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Status of Granular Bed Filter Development Program

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3.3 Status of Granular Bed Filter Development Program

CONTRACT INFORMATION

Contract Number DE-AC21-90MC27423

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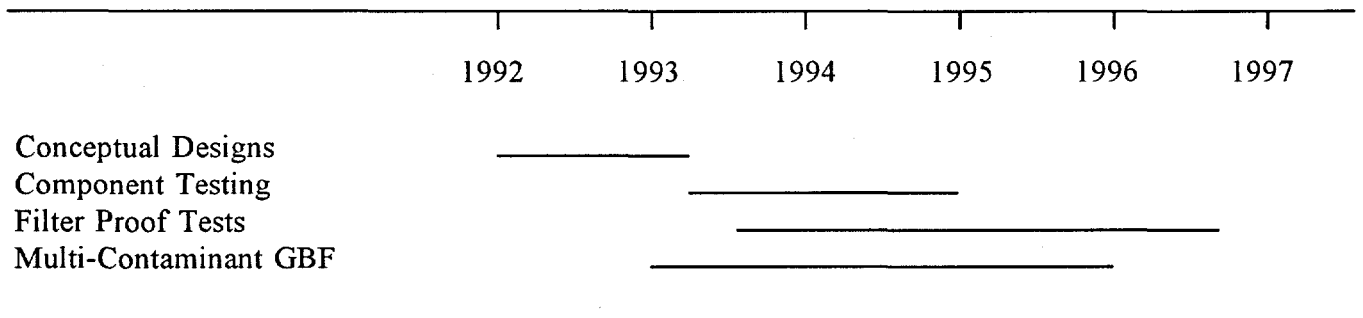
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Period of Performance October 1992 to April 1995

Schedule and Milestones

FY92-97 Program Schedule



OBJECTIVES

Efforts to design and operate coal-fired gas turbines plants in advanced gasification and combustion power cycles have been intensified in recent years. These efforts, such as those carried out by Combustion Power Company in the early 1970's, have been plagued by turbine problems due to ash-laden combustion gases. It is generally recognized that a hot gas cleanup

train must be used before the gas turbine to remove the major portion of the particulate. Advantages are also evident for a filter system that can remove other coal derived contaminants such as alkali, halogens and ammonia. With most particulate and other contaminants removed, erosion and corrosion of turbine materials, as well as deposition of particles within the turbine, are reduced to acceptable levels.

The contract is arranged as a base contract with three options. The objective of the base contract was to develop conceptual design(s) of moving granular bed filter (GBF) and ceramic candle filter technology for control of particles from integrated gasification combined cycle systems, pressurized fluidized-bed combustors (PFBC), and direct coal fueled turbine environments. The conceptual design(s) of these filter technologies were compared, primarily from an economic perspective.

Three program options follow the base contract as shown in the schedule above. The objective of Option I, Component Testing, is to identify and resolve technical issues regarding granular bed filter development for gasification and PFBC environments. The objective of Option 2, Filter Proof Tests, is being fulfilled by a separate contract to test and evaluate the moving granular bed filter system at a government-furnished test facility. This facility is at Southern Company Services, Wilsonville, Alabama. The objective of Option III, Multi-contaminant GBF, is to develop moving granular-bed filtration technology for control of particles and other coal-derived contaminants such as alkali, halogens and ammonia.

BACKGROUND INFORMATION

The granular bed filter was developed through low pressure, high temperature (1600°F) testing in the late 1970's and early 1980's (Guillory, 1980). Collection efficiencies over 99% were obtained. In 1988, high pressure, high temperature testing was completed at New York University (NYU), Westbury, N.Y., utilizing a coal-fired pressurized, fluidized bed combustor. High particulate removal efficiencies were confirmed as it was shown that both New Source Performance Standards and turbine tolerance limits could be met (Wilson, 1989).

The early scale-up work of the granular bed filter indicated potential limitations due to size, cost, and mechanical complexity. These limitations were addressed in the base contract of the present program (Wilson, 1992). It is currently proposed to use large diameter filters with 6 mm spherical filter medium to increase filtration capacity and reduce system complexity. Figure 1 shows a granular bed filter designed for a 100 MWe KRW (air) gasifier. The filter

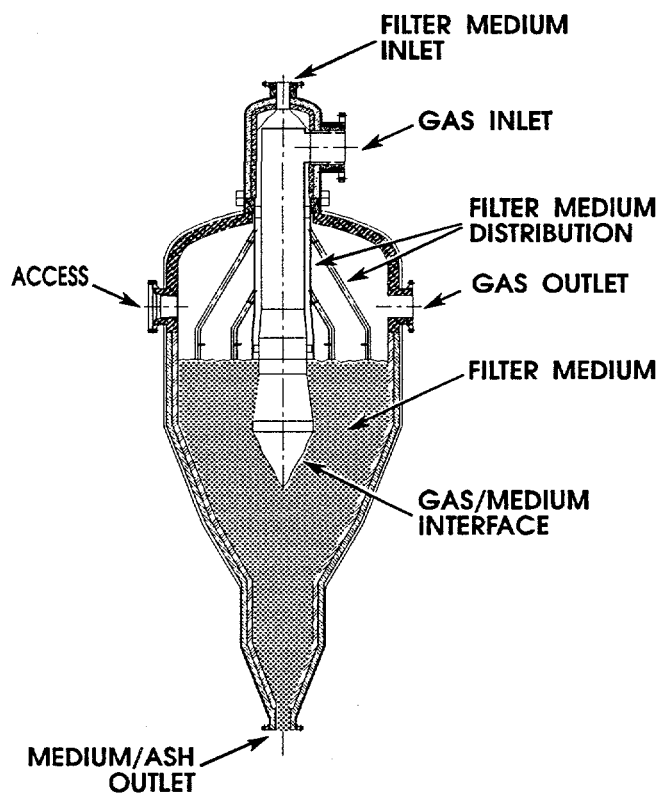


Fig. 1 Granular Bed Filter for 100 MWe KRW (Air) Gasifier

has an inside diameter of 14 ft with a nominal bed depth of 5 ft.

Dust laden gas enters the filter through an inlet duct which conveys the gas and dust into the filter medium. The gas initially flows downward, then turns and flows across the filter medium and then upward flow countercurrent to

the downward moving filter medium. As the gas and dust passes through the filter medium, dust is removed. Dust and filter medium are removed at the bottom cone of the filter. A pressurized pneumatic lift pipe moves the filter medium for return to the filter. The transport gas and dust, after separation of the filter medium, are cooled in a recuperative heat exchanger and passes through a pressurized bag house which removes the collected dust. The cleaned transport gas pressure is boosted 15 psi through a blower, is reheated in the recuperative heat exchanger and returned to the bottom of the lift pipe. The cleaned filter medium from the de-entrainment vessel at the top of the lift pipe flows by gravity back into the top of the filter.

PROJECT DESCRIPTION

GBF Component Development Program

Task 2 of the GBF development program identified technical issues which needed to be addressed. Some of the issues such as filter efficiency under different operating conditions are best resolved during testing at DOE's Power Systems Development Facility. Other issues such as filter scale-up are best addressed in a Component Test Facility. Besides scale-up, the following issues are being addressed in the Component Test Facility: 1) The overall height of the filter may be reduced by using a shallower cone angle at the bottom of the filter. 2) The affect of cone angle on the motion of the filter medium needs to be determined. 3) The maximum gas filtration rate needs to be determined; as well as, other variables which influence the filtration rate. 4) During the NYU tests, the refractory in the lift pipe experienced abnormal wear indicating a need to evaluate different refractories for abrasion resistance with GBF media. 5) Six mm diameter filter medium needs to be evaluated for durability and structural integrity. 6) Computational fluid dynamics (CFD) showed that the pressure drop

through the filter could be reduced by enlarging the gas inlet duct at the gas filter medium interface. CFD results needs verification as well as determining its affect on the flow the filter medium.

The specific objectives of the GBF Component Test Facility are: 1) to determine filter dimensions to insure mass flow of the filter medium, 2) measure the spouting velocity of the filter medium, 3) confirm the suitability of the enlarged gas inlet, 4) measure the minimum fluidization velocity of the 6 mm filter medium, 5) determine the effect of surface roughness on filter medium flow, 6) confirm CFD model and scale-up factors, 7) evaluate wear resistance of candidate pipe liners, and 8) evaluate strain and deflection of the gas inlet pipe. To accomplish these objectives, several arrangements of equipment are used. The first tests were conducted in a 3.5 ft diameter spilt filter with a transparent cross section which allowed observation of the motion of filter medium. The split filter used surfaces with different roughness to simulate the effect of a refractory liner. Two cone angles were tested with the split filter. Two inlet geometries were also tested. One inlet configuration emulated the high velocity design used for the testing at NYU. The other design had a larger inlet area designed to reduce filter pressure drop. Following the tests with the split filter, tests will be run in a 3.5 ft diameter full circumference filter and in a 6.0 ft diameter filter. These tests will help evaluate scale-up. Pipe liner abrasion resistance tests are proposed in a rolling drum containing filter medium and refractory test specimens. Fluidization properties of the filter medium were evaluated in a 1 ft diameter fluidized bed.

Multi-Contaminant Control

Besides particulate removal, a GBF may be able to capture other coal contaminants through the

use of chemically reactive filter material. Combustion Power Co. proposed to develop a reactive of filter material composed of limestone and clay for the removal of sulfur species and alkali (Wilson 1994). This approach was changed because of the well devolved alternative methods of sulfur removal, the thermodynamic limitations of limestone for the capture of H₂S, and the problems associated with the oxidation of calcium sulfide to sulfate. Combustion Power entered a teaming agreement with Research Triangle Institute (RTI) to investigate three types of reactive filter medium. The program is divided into four phases. The first phase will investigate clay based sorbents for control of alkali. Option 1 investigates clay based sorbents for the additional sorption of lead, cadmium, barium beryllium, and chromium. Option 2 investigates the sodium based sorbents for the sorption of halogens and metalloid, and Option 3 investigates ammonia decomposition catalysts.

The filter medium would continue to be 6 mm spheres as is used for particulate control. The following five clays have been identified as potential alkali sorbents: Emathlite (Bachovchin, 1986), Kaolin (Uberoi, 1990), Bauxitic kaolin, Attapulgate (McLaughlin, 1990), and Calcium montmorillonite (McLaughlin, 1990). Thermal gravimetric analysis (TGA) reactivity tests will be used to screen the clays. Each clay will be mixed with NaCl and heated in a TGA apparatus in both a oxidizing and reducing gas. The mixture with the lowest weight loss will retain the most sodium. Three of the five clays will be selected for evaluation of sorption of lead, cadmium and chromium in a reducing gas. Two types of clay will be chosen for further evaluation. The selection process will be based on the reactivity of each clay with sodium chloride, with each of the heavy metals and the relative cost of the each of the clays.

Each clay will be pelletized, using an extrusion process, into 3 mm and 6 mm pellets and

evaluated in terms of strength, attrition resistance and chemical reactivity.

The most promising of the two clays will be used in binder and pelletization studies. Five binders have been identified for evaluation with pelletization through extrusion with pellet rounding and by disk pelletization. The 20 formulations will be evaluated in terms of strength, attrition resistance and chemical reactivity. The reactivity tests will use a TGA to measure the weight gain of pellets over which passes a reducing gas containing 40 ppmv concentration of NaCl.

Based on the above screening tests, one clay formulation will be chosen for detailed characterization. Sodium saturation capacity of the sorbent will be evaluated with a TGA in which sodium chloride vapors pass over the sorbent. The test will continue until the reaction rate has decline to 5% of the initial rate. Test will be run with and without HCl a known inhibitor of alkali sorption (McLaughlin, 1990). Integral fixed-bed experiments will be run on a deep bed, 8 cm diameter by 30 cm, with the preferred formulation. Four integral tests are planned to evaluate the effects of gas composition and HCl concentration of the reaction kinetics. The strength of cured, calcined, and reacted pellets of the preferred formulation will be determined with crush and attrition tests.

The kinetic data from the integral reactor tests will be used to develop a kinetic expression for the reaction of alkali vapors with the clay sorbent. The kinetics will take into account the effect of alkali vapor concentration and the effect of HCl on reaction rates. The kinetic expression will be incorporated in an engineering model of the GBF.

GBF Testing at the Power Systems Development Facility

Southern Company Services, Inc has entered into a cooperative agreement with the Department of Energy, Morgantown Energy Technology Center (DOE/METC) for the design, construction and operation of a hot gas cleanup test facility for gasification and pressurized combustion. This facility is being installed in Wilsonville, Alabama. Shakedown and testing will commence in late 1995.

The primary objective of the Power Systems Development Facility (PSDF) at Wilsonville is to carry out meaningful systems and component testing for advanced coal-based power development. The integration of the granular bed filter into the PSDF addresses the advanced power generation research and development need as identified by industry and DOE/METC.

The basic filter design is patterned after the test units from Combustion Power Company development in the 1980's and the successful tests at New York University. Filter design changes are based on principles determined by computational fluid dynamics. Dimensions of the filter are adjustable. The depth of the filter can be changed from 5' to 10' if it is determined that a deeper filtration bed is needed for ash collection efficiency. The filter diameter can be adjusted to allow operation at different capacities. System design of the granular-bed filter is the same as for a commercial unit.

RESULTS

GBF Component Development Program

The split filter was used for observation of gas and filter medium flow. Figure 2 shows a gas velocity profile at the top surface of the filter. The filter medium at the surface is contoured

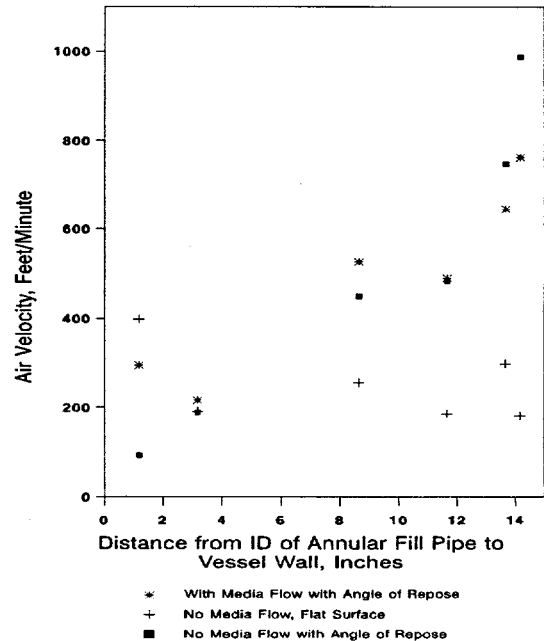


Fig.2 Air Velocity Profile at Surface of GBF

due to its angle of repose. As a result, the gas flow varies across the surface, being higher in the valleys and lower near the filter material inlets. The filter medium along the outside wall of the filter is a valley which has relatively high gas velocity. When the surface of the filter medium was leveled to eliminate the effect of changing filter medium depth, the gas velocity profile across the surface was relatively uniform. This result agrees with CFD modeling which predicted flow variation across the contoured surface but showed uniform flow about a foot below the lowest point on the filter. Within the scatter of the data, filter medium motion did not appear to effect the gas flow profile.

Figure 3 shows the velocity profile of the filter medium at the surface of the filter for different gas flows using the high gas velocity gas inlet. The filter material moves uniformly at all positions except very near the outside wall. Although the filter medium moves in mass flow with no stagnation areas it is not perfect plug flow. This observation was true for the split

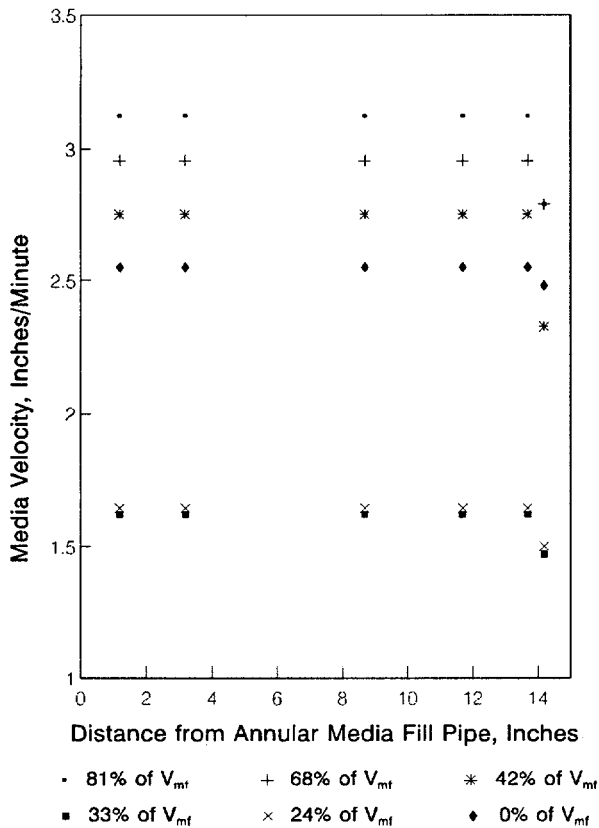


Fig.3 Filter Medium Velocity Profile

filter using the high velocity inlet with either a low friction wall surface or with a high friction surface. Filter material slip at the outer wall did not appear to adversely affect the filters tested at other locations.

The split filter allowed observation of the gas/filter medium interface below the gas inlet duct. With the high gas velocity inlet design, the interface appeared to be unstable at gas velocities approaching 50% of the minimum fluidization velocity. Some filter material was entrained in the gas flow and swirled in the gas space under the inlet pipe. At higher gas velocities, a gas bubble would form at the outer edge of the gas duct and begin to move up through the filter where it was absorbed into the filter medium. With the low velocity gas inlet

having a larger cross sectional area, the filter medium was stable with a gas flow of 50% of minimum fluidization velocity. There was relatively little filter material motion and no bubble formation until higher gas flows.

Figure 4 shows velocity versus pressure drop for the high velocity gas inlet, for the low velocity inlet and for filter medium in a packed bed with a uniform gas distributor. The velocity is made non-dimensional by dividing by the minimum fluidization velocity, V_{mf} , and the pressure drop is made non-dimensional by dividing by the weight of the bed per unit area. At a gas velocity of 50% of the minimum fluidization velocity, the pressure drop of the low velocity inlet is 36% lower than that of the high velocity gas inlet. The pressure drop of the low velocity

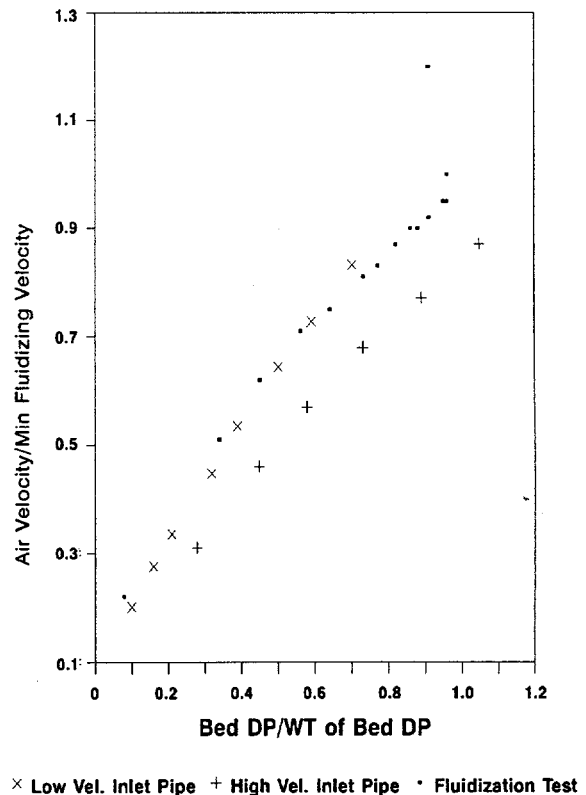


Fig.4 GBF Pressure Drop

gas inlet is similar to that of a packed bed with

uniform gas distribution.

All the testing with the split flow filter was without the presence of dust in the gas. When dust was used, there was dust by-pass in the corners of the filter formed by the intersection of the vertical face with the surfaces of the filter. With this caveat we have drawn the following conclusions: 1) The filter medium moves in mass flow with slip occurring at solid surfaces. 2) There is increased gas flow at the top surface near the outer wall of the 3.5 ft diameter filter due to the surface contour of the media. 3) Filter medium flow in the counterflow zone was not affected by change to a higher friction wall surface. 4) The larger gas inlet duct had a lower pressure drop and a more stable gas/filter medium interface than the high velocity gas inlet duct. 5) A change in filter cone angle from 70° to 60° did not change the flow profile of filter medium in the cylindrical section of the filter.

Multi-Contaminant Control

Table 1 shows the composition the clays to be evaluated as reported by the commercial suppliers. The GTA evaluation test are just getting underway.

FUTURE WORK

Testing at the component test facility is expected to be completed by Oct. of '95. The first phase the multi-contaminant control investigation will be completed in May of '96. The latter 3 phases of multi-contaminant control would be completed by Dec of '96. Testing at the PSDF is scheduled to occur during 1996.

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Table 1 Composition of Clays

	<u>Emathlite</u> Mid Florida Mining	<u>Kaolin</u> Albion Kaolin	<u>Bauxitic</u> <u>Kaolin</u> CE Min.	<u>Attapulgate</u> Floridin	<u>Ca Montmorillonite</u> Floridin
SiO ₂	72.3	52.3	37.8	66.2	62.3
Al ₂ O ₃	11.4	41.1	58.0	11.7	25.5
TiO ₂	0.5	2.3	2.2	0.6	
Fe ₂ O ₃	3.2	0.8	1.1	4.0	1.8
CaO	8.4	0.0	0.1	2.9	4.9
MgO	3.8	0.1	0.1	9.7	2.9
K ₂ O	0.4	0.6	0.0	1.1	0.6
Na ₂ O		0.1	0.1		2.0

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