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Integrated Low Emissions Cleanup System for Direct Coal-Fueled Turbines

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Integrated Low Emissions Cleanup System for Direct Coal-Fueled Turbines

CONTRACT INFORMATION

Contract Number	DE-AC21-87MC24257
Contractor	Westinghouse Electric Corporation Science & Technology Center 1310 Beulah Road Pittsburgh, PA 15235 (412) 256-2440
Contractor Project Manager	Thomas E. Lippert
Principal Investigators	Richard A. Newby Mary Anne Alvin Dennis M. Bachovchin Eugene. E. Smeltzer Wen-Ching Yang
METC Project Manager	Richard A. Dennis
Period of Performance	September 30, 1987 to December 31, 1992

Schedule and Milestones

FY 1992 Program Schedule

	S	O	N	D	J	F	M	A	M	J	J	A	S
Phase II													
Facility Design	—	—	—	—									
Facility Assembly		—	—	—	—	—	—	—	—	—			
Shakedown Testing						—	—	—	—	—	—		
Phase III													
Testing									—	—	—	—	—
Evaluation												—	—

OBJECTIVES

The Westinghouse Electric Corporation, Science & Technology Center (W-STC) is developing an Integrated Low Emissions Cleanup (ILEC) concept for high-temperature gas cleaning to meet environmental standards, as well as to provide economical gas turbine life. The ILEC concept simultaneously controls sulfur, particulate, and alkali contaminants in high-pressure fuel gases or combustion gases at temperatures up to 1850 °F for advanced power generation systems (PFBC, APFBC, IGCC, DCFT). The objective of this program is to demonstrate, at a bench scale, the conceptual, technical feasibility of the ILEC concept.

BACKGROUND INFORMATION

The Westinghouse ILEC concept is an attempt to integrate multiple gas cleaning functions into a single vessel, thus increasing the value of the ceramic barrier filter system above that of removing particulate. In the concept, shown in Figure 1, a ceramic barrier filter vessel cleans either an oxidizing gas (eg., PFBC or the dilution zone of a DCFT), or a reducing gas (eg., gasifier fuel gas or DCFT combustor quench zone gas). Vertical arrays of filter elements, candle-type, cross-flow type or ceramic bag-type, are depicted as being supported from a tubesheet, and are housed in a refractory-lined pressure vessel. Filter cake is periodically released from the filter elements by back-pulsing with clean gas. The released filter cake drops into a conical bin at the base of the vessel for removal. The ILEC concept is operated with the injection of sulfur sorbents, alkali sorbents, and possibly selected deposit-modifying additives (e.g., kaolin) that produce a filter cake on the filter elements that is easily removed by pulsed cleaning. The injected sulfur sorbents are -325 mesh calcium-based sorbents, or other sorbent materials that effectively capture sulfur (H_2S or SO_2) at the ILEC temperature in the contact time available in the filter vessel. The sulfur removal may represent either bulk sulfur removal or a second-stage sulfur removal function. The injected alkali sorbent is -325 mesh emathlite that removes alkali species (sodium and potassium components) from the gas to meet projected turbine alkali limits. Other alkali sorbents such as hectorite and bauxite are also candidates.

W-STC in-house and field testing at temperatures up to 1700°F has shown that ceramic barrier filters can exceed the particulate removal needed for both environmental standards and for turbine erosion and deposition protection. A concern for the use of ceramic barrier filters in high-temperature, coal-fired, turbine applications

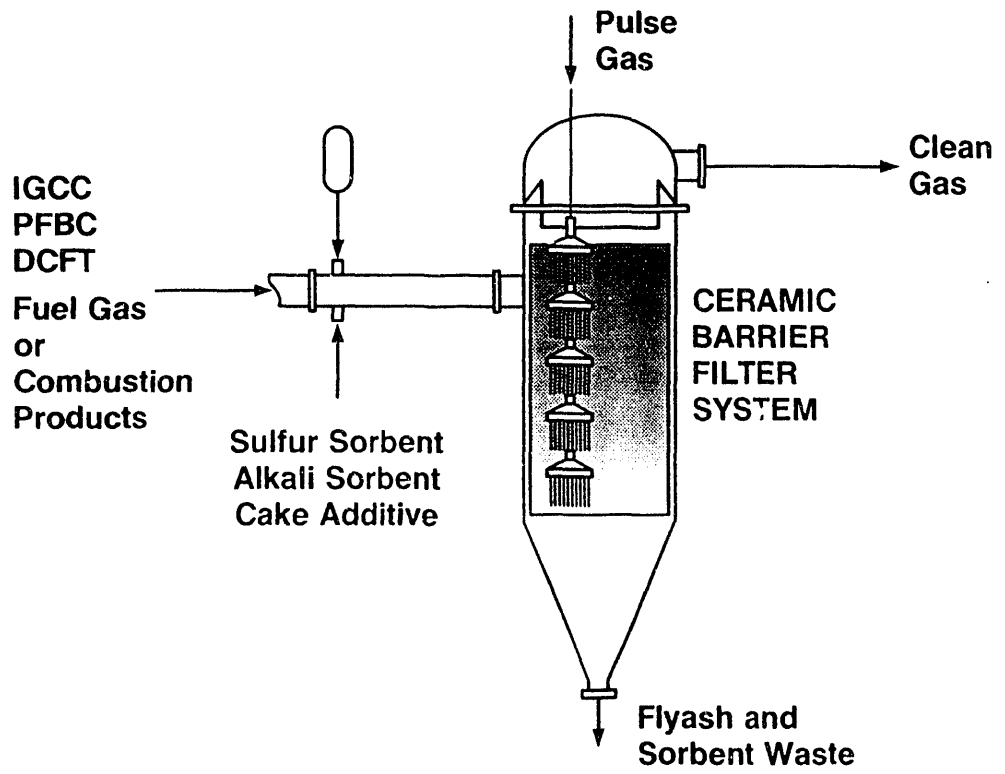

Figure 1. Westinghouse ILEC Concept

is that adhesive particles (slag particles or sticky fly ash particles) may be emitted that may form a filter cake that has low permeability and/or that is difficult to remove from the filter elements by normal pulse cleaning. In the ILEC concept, adhesive particles will interact with injected sorbent particles, and/or injected additive particles to modify the filter cake adhesive nature so that it is effectively cleanable and has higher permeability. Other concerns exist for the operation of ceramic barrier filters at temperatures above about 1400°F that relate to the design of uncooled metal structures and the durability of ceramic filter elements and gaskets. Aspects of these concerns are also considered in this program.

PROJECT DESCRIPTION

The ILEC development program has a 3 phase structure:

- Phase 1 - Laboratory-Scale Testing
- Phase 2 - Bench-Scale Equipment Design and Fabrication
- Phase 3 - Bench-Scale Testing

Phase 1 laboratory testing has been completed. In Phase 1, entrained sulfur and alkali sorbent kinetics were measured and evaluated, and commercial-scale performance was projected (Newby, et al., 1991). Related cold flow model testing has shown that gas-particle contacting within the ceramic barrier filter vessel will provide a good reactor environment. The Phase 1 test results and the commercial evaluation conducted in the Phase 1 program (Newby, et al., 1990) support the bench-scale facility testing to be performed in Phase 3. Phase 2 is nearing completion with the design and assembly of a modified, bench-scale test facility to demonstrate the technical feasibility of the ILEC features. This feasibility testing will be conducted in Phase 3.

RESULTS

Bench-Scale Facility Design

An existing natural gas-fired, bench-scale, high-pressure, high-temperature test facility, currently operated at the W-STC site for the development of ceramic barrier filters at simulated PFBC conditions using reinjected PFBC fly ash, is being modified to study ILEC performance under simulated, coal-fired combustion conditions. The current system is designed to operate at temperatures up to about 1650°F.

The objective of this bench-scale simulation is to produce a gas having pressure, temperature, gas composition (SO_2, alkali content, and particulate content), and fly ash particulate characteristics similar to actual coal-fired PFBC or DCFT combustors. In general, such a simulation can be achieved, with major factors being heat losses and slag deposition in the combustor. Temperatures ranging from 1550°F to about 1850°F are considered. The test facility will produce a gas flow of about 90 acfm, at 10 atmospheres pressure, and will fire coal representing from 5 to 40 % of the total energy input. Nominal material flow rates for the testing are:

Coal: 2 to 18 lb/hr
Sulfur sorbent: 1 to 5 lb/hr
Alkali sorbent: 0.01 to 0.1 lb/hr
Total dust loading to filter: 3,000 to 7,000 ppmw

An assembly drawing of the modified facility is shown in Figure 2. A horizontal, coal-natural gas combustor is attached to a vertical, filter pressure vessel. The coal-natural gas combustor has been designed to couple to the

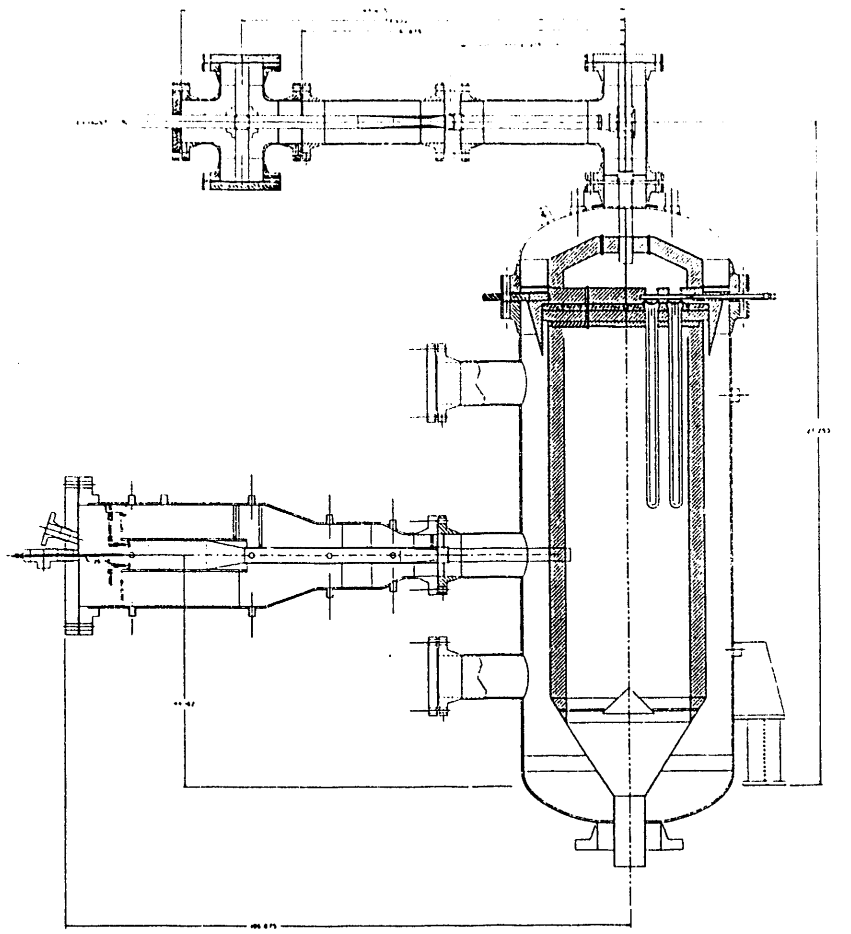

Figure 2. Modified Test Facility Assembly Drawing

existing pressure vessel inlet flange. The exhaust gas piping system incorporates multiple points for gas sampling.

The combustor is a carbon steel pressure vessel, refractory-lined, with an internal, high-alloy steel liner. It is designed to operate entirely on natural gas, or with coal and natural gas combinations. Micronized coal is injected axially with natural gas and primary combustion air to achieve sufficient combustion temperatures in the primary zone under fuel lean conditions. Secondary air is injected after the primary combustion section to reach the selected test temperature. Sulfur sorbents, alkali sorbents, or deposit additives are injected into the secondary zone of the combustor also. The combustor vessel is designed with internal cast refractory insulation, and internal metal surface cooling may be added if needed to minimize slag deposition.

The existing filter pressure vessel has been modified to operate up to 1850 °F by the addition of an internal layer of fiber insulation and a high-alloy, metal liner. A new, uncooled tubesheet, with a 31-inch plate diameter, has also been designed with special features to allow higher-temperature operation. The tubesheet supports six ceramic candle filter elements, each 1.0 meter in length. The candle ceramic material is mullite, an oxide-based ceramic superior to non-oxide ceramics for high-temperature duty, manufactured by Coors. These candles are pulsed cleaned in sets of two. The inlet gas enters the vessel horizontally, below the level of the candles, with no baffle to deflect the inlet jet.

The outlet piping section incorporates gas sampling for particulate content, alkali content, sulfur content, and other gas species of interest, as well as instrumentation to measure total gas flow and temperature.

During the Phase 2 design phase, several additional test efforts were conducted to support the design and operation of the bench unit with specific, critical information. These are:

- Cold flow model simulation
- Candle and gasket high-temperature durability
- Filter cake additive testing

Cold Flow Model Simulation

An existing cold flow model of a ceramic barrier filter similar in size to the ILEC test unit was operated to confirm the effectiveness of the gas inlet configuration. This cold flow model had previously been operated with an array of cross-flow filters to simulate the cross-flow filter unit installed at the Foster Wheeler Development Corporation Second-Generation PFBC test site in Livingston, New Jersey. It had also been operated for cold flow simulation of a candle filter array for the AEP Advanced Particle Filter at the Tidd, PFBC plant. The cold flow model was designed to simulate high-temperature, high-pressure flow fields, with the dimensionless Reynolds Number and Froude Number being consistent at the near atmospheric-pressure, low-temperature test conditions. The materials of construction of the metal internals are also selected to result in vibrational information that can be easily related to the high-alloy, and high-temperature, high-pressure conditions.

An array of 6 candle elements having the configuration to be used in the ILEC bench-scale testing was installed in the cold flow unit. The gas inlet configuration was modified to provide inlet conditions simulating those to be used in the ILEC bench-scale unit. The gas enters the filter vessel radially through a 2" ID nozzle at a velocity of nominally 70 ft/s. No baffle has been placed at the nozzle exit to deflect the gas, this being specifically avoided so that slag deposition will not occur. The inlet nozzle is 8" below the bottom of the candles, and the six candles are arranged so that the upward directed eddy that will be produced will not impinge directly on the candles.

A key aspect for the selection of the in et flow distribution configuration was its ability to survive the high-temperature environment, and its practicality for fabrication and attachment in the high-temperature unit. Each of the inlet flow distribution configurations were tested at the maximum gas flow rate with smoke tracer to provide visualization of the flow field that resulted in the vessel. The configuration was judged acceptable if it provided an inlet jet that did not penetrate excessively to the opposite vessel wall, did not impinge directly on the candle filters, and promoted an internal gas circulation field in the vessel that did not result in flow induced vibration. A simple inlet design was selected from the testing. The jet issued from the nozzle reached across the vessel and was deflected tangentially outward causing two recirculating gas loops that travelled up the vessel, and a stream moving down the center of the vessel. Gas velocities were relative low after the jet was deflected, and no vibration or motion of the candles was detected. It is possible that erosion might occur on the metal liner directly across from the nozzle, or a deposit might form on the liner at that point. Neither of these would be of significant concern over that duration of the test program.

A second phase of testing was conducted to compare the observed gas flow profiles when using a simple inlet flow device that will direct the inlet gas slightly downward to dissipate the jet further from the candles. This inlet configuration was selected also for its simplification of design and ease of support at the high temperature conditions. The gas flow pattern was not improved by having a baffle on the inlet to deflect the gas downward. The mixing within the vessel was just as intense as without the baffle and the gas flow pattern was very similar except that there was more mixing within the conical region at the base of the vessel. It is concluded that the design having no inlet gas baffle is acceptable for the test program.

Candle and Gasket High-Temperature Durability

Several tests were conducted to assess the short-term durability of ceramic candle elements and gaskets when subjected to temperatures of interest to this program, temperatures up to 2100°F. These tests were integrated with parallel testing in other DOE/METC sponsored programs looking at the durability of ceramic barrier filter elements. Sections from candle filters (alumina/mullite, F40 Dia Schumalith, and Refractron 505 materials), and ten candidate gasket materials were subjected to oven and flow-through tests for times ranging from about 400 hours, up to 1500 hours. The candles were characterized with respect to permeability and strength relative to their virgin properties, and the gaskets were characterized according to resiliency and compressibility. A recent W-STC paper has reviewed much of this work (Alvin, et al., 1992). Several general conclusions can be drawn from the work completed and under way:

- Non-oxide ceramics (eg., SiC) loose strength rapidly due to steam and alkali interaction, and will not be suitable materials for filter elements in the temperature range of interest (> 1500°F).

- Oxide-based ceramics (eg., mullite) do not loose significant strength, at least over 2000 hour test periods, and will be suitable filter element materials. Longer term durability is still uncertain.

- In-situ alkali removal within the filter vessel may result in better filter element durability.

- Several gasket materials show sufficient short-term durability for the conditions of interest.

- Factors such as thermal shock may also be a key filter element failure mechanism at this higher temperature operating range.

Filter element durability and mechanisms of failure continue to be evaluated in laboratory tests and field tests.

Filter Cake Additive Testing

Some preliminary filter cake additive tests were conducted in a test unit very similar in design to the bench-scale unit under construction. The objective of the testing was to confirm that the filter performance and pulse cleaning effectiveness with a difficult fly ash could be improved by using a small injection of additive into the filter vessel. The tests were performed with five ceramic filter elements supported in the vessel at a temperature of about 1600°F, and a pressure of 100 psig. The candle elements were 1.5 meter long, mullite candles, manufacture by Coors to a W-STC specification. The filter was operated under oxidizing conditions with a face velocity of about 7 ft/min. A fly ash material known to result in difficult filter cleaning was utilized (Grimethorpe "Red" fly ash). Two tests were performed. The first used the Grimethorpe Red fly ash with a dust loading of 9450 ppmw in the gas. The filter pressure drop was recorded during the test operation with the cleaning pulse set to trigger when the pressure drop reached 40 iwg. The pressure drop history of the run is shown in Figure 3. The baseline pressure drop is seen to increase, and the pulse period decrease

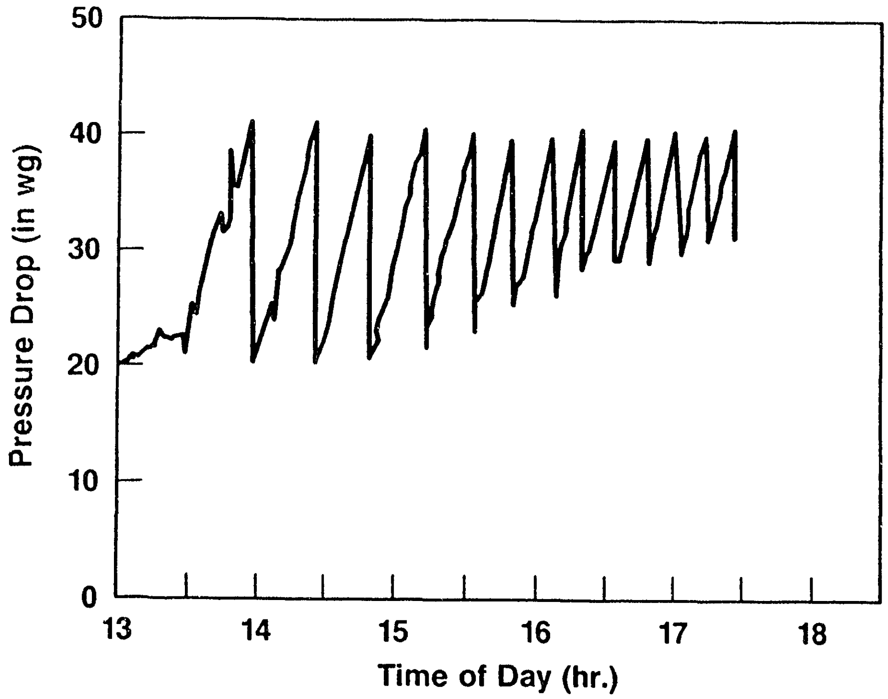

Figure 3. Filter Pressure Drop Behavior with Difficult Fly Ash (Grimethorpe Red)

with time. A total of 13 pulse cleans were conducted during the test. The baseline pressure drop degradation is more rapid the typical conditioning that ceramic barrier filter elements experience and is equivalent to a "deposit" formation on the elements. This performance would lead to unacceptably frequent pulsing of the filter system, and eventually high filter system pressure drop.

The filter elements were removed and cleaned. After reinstallation, a second test was initiated using the same feed rate of Grimethorpe Red fly ash with micronized dolomite mixed in to 10 wt%, resulting in a dust loading of 10,390 ppmw. The dolomite was 92 wt% less than 325 mesh, relatively coarse compared to the fly ash. Volumetrically, the dolomite represented less than 5% of the mixture. In this second test, the trigger pressure drop was increased to about 45 iwg to maintain the same initial difference between the baseline and trigger pressure drop.

Figure 4 shows a portion of the filter pressure drop trace, having generally less increase in the baseline pressure drop and less reduction in the pulse period. Two effects can be measured in the test. The first, the relative filter cake flow resistance, is illustrated in Figure 5. The filter cake resistance is plotted against operating time for both tests, and the resistance when the additive is included is about half of that of the fly ash only. This is itself a significant filter performance improvement. The second factor, the degradation in the filter baseline pressure drop, or the effective "deposit" formation on the filter elements, is illustrated in Figure 6. Here, the effective deposit pressure drop over the initial, clean filter element pressure drop is plotted against time. Initially, the operation with cake additive shows a more rapid degradation in baseline pressure drop, but ultimately the additive case results in a lower deposit pressure drop. Longer term testing is required to see if the baseline pressure drop

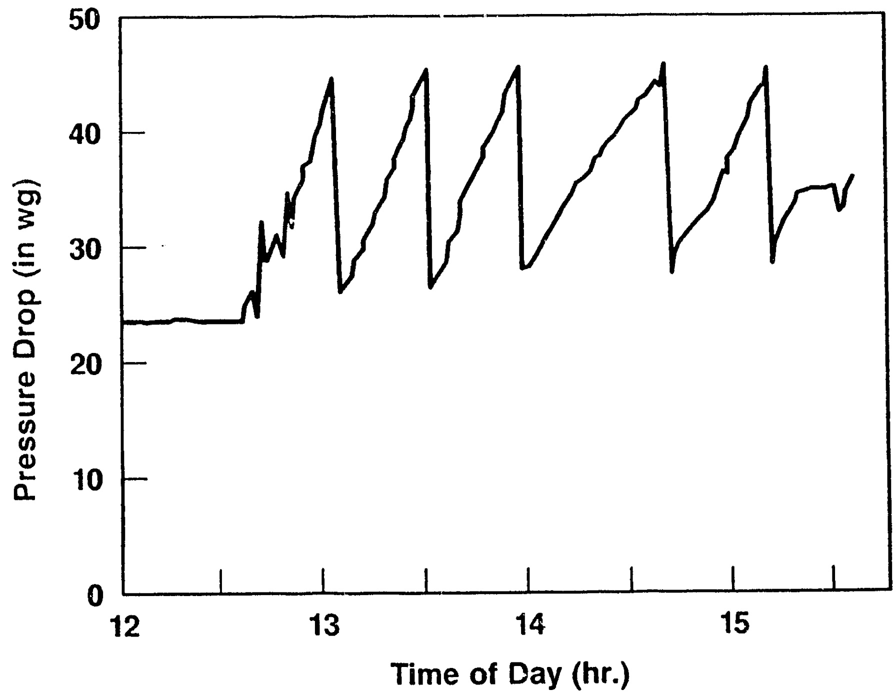

Figure 4. Filter Pressure Drop Behavior with Cake Additive (10 wt% Dolomite)

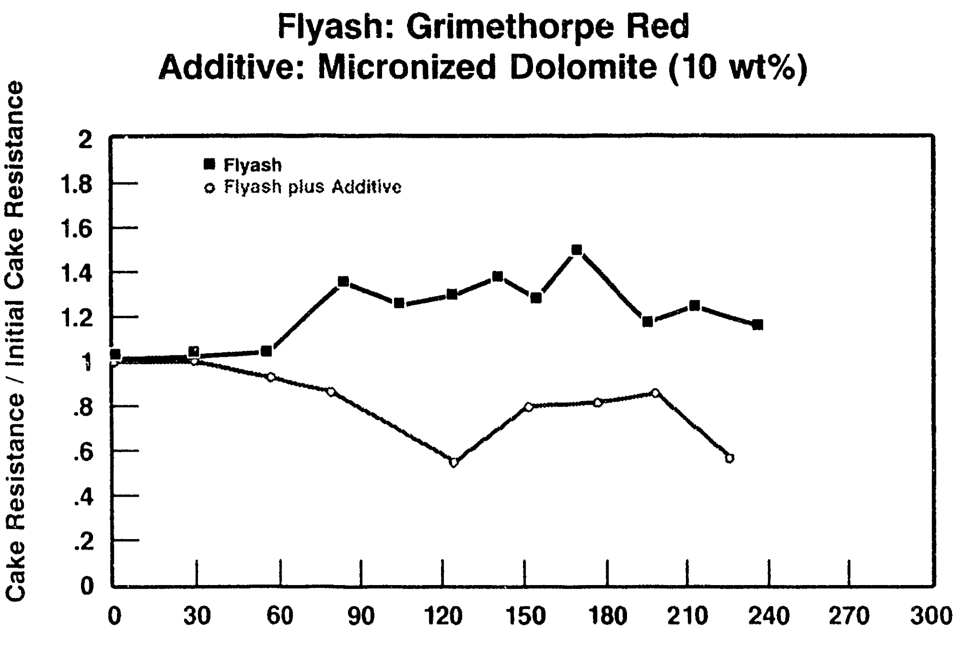

Figure 5. Filter Cake Flow Resistance Behavior

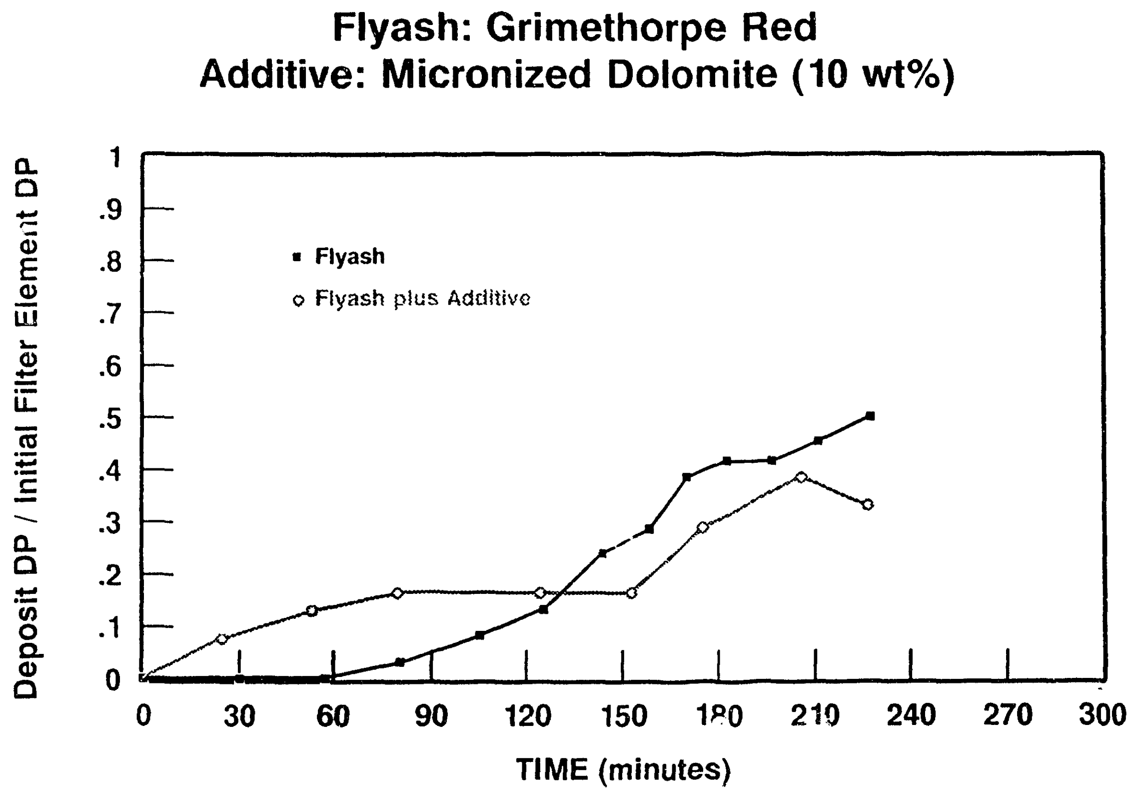

Figure 6. Filter Deposit Pressure Drop Behavior

degradation will reach a lower, steady level. This type of testing will be continued in Phase 3.

Bench-scale Facility Fabrication and Assembly

The status of the bench-scale facility fabrication and assembly is as follows:

- The coal-natural gas-fired combustor vessel, burner internals, and liners have been fabricated. Refractory has been cast is the vessel and the combustor is being assembled.

- The tubesheet has been fabricated and insulation has been installed.

- The filter vessel liners have been fabricated and insulation has been installed in the vessel.

- The pressurized, coal feed system has been purchased and installed.

- Water-cooled exhaust gas piping has been fabricated and awaits installation.

- Instrumentation for gas flow measurement and SO_2 measurement has been obtained. An alkali sampling probe will be fabricated to measure vapor-phase alkali at the filter vessel outlet.

- Micronized coal and emathlite have been received for the test program. 200 pounds of emathlite has been pulverized to -325 mesh and was supplied by MFM. A 2.5 ton sample of coal, lower Kittanning Seam bituminous coal, has been micronized to 90% < 325 mesh, and stored in inerted drums. The coal contains about 4.4 wt% sulfur, and about 11 wt% ash. Pulverized dolomite will be used as the sulfur sorbent in the test program. A highly reactive lime being developed by the Illinois State Geological Survey will also be tested.

FUTURE WORK

Phase 3 of this development program will conduct testing of the integrated, bench-scale ILEC system to determine its performance with respect to sulfur removal, alkali removal, filter cake cleanability and general filter operability, and high-temperature durability of components. The test parameters are:

- Temperature (1550°F to 1850°F)
- Sulfur sorbent type and Ca/S ratio
- Alkali sorbent feed rate
- Deposit additive type and feed rate

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