractory, and liner to move together while still permitting freedom of movement at the bellows area. (Most of the expansion joints undergo angular rotation, not axial movement.)

7. The flow liner tees were modified to function as 90° elbows where possible. The blind end of the tee was cut off and a curved plate was welded onto the tee to form an elbow. The end of the outer tee was filled with cast insulating refractory in order to better insulate the blind flange. This change will reduce the possibility of ash collecting in the dead end of a tee and becoming dislodged and being carried into the gas turbine.

Figure 4 provides a comparison of the original and modified designs of the pipe sections.

Following initial operation of the system, both cyclones were opened and inspected by the manufacturer, refractory supplier, and refractory installer. Some cracking of the refractory was apparent, but was not considered to be serious. Some corrosion was evident on the man way nozzle and flange. As a result, Plasite (epoxy) coating was applied to nozzles and flange faces on the cyclones and the APF vessel.

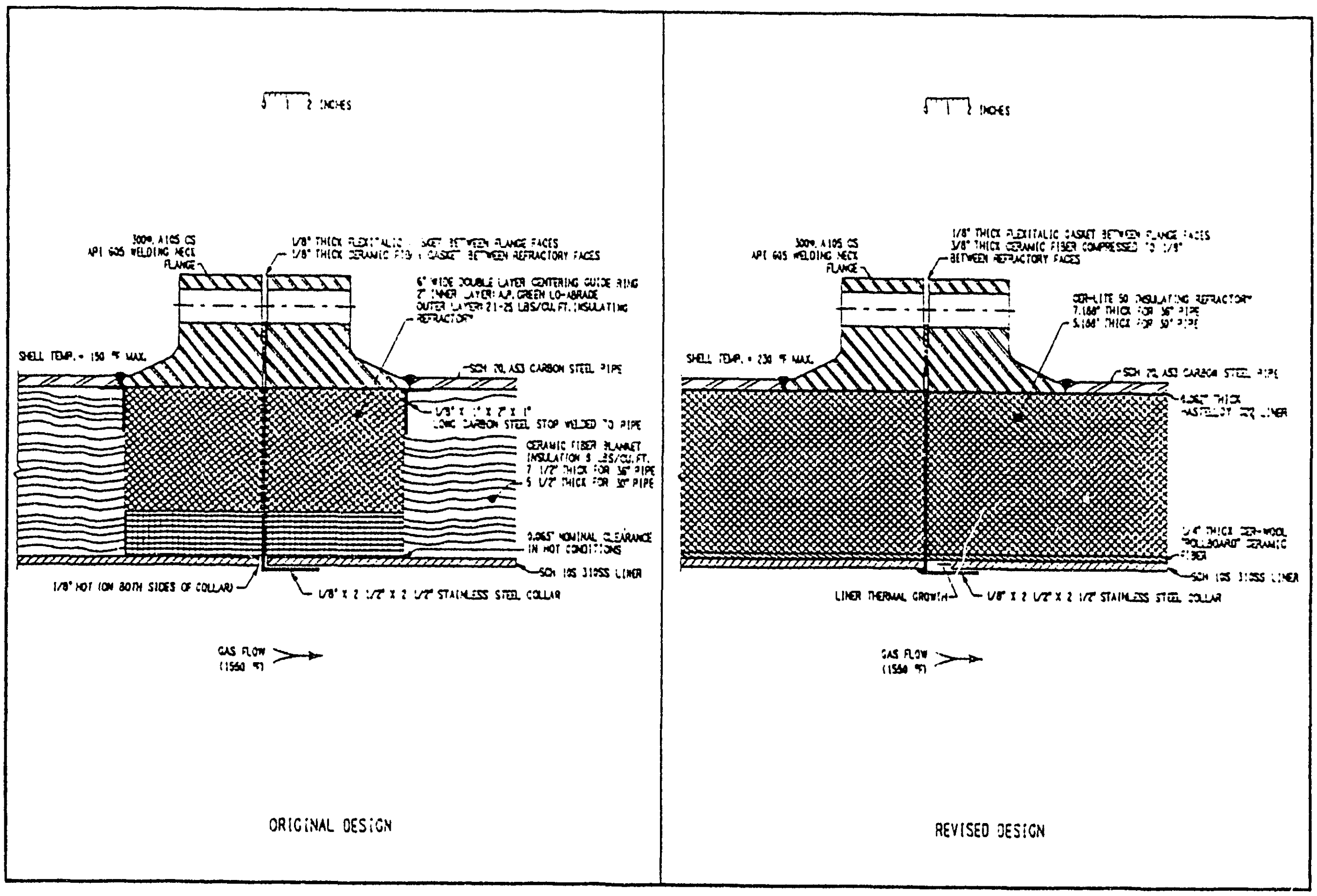


Figure 4. HGCU Pipe Section

FUTURE WORK

The engineering and design of the above modifications were completed during the summer of 1992, and in September,1992, reassembly of the pipe sections began at Tidd. The HGCU system will be commissioned with the APF in October, 1992. Present plans are to operate the APF system throughout the rest of the Tidd three-year test program which is scheduled to end in February, 1994.

In mid-1993, the Schumacher Dia-Schumalith candles may be replaced with alumina\mullite candles pending the results of the proof of concept testing currently underway on the alumina\mullite candles.

REFERENCES

Durner, M. W. 1990. Tidd PFBC Hot Gas Clean Up Test Facility, presented at the Seventh Annual Coal-Fueled Heat Engines and Gas Stream Clean Up Systems Contractors Meeting, March, 1990. DOE/Metc-90/6110, NTIS/DE90000480.

Mudd, M. J. and M. W. Durner. 1991. AEP's PFBC Hot Gas Clean Up Test Program. Proceedings of the 1991 International Conference on Fluidized Bed Combustion, Volume 2, ed. E. J. Anthony, p. 953-957.

Hoffman, J. D. 1991. Update of Tidd PFBC Hot Gas Clean Up Test Facility, presented at the Eighth Annual Coal-Fueled Heat Engines and Gas Stream Clean Up Systems Contractors Meeting, July,1991. DOE/METC-91/6122, NTIS/DE91002091.

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