

INTEGRATED LOW EMISSIONS CLEANUP SYSTEM FOR
DIRECT COAL FUELED TURBINES
(Moving Bed, Fluid Bed Contactor/Ceramic Filter)

Seventeenth Quarterly Report

Quarterly Status Report for the Period October - December 1991

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ABSTRACT

The United States Department of Energy, Morgantown Energy Research Center (DOE/METC), is sponsoring the development of direct coal-fired turbine power plants as part of their Heat Engines program. A major technical challenge remaining for the development of the direct coal-fired turbine is high-temperature combustion gas cleaning to meet environmental standards for sulfur oxides and particulate emissions, as well as to provide acceptable turbine life.

The Westinghouse Electric Corporation, Science & Technology Center, is evaluating two Integrated Low Emissions Cleanup (ILEC) concepts that have been configured to meet this technical challenge: a baseline ceramic barrier filter ILEC concept, and a fluidized bed ILEC concept. These ILEC concepts simultaneously control sulfur, particulate, and alkali contaminants in the high-pressure combustion gases at turbine inlet temperatures up to 2300°F. This document reports the status of a program in the seventeenth quarter to develop this ILEC technology for direct coal-fired turbine power plants.

EXECUTIVE SUMMARY

During the Seventeenth Quarter of the program, the Phase 3 tasks for the design and fabrication of the bench-scale test facility has been the main focus. While the facility design activities have been completed, several areas of potential concern have been reassessed to confirm the designs, or to define backup approaches:

- excessive thermal gradients between the tube sheet and the ceramic candles,
- candle and gasket high-temperature durability at 1850 and 2100°F,
- vessel inlet gas flow field and direct impingement damage to the candle elements,
- excessive metal liner temperatures in the combustor, as well as high-alloy liner fabrication problems,
- combustor flame stability.

Design modifications and backup approaches have been developed for all of these areas.

Almost all of the equipment and materials for the facility have been received, and assembly has continued during the quarter. The facility will start test operation in early March, 1992. Arrangements have continued for the supply of coals, sorbents and additives for the test program.

1. INTRODUCTION

Development of direct coal-fueled turbine power cycles, in the Department of Energy Heat Engines program, is focused on staged, slagging combustor designs that potentially provide high performance, compact and low cost power generation systems. The power generation systems demand high performance from hot-gas cleaning equipment to meet environmental requirements and to satisfy turbine protection requirements, using concepts that are, as yet, undeveloped.

To provide emissions control and turbine protection from gas- and solid-phase contaminants in direct coal-fired turbine systems, contractors are currently testing: beneficiation of coal to minimize ash and sulfur content; injection of sulfur sorbents into or following the combustor; staged combustion to limit NO_x formation; slag removal by impaction; inertial particle collection; and barrier filters within the combustor-cleanup train. While there is a basis for the development of some of these proposed approaches to hot-gas cleaning a number of concerns make the development of an innovative, integrated, low emission, gas cleanup (ILEC) concept desirable. Specific concerns include the high cost of highly beneficiated coals, the economic penalty of separate gas cleaning functions arranged in series, the potentially limited ability of in-situ sulfur control to achieve low sulfur emissions, the potentially limited ability of inertial collection to achieve sufficiently low particulate emissions, and the need for gas-phase alkali control to provide acceptable turbine life.

New approaches for sulfur and alkali control may be required at the proposed temperature levels of some direct coal-fired systems, and new approaches for particulate control may be required in the environment of potentially molten and/or sticky particles. An

integrated, multi-function cleaning stage may be an economic requirement when using minimally-cleaned, high-sulfur, high-ash coals.

In addition, the ILEC system must be compatible with the application. In its programs on Heat Engines, the Department of Energy is attempting to develop coal-fueled turbines for large electric utility power plants, for industrial power plants, and for small, stationary and transportation power generation systems. This broad range of applications encompasses a large variety of turbine sizes and designs, a range of turbine operating conditions, different arrangements for coupling the coal combustor to the gas turbine, and greatly differing gas cleanup requirements. ILEC concepts that can be adapted to all of these applications are needed.

In this program, two advanced, high-temperature Integrated Low Emissions Cleanup concepts are addressed that combine particulate and gas phase contaminant removal in a single, compact filter device that is intended for operation in direct, coal-fueled turbine systems. The program will investigate the key process and design parameters of the concepts, evaluating both a "baseline" and a fluid bed ceramic filter with immersed barrier filters. In both concepts finely sized sulfur and alkali sorbents are injected into the combustion gas stream, react with the gas-phase sulfur and alkali species while modifying the sticky nature of the ash that is carried over from the combustor. Additives may also be injected to control the filter coal behavior. Sorbent and ash particles are collected on ceramic barrier filters placed in the contactor vessel.

The program has been divided into three phases. Phase I of the program deals with critical laboratory testing and conceptual commercial design evaluation. Phase I has been completed, although continuation of some key Phase I test work has been undertaken. In Phase II, upgrading of a HTHP bench-scale facility will take place along with the design and procurement of the baseline integrated cleanup test system. Phase II

has been initiated. Phase III of the program involves the actual HTEP bench-scale testing and engineering assessment of the integrated cleanup devices and systems.

2. WESTINGHOUSE ILEC CONCEPTS

The Westinghouse ILEC concepts are extrapolations to higher temperatures of gas cleaning technologies being developed for similar technical purposes in other applications. These generally lower temperature technologies are:

- ceramic barrier filter particulate control (up to 1700°F)
- fluidized bed filtration (up to 1200°F)
- sulfur sorbent injection into high-temperature gas streams (up to 3000°F), and fluidized bed desulfurization (up to 2000°F)
- alkali sorbent injection into high-temperature gas streams (up to 1600°F)

These technologies are currently being developed for applications that require high-pressure gas cleaning at temperatures up to about 1700°F (Pressurized fluid bed combustion and pressurized coal gasification systems, for example). Additional technical basis for the development of these ILEC concepts is provided by the Department of Energy and GRI development programs for high temperature heat recovery systems using fluidized bed heat exchangers,¹ and for high temperature ceramic heat exchangers that operate at temperatures exceeding those required for direct coal-fired turbines.^{2,3}

Ceramic barrier filters have the potential to provide extremely high particle removal efficiencies at high gas temperatures. Testing at temperatures up to 1700°F has shown that they can exceed the particulate removal needed for both environmental standards and for turbine erosion and deposition protection. The major concern for their use in direct coal-fired turbine applications is that adhesive particles (slag

particles or sticky fly ash particles) will be emitted from the coal combustor that may form a filter cake that is difficult to remove from the filter elements by normal pulse cleaning. It is the premise of the ILEC concepts proposed in this program that the combustion gas containing adhesive particles will interact with added sorbent particles, or inert additive particles, to either remove the adhesive particles before they reach the ceramic barrier filter elements, or to modify the filter cake adhesive nature so that it is removable. This premise is applied in the two ILEC concepts pictured in Figures 2.1 and 2.2.

In the first concept shown in Figure 2.1, the "baseline" ILEC concept, is a ceramic barrier filter vessel having a design much like that of the ceramic barrier filters vessels being developed for lower temperature applications. An array of vertical filter elements, candle-type or cross-flow type, is supported from a tube sheet, and is 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 baseline 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 potential success of the baseline ILEC concept is suggested by deposit formation observed in other programs that inject sulfur sorbents into conventional coal-fired furnaces, and programs that have injected deposit additives into coal-fired turbine gases.^{4,5,6} The injected sulfur sorbents are -325 mesh calcium-based sorbents, or advanced sulfur sorbents (strontium carbonate, for example), that effectively capture SO_2 at the turbine inlet temperatures in the relatively short contact times available. The injected alkali sorbent is -325 mesh emathlite, hectorite, or others, that removes alkali species (sodium and potassium components) from the gas to meet projected turbine alkali limits. The

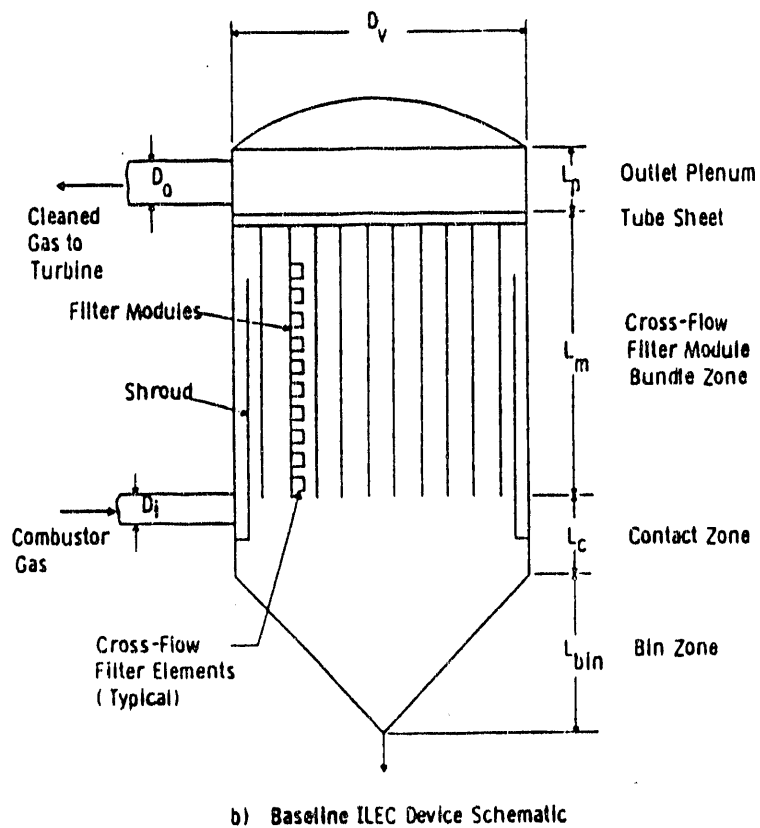
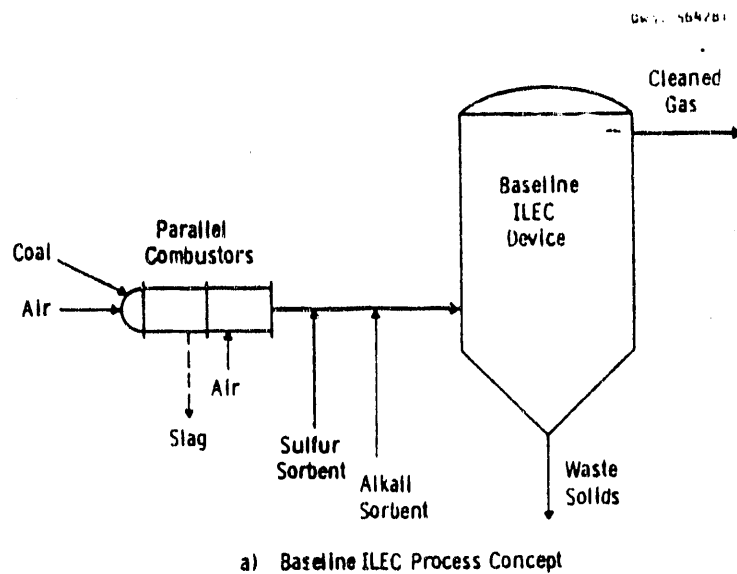


Figure 2.1 - Baseline ILEC Concept

effectiveness of emathlite has been demonstrated at a small-scale at temperatures up to about 1600°F in both reducing and oxidizing gases.⁷ Other alkali sorbents such as hectorite and bauxite are also candidates.

The second ILEC concept, in Figure 2.2, is a fluid bed filter concept. In this concept the combustion products are passed through a fluidized bed of either inert particles or sulfur sorbent particles. The adhesive particles agglomerate with the fluid bed media, removing them from the gas. The effectiveness of fluidized bed filters for particle removal by agglomeration phenomena has been demonstrated in other development programs at lower temperatures. Ceramic candle filters are vertically immersed into the fluid bed to prevent the elutriation of coarse particles, or the entrainment of fine particles from the fluid bed. In addition, the mixing action of the fluid bed provides cleaning of the filter cake from the ceramic candle filter surfaces, resulting in the potential elimination, or minimization, of the pulsed gas filter cleaning system. A similar fluid bed filter concept, using immersed candle filter elements in the bed, has been previously proposed for use in catalytic reactor systems.⁸

The fluid bed media has a particle size similar to particles used in bubbling PFBC applications. The fluid bed media if inert could be either alumina, sintered dolomite, slag particles generated in the combustor, or fly ash particles generated from the plant solid waste. The most economical material is used. If the fluid bed media is to function as a sulfur sorbent, it would be a cheap, calcium-based material such as dolomite. Sulfur sorbent particles and alkali sorbent particles can also be injected into the gas stream prior to the fluid bed filter.

The gas distributor for the fluid bed requires a design that is free from plugging of the orifice holes. Prior technology development suggests that water cooling, or air cooling, of the distributor plate to some critical temperature, combined with the selection of large orifices having sufficiently high gas velocities will provide protection against

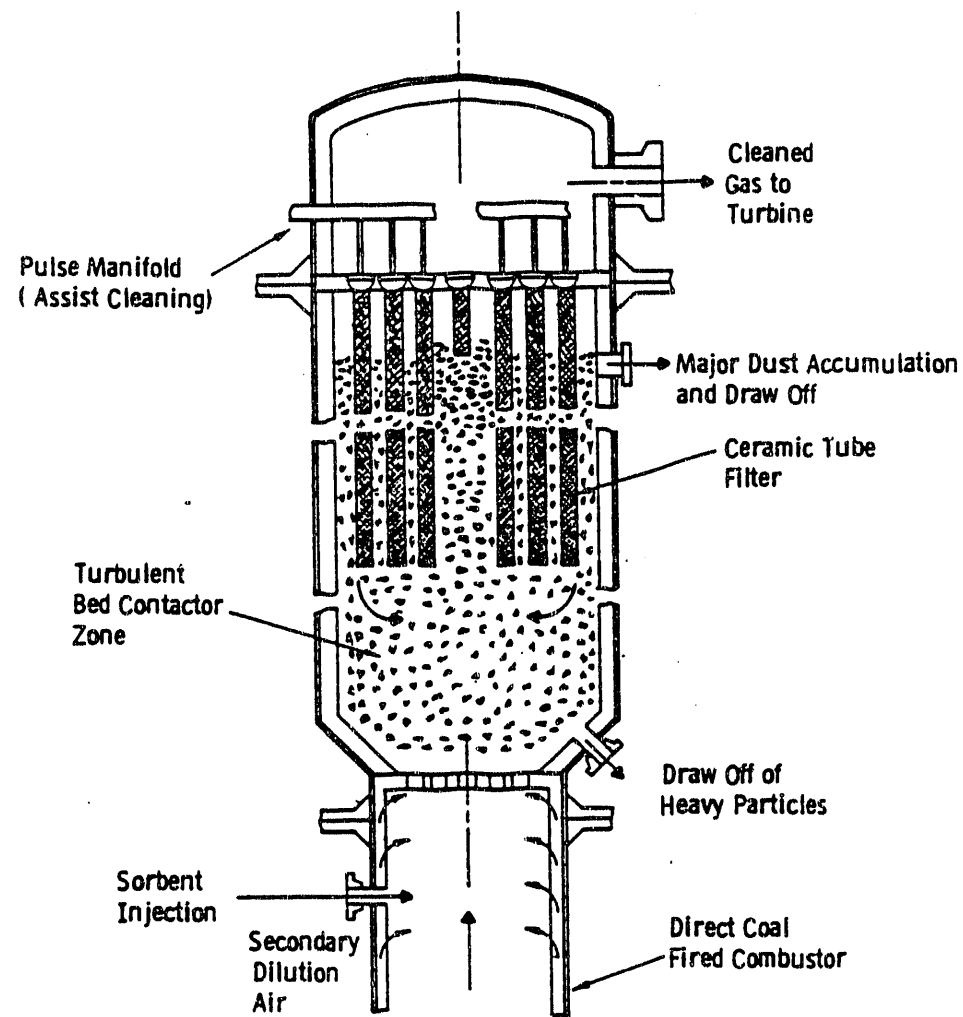


Figure 2.2 - Fluid Bed ILEC Concept

deposit formation and plugging. The resulting fluid bed is relatively compact because the immersed ceramic candle filters permit the size of the freeboard region above the fluid bed to be minimized. The captured adhesive particles are removed with a continuous underflow stream of bed media. Fine particles that are not adhesive in nature will tend to segregate to the top of the fluid bed where they can be separately removed from the vessel.

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3. PROGRAM STRUCTURE AND OBJECTIVES

The program is being conducted in three phases to demonstrate at the bench scale the ILEC concepts. Phase I of the program has been completed, but some Phase I extended testing is being conducted. Phase I of the program deals with laboratory sorbent screening tests, cold flow testing, and commercial system evaluation of the ILEC concepts to support the bench-scale facility design and testing in Phases II and III. In Phase II, upgrading of a HTHP facility will take place along with the design and procurement of the filter test systems. The bench-scale test program will utilize an existing, high temperature, high pressure (HTHP) facility located at the Westinghouse Science and Technology Center. The facility will be upgraded for coal feeding to attain a range of combustion gas conditions that would be typical of the conditions expected at the exhaust of direct coal-fired combustors being developed in the current DOE Heat Engines programs. This facility will be used in Phase III to test the components and advanced design features of the baseline ILEC systems and to verify the engineering design principles of the concepts.

4. SUMMARY OF SEVENTEENTH QUARTER PROGRAM STATUS

4.1 - PHASE I CONTINUATION: SUPPLEMENTAL LAB-SCALE TESTING

Objectives: Conduct laboratory testing that supports the bench-scale facility design and operation, as well as testing of critical fluid bed ILEC concept issues.

OBJECTIVE I-1 - TEST PLAN DEVELOPMENT

Identify areas requiring supplemental laboratory testing to support the bench-scale facility modification design and operation. Include critical issues for fluid bed ILEC concept. Define detailed test plan for each supplemental area. The test plan shall be reviewed and approved by the DOE COR.

Status

The test plan development has been completed. Some aspects of the test plan have been modified as the program focus and issues have been re-established. No effort has been expended on this task during this quarter.

OBJECTIVE I-5.1 - ENTRAINED SULFUR REMOVAL

Conduct tests of HTHP sulfur removal in the existing entrained reactor at specific test conditions to optimize sorbent properties and operating conditions for effective sulfur removal, as detailed in the Objective I-1 test plan.

Scope

Conduct tests to measure sulfur removal kinetics with the specific sulfur removal sorbents to be used in bench-scale testing. Preliminary range of test conditions:

- 1850 to 2100°F
- calcium-based sorbents (limestone, dolomite, hydrated lime)
- 0.1 to 1 second gas residence time
- oxidizing conditions
- sorbent particle size a parameter

Analyze the reaction products and the kinetic data. Confirm the existing entrained sulfur removal model by evaluation of known DCFT test data. Select the sulfur sorbent types, sizes and feed rates to be used in the bench-scale testing.

Status

This testing has been completed, with an option to return to complete some critical testing if needed at a later date. The data collected has been combined with past data, including DCFT tests reported by Solar Turbines, and an evaluation has been completed. Commercial ILEC sulfur removal performance has been projected. The sulfur removal evaluation was presented in the Twelfth Quarterly Report. No effort was expended on this task during this quarter.

OBJECTIVE I-5.2 - ALKALI REMOVAL

Modify the entrained reactor and conduct tests, as detailed in the Objective I-1 test plan, of HTHP alkali removal at specific conditions to optimize sorbent properties and operating conditions for effective alkali removal.

Scope

Design the entrained reactor modification required to test alkali removal kinetics. Modify the equipment. Conduct tests to measure alkali removal kinetics with the specific alkali removal sorbents to be used in bench-scale testing. Preliminary range of test conditions:

- 1850 to 2100°F
- emathlite and hectorite sorbents
- 0.1 to 1 second gas residence time
- oxidizing and reducing conditions
- sorbent particle size a parameter

Analyze the reaction products and the kinetic data, and re-assess the existing entrained alkali removal model. Select the alkali sorbent types, sizes and feed rates to be used in the bench-scale testing.

Status

A total of 22 tests have been conducted in the program, with temperatures of 1850 and 2100°F, and NaCl vapor contents ranging from 1.3 to 112 ppmw. Two operating modes of testing were used to assess the relative contributions of the entrained and the cake removal. In all of the tests the gas-particle contact time in the entrained zone was 2 seconds, and in the cake zone the particles resided for 15 minutes. The test results have been reported in the 15th and 16th Quarterly Reports. Conversions up to 9.24 weight percent of the emathlite reaction product

were measured, almost 50% of the saturation conversion of emath¹be. In general, the performance under entrained conditions was better than with a cake only. The results have been correlated and estimates of commercial alkali removal performance in the ILEC have been developed. The complete evaluation will be reported in the task topical report currently in preparation.

OBJECTIVE I-5.3 - ADDITIVE SELECTION AND PERFORMANCE

Select deposit additives for the specific operating conditions, coal ash types, alkali and sulfur sorbents to be used in the bench testing. Confirm additive effectiveness in furnace tests.

Scope

Use prior test results and thermodynamic phase diagrams to select economical additives for filter cake modification. Procure these additives. Conduct furnace tests with the mixtures to confirm their performance.

Status

This objective has been reduced in scope to a minimum effort of identifying appropriate additives for Phase 3 testing. No effort has been expended on this task during this quarter.

OBJECTIVE I-5.4 - FLUID BED CONCEPT CRITICAL ISSUES TESTING

Design, construct, and operate cold flow hydrodynamic simulation of fluid bed filter based on Phase I commercial conceptual design.

Scope

Identify critical issues, including distributor design, ash-bed separation, entrained sorbent mixing in the bed, filter element movement, filter element self-cleaning, element arrangement, etc. Include continuous ash feeding and ash removal capabilities. Eliminate fluidized slugging bed behavior by sizing gas flow to near 1000 actual cubic foot per minute. Prepare detailed design and assemble the facility. Select and procure commercial candle elements. Conduct tests as detailed in the Objective I-1 test plan. Re-assess critical issues and re-evaluate commercial design concept. Develop test plan for HTHP fluid bed testing.

Status

In prior cold model testing effective design and operating conditions have been identified. The major feature remaining to be developed is the removal of the fly ash particles from the fluid bed filter. The fluid bed filter concept appears to be of significant interest to some high-temperature applications:

- applications of relatively small gas flow where the tube sheet required to support the single layer of ceramic candles does not become too large in diameter to be practical;
- applications having primarily "sticky" fly ash particles that will be substantially removed by injection into the fluid bed media.

The small-scale, industrial DCFT applications such as those of Solar Turbine and Allison Gas Turbine appear to fit this description. The ability to simulate sticky fly ash particle behavior in the cold model,

while possible, would be very uncertain, and it seems likely that cold model testing will not be appropriate for the development needed for this process. Hot testing of the concepts is needed under simulated DCFT conditions.

OBJECTIVE I-6 - TOPICAL REPORTS

Prepare a Phase I Technical Report detailing the supplemental lab-scale efforts and two topical reports, i.e., High Temperature, High Pressure Deposit Additives; and Sorbents for High Temperature, High Pressure Vaporous Alkali Species Removal.

Status

Topical reports are scheduled near the completion of the appropriate Objectives. No topical reports have been completed during this quarter.

4.2 - PHASE II: BENCH-SCALE FACILITY DESIGN AND FABRICATION

OBJECTIVE II-1 - TEST PLAN DEVELOPMENT

Update from Phase I the test plan for the bench-scale facility test program based on the Westinghouse baseline ILEC concept. Include integrated particle, sulfur, and alkali removal performance, deposit additive characteristics of the filter cake, pressure drop, cleaning, and materials.

Scope

Estimate test conditions to evaluate the performance of simulated coal-fired turbine operation with the Westinghouse baseline ILEC concept. Include integrated

- particle removal performance
- sulfur removal performance
- alkali removal performance
- filter cake modification performance
- filter pressure drop and cleaning performance
- filter material behavior

Status

A preliminary test plan development has been completed that has focused on testing at temperatures of 1850 and 2100°F. The test plan will be expanded to include lower temperatures to broaden the applicability of the testing to PFBC and IGCC as well as DCFT. No effort has been expended on this task during this quarter.

OBJECTIVE II-2 - BENCH-SCALE FACILITY MODIFICATION DESIGN

Develop detailed design of the facility for the baseline ILEC concept bench-scale testing that meets the test plan requirements. Designs shall be submitted to the DOE COR for review and approval.

Scope

Utilize an existing HTHP filter test facility modified for

- temperatures up to 2100°F
- oxidizing environment
- partial coal injection/methane-fired
- sulfur removal with calcium-based sorbents
- alkali sorbent injection
- deposit additives
- cross-flow and candle filters elements

Select:

- appropriate candle material for this duty
- appropriate instrumentation for SO_x, and alkali measurement
- sorbent and additive feeding equipment and feed nozzles

Prepare:

- material and energy balances
- process flow diagrams
- equipment sizes, designs, and specifications
- vessel fabrication drawings

Status

The bench-scale facility design modifications have been completed. Additional considerations have been made to check the possibility of problem areas and to define backup approaches:

- excessive thermal gradients between the tube sheet and the ceramic candles,
- candle and gasket high-temperature durability at 1850 and 2100°F,

- vessel inlet gas flow field and direct impingement damage to the candle elements,
- excessive metal liner temperatures in the combustor, as well as high-alloy liner fabrication problems,
- combustor flame stability.

The possibility of extreme temperature gradients between the convectively-cooled tube sheet and the supported, relatively hot candle elements was assessed, to consider this as a possible mode for candle failure. It was concluded that the porous nature of the Coors candle at the flange and the resulting partial gas flow through this region, and the relatively low thermal conductivity of the porous ceramic in this region would make this an unlikely problem. This will be monitored by the continuous recording of thermocouples placed at several locations on the tube sheet in the vicinity of the candle penetrations. The commercial configuration of the candle supports would make this problem even less remote than the test unit configuration. A similar concern for candle failure due to cold gas pulse cleaning was assessed by applying Westinghouse models of pulse cleaning dynamics to the systems. The minimum candle temperatures were estimated during pulse cleaning and the pulse system design was modified to maximize the eduction of hot gas during cleaning. This modification simplified much of the pulse piping significantly, providing a single pulse point for all six of the candle located at a remote location rather than directly over each candle exit.

Several special high-temperature tests of various candle materials and gasket materials have been completed. In general, the Coors candles appear to be well suited for the high-temperature operation, and appropriate gasket materials can be identified also. A review of the testing and evaluation work completed is presented in Appendix A.

Cold model testing of the vessel inlet configuration and the gas flow pattern issued from the inlet nozzle was conducted and it was concluded that the configuration, without any inlet baffle would be

acceptable. Operation without an inlet gas baffle permits sticky, molten particles to be retained by the inlet gas to subject the filters to worst conditions.

The initial natural gas-coal combustor uses a high-alloy, uncooled metal liner. Difficulties in fabricating this liner have been identified by vendors requested to supply the liner. Also, analysis indicates that the liner temperature could exceed design temperatures and limit the liner life. Alternative air-cooled, water-cooled, and uncooled refractory liners have been evaluated. The complexity of the air- and water-cooled designs, and the excessive heat losses of the water-cooled design, make the refractory design preferable. This cast refractory design will be completed in place of the high-alloy, uncooled design. The details of the natural gas flame and the coal flame stability have also been reassessed, and new coal inlet configuration and new swirler design have been completed and will replace the original design. The possibility of loss of flame during pulse cleaning pressure surges has also been evaluated. Past test experience indicates that acceptable operation should be achievable.

OBJECTIVE II-3 - BENCH-SCALE FACILITY FABRICATION AND ASSEMBLY

Prepare the facility for testing the baseline ILEC by modifying the existing HTHP test facility as required.

Scope

Fabricate the facility modifications and required new test vessels. Purchase equipment, candle and cross-flow filters, and instruments. Assemble the facility. Procure and characterize sulfur sorbents, alkali sorbents, deposit additives, coals, and coal ashes.

Status

During the quarter almost all equipment and materials have been received. Assembly of the test facility equipment has continued, with startup still scheduled for early March, 1992. The DOE Project Officer visited the STC site during the quarter and toured the facility.

A source of coal, a bituminous coal and a Western subbituminous coal, already prepared to our specifications (pulverized to -325 mesh, dried and stored in inerted 55-gal drums) has been identified at another Westinghouse site. The coal, purchased for a completed PETC program, is available in sufficient quantity for the test program. A formal request has been made to take possession of the coal. Amax Coal has also been contacted to supply coals for the program as a backup. A decision must be made soon to select the coal supplier in case the existing supply is not made available to this program.

A source of sulfur sorbent, highly activated lime has been arranged for the test program from the Illinois State Geological Survey. They are currently producing large quantities of the lime for sulfur removal testing in conventional boilers. Sulfur sorbents of commercial grade lime and pulverized dolomite will also be procured for comparative sulfur removal testing. Pulverizer emathlite, for entrained alkali

removal will be purchased from MFM Industries. Several clay-type additives will also be procured for use as modifier for the filter cakes during the test program. Effort is still underway to arrange storage either at the STC site or at some other Westinghouse site.

OBJECTIVE II-4 - BENCH-SCALE SHAKEDOWN TESTING

Conduct shakedown testing of the bench-scale facility and instruments to demonstrate the operating capabilities and acceptance to design requirements.

Scope

In support of the Objective II-2 facility modification design, operate the existing facility, prior to modification, to determine its current capabilities for high temperature operation and conduct brief tests to examine the consequences of high temperature operation. Operate the modified facility at maximum and minimum flow test conditions. Operate coal, ash, sorbent and additive feed equipment. Confirm accuracy of instrumentation.

Status

Shakedown testing of the modified facility is scheduled to be initiated following completion of Objective II-3.

OBJECTIVE II-6 - TOPICAL REPORTS

Prepare the required Phase II Technical Report

Status

No reports are currently being prepared.

OBJECTIVE II-7 - PROGRAM MANAGEMENT AND ADVISORY BOARD

Provide overall project management for meeting research objectives and for cost and schedule control. Continue Phase I Advisory Board activities in obtaining Heat Engine contractors' consultation and integration of ILEC cleanup research efforts through exchange of technical requirements and information.

Status

No discussions with heat engine contractors on the subject of this program were made this quarter. Discussions with Northern States Power on this program have been continued with interest toward filter DCFT program development.

APPENDIX A

EVALUATION OF CERAMIC CANDLE FILTER MATERIAL THERMAL STABILITY

APPENDIX A

EVALUATION OF CERAMIC CANDLE FILTER MATERIAL THERMAL STABILITY

Preliminary information was generated in order to determine whether currently available candle filter materials are thermally stable at the higher operating temperatures imposed by the direct coal fired application.

Twenty mm (~8 inch) sections of porous ceramic material were removed from a Coors Ceramics (alumina/mullite), Refractron (clay bonded silicon carbide), and Schumacher Dia Schumalith (clay bonded silicon carbide) candle filter. Each section of material was placed in a high temperature furnace and then subjected to 400 hours of exposure to temperatures of either 1010°C (1850°F) or 1150°C (2100°F). Note that Schumacher's maximum permissible operating temperature for the Dia Schumalith matrix is 1000°C (~1830°F), which is somewhat lower than expected coal-fired turbine temperatures. After 400 hours of static air exposure all candle filter samples remained intact, and had neither "slumped" nor deformed at either 1010°C or 1150°C.

C-rings were removed from each of the 1010°C and 1150°C exposed candle filter samples, as well as from as-fabricated sections of candle filter material. Although candle wall thickness varied (i.e., Coors: 10 mm; Refractron: 10 mm; Schumacher: 15 mm), the thickness of the C-rings was kept constant at 15 mm. C-rings cut from the 1010°C and 1150°C static air exposure tests will be strength tested at their original test temperature in December. C-rings cut from the as-fabricated filter sections have been subjected to C-ring testing at room temperature (five C-rings) and at 870°C (five C-rings). These data are summarized in Table 1.

Table 1

STRENGTH OF POROUS CERAMIC CANDLE FILTERS

As-Fabricated Matrix	Room Temperature	870°C
Coors	12.292 _± 1.727	13.680 _± 1.536
Refractron	17.528 _± 1.060	17.282 _± 1.583
Schumacher	8.864 _± 1.361	7.720 _± 0.721

Both the Coors Ceramics alumina/mullite and Refractron clay bonded silicon carbide candles appear to be stronger at room temperature and at 870°C than the Schumacher clay bonded silicon carbide candle. From these data the hot strength of the silicon carbide materials appears to be slightly less than their room temperature strength, while the converse appears to be true for the Coors matrix. Keep in mind that only five C-rings were tested at each temperature, and that further testing would be required to place statistical significance on the differences of the room temperature and hot strength data.

Strength testing at both room temperature and at 870°C does, however, indicate that each material fractures in a brittle manner. As show in Figure 1, temperature tends to broaden the load versus deflection curve for each material implying that a softening occurs within each matrix at 870°C.

Testing of each ceramic candle filter material that experienced 400 hours of exposure at temperatures of 1010°C and 1150°C in static air will tentatively be completed in December. Crystallization has already been demonstrated for the Coors alumina/mullite matrix as a result of prolonged heating at 870°C. Crystallization of the alumina/mullite matrix is directly related to an increase in strength of the porous ceramic matrix. Therefore the objective behind this exercise is to determine whether similar microstructural changes occur within the Refractron or Schumacher clay bonded silicon carbide materials, and to identify whether the higher temperatures accelerate crystallization and strengthening of the Coors alumina/mullite matrix. For completion of our strength database, testing of each heat-treated matrix will also be performed at room temperature.

Additional testing will include O-ring strength testing of each material at room temperature in order to complete our preliminary survey of the candle filter strength data, and to confirm our result with those of others. This effort will tentatively be completed in December.

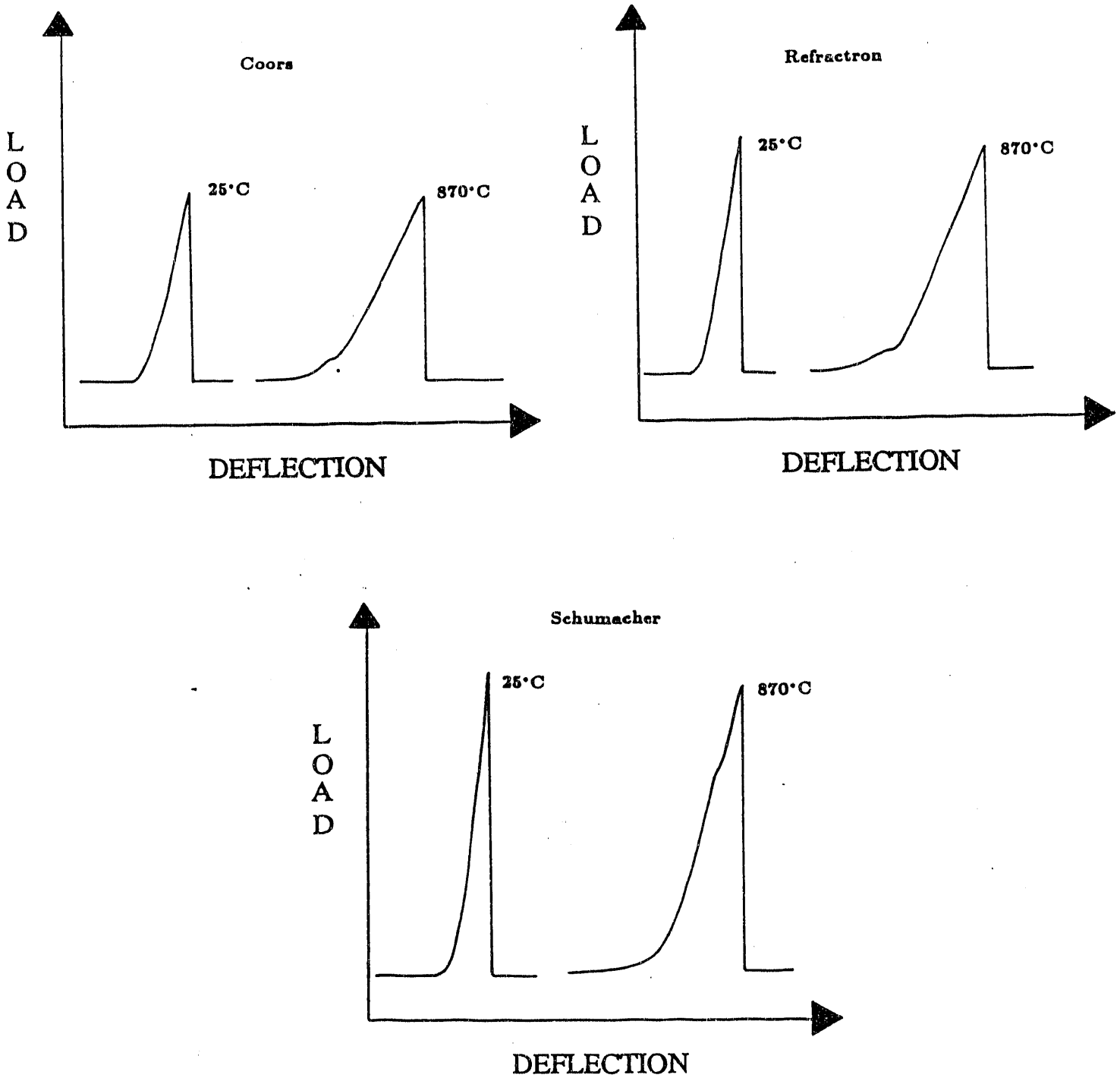


Figure 1 - Room Temperature And 870°C Load Versus Deflection Curves For Each Porous Ceramic Candle Filter Material

END

**DATE
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9 / 10 / 92

