DOE/MC/27423-93/C0215

Applications of Moving Granular-Bed Filters to Advanced Systems

Authors:
- K.W. Wilson
- J.C. Haas
- M.B. Eshelman

Contractor:
- Combustion Power Company
- 1020 Marsh Road, Suite 100
- Menlo Park, CA 94025

Contract Number:
- DE-AC21-90MC27423

Conference Title:
- Coal-Fired Power Systems 93 -- Advances in IGCC and PFBC Review Meeting

Conference Location:
- Morgantown, West Virginia

Conference Dates:
- June 28-30, 1993

Conference Sponsor:
- Morgantown Energy Technology Center

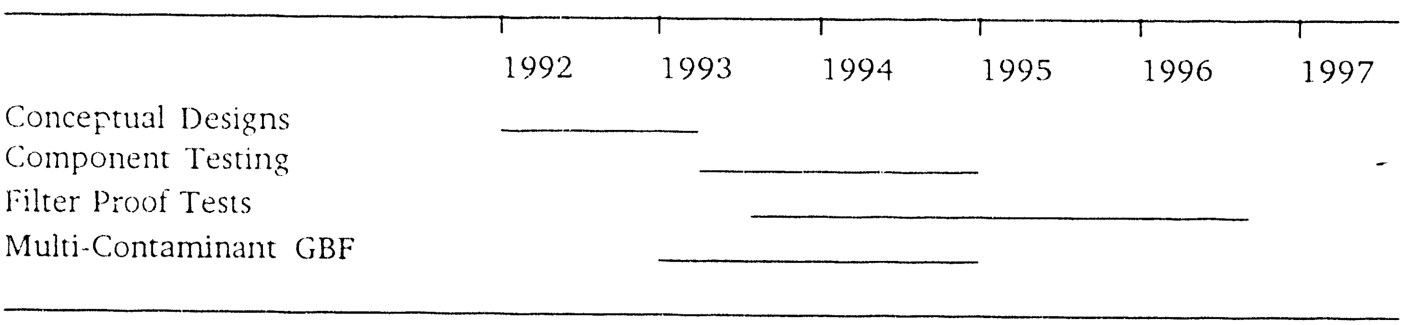
5.6 Applications of Moving Granular-Bed Filters to Advanced Systems

CONTRACT INFORMATION

Contract Number	DE-AC21-90MC27423
Contractor	Combustion Power Company 1020 Marsh Road, Suite 100 Menlo Park, CA 94025
Contractor Project Manager	Keith B. Wilson, PE
Principal Investigators	Dr. John C. Haas Milton B. Eshelman, PE
METC Project Manager	Richard A. Dennis
Period of Performance	September 28, 1990 to August 19, 1994

Schedule and Milestones

FY92-96 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-ladened 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 sulfur and alkali. 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 is to develop conceptual design(s) of moving granular bed filter and ceramic candle filter technology for control of particles from integrated gasification combined cycle (IGCC) systems, pressurized fluidized-bed combustors (PFBC), and direct coal fueled turbine (DCFT) environments. The conceptual design(s) of these filter technologies are compared, primarily from an economic perspective.

Three program options may 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 to test and evaluate the moving granular bed filters system at a Government-furnished hot gas cleanup test facility. This facility is presently Southern Company Services, Wilsonville, Alabama. The objective of Option III, Multi-contaminant GBF, is to investigate development of moving granular-bed filtration technology for control of particles and other coal-derived contaminants such as sulfur and alkali.

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[1]. Collection efficiencies over 99% were obtained. In 1988, high pressure, high temperature testing was completed at New York University, 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[2].

PROJECT DESCRIPTION

Two advanced power generating plants were chosen for developing conceptual designs and cost estimates of the commercial sized filters. One is the 450 MWe, second generation pressurized fluidized bed combustion plant defined by Foster Wheeler[3]. This plant originally included cross-flow filters for hot gas cleanup. The other plant under study is a 100 MWe, KRW air blown gasifier[4]. A cross-flow filter was utilized for gas stream cleanup in this study also. Granular bed and ceramic candle filters were substituted for the cross-flow filters in both these plants, and the resulting costs were compared.

In the second generation PFB combustion plant concept, coal is fed to a pressurized carbonizer which produces a low BTU fuel gas and a char. The char from the carbonizer is burned in a circulating pressurized fluidized bed combustor (CPFBC) with high excess air. Hot gas clean up (HGCU) devices are used to remove the particulate from the carbonizer fuel gas and from the vitiated air from the combustor; see Figure 1. Carbonizer fuel gas combines with CPFBC offgas at a gas turbine. Steam generated in a heat recovery boiler downstream of the gas turbine and in a fluidized bed heat exchanger connected to the CPFBC, drives a steam turbine generator to supply the balance of the plant electricity. The plant is arranged in two parallel equipment trains each with about 225 MWe

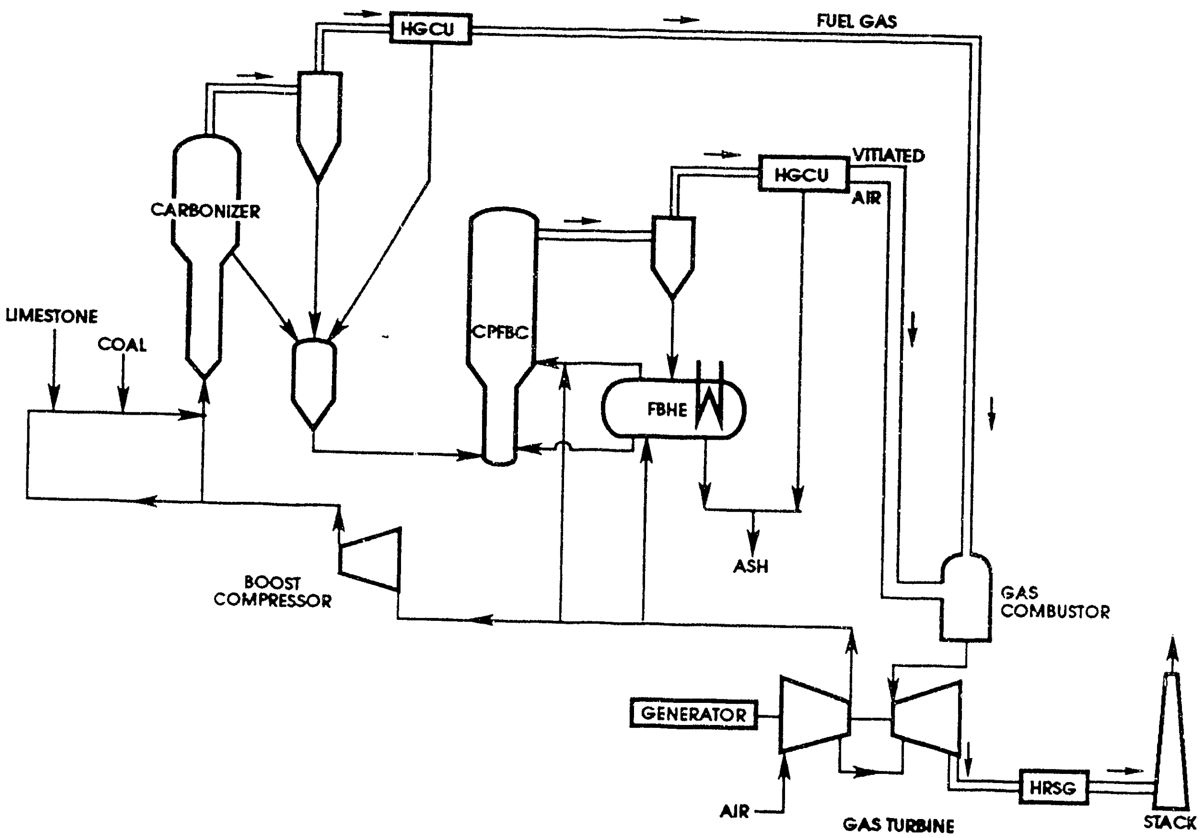


Figure 1. Second Generation PFB Combustion Plant

capacity. Each HGCU module for the CPFBC is sized for 175,000 acfm at 1600°F and 188 psia (2,644,236 lb/hr) with an inlet ash concentration of 4000 ppmw. There are four granular-bed or ceramic candle filters per 225 MWe module. Each HGCU module for the carbonizer is sized for 15,800 acfm at 1500°F and 208 psia (244,650 lb/hr) with an inlet ash concentration of 10,000 ppmw.

The KRW air blown gasifier is the second power cycle considered for conceptual designs of a granular-bed and a ceramic candle filter. In this process coal is gasified in a fluidized bed reactor using air as the oxidant. Fuel gas and recycle solids from the gasifier are quenched with cooled recycle gas. A primary cyclone returns recycle solids to the gasifier. A secondary cyclone removes additional solids from the fuel gas before the fuel gas enters the HGCU device shown on Figure 2. The gas is further cooled in a heat recovery boiler and then passes through a fixed bed of zinc ferrite for removal of H_2S. The fuel gas is burned in a gas turbine with air from the turbine driven compressor. Further heat is recovered in a heat recovery boiler which generates steam for the steam turbine. The plant power output is 100 MWe with a net heat rate of 9000 Btu HHV/kWh. The gas flow to the filter is 12,600 acfm at 1600°F and 385 psia (312,800 lb/hr). Ash loading at the filter inlet is 8,500 ppmw. As in the Foster Wheeler study, a ceramic cross-flow filter vessel is replaced with a single granular bed and with a single ceramic candle filter for cost comparison purposes.

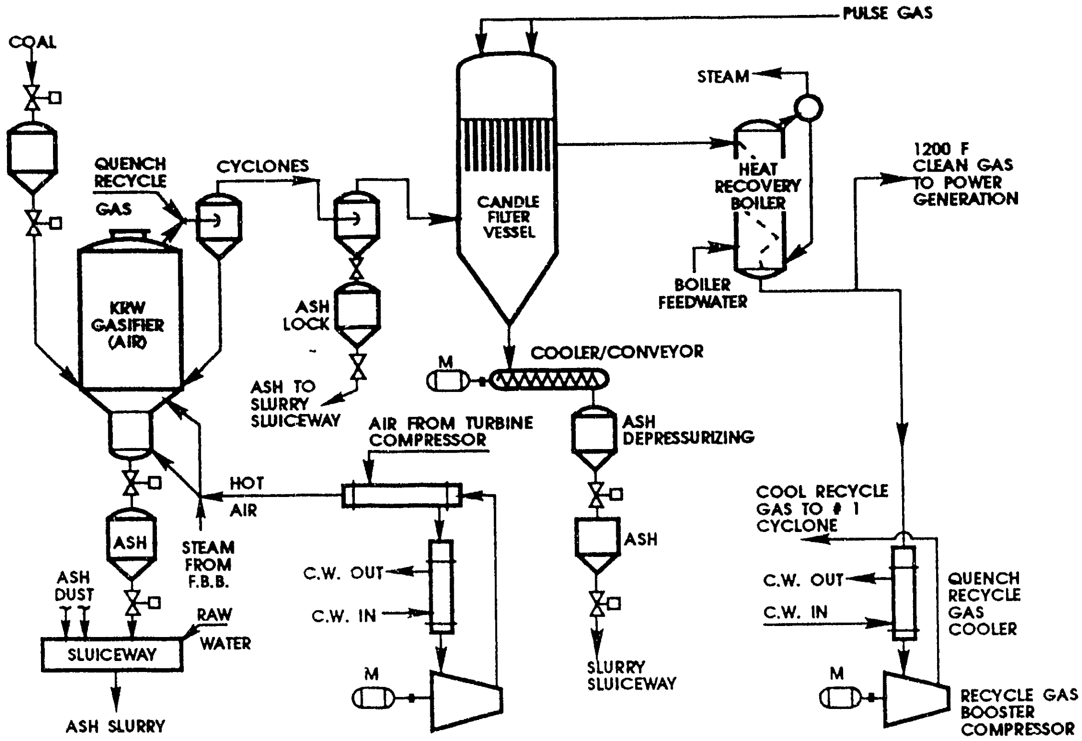
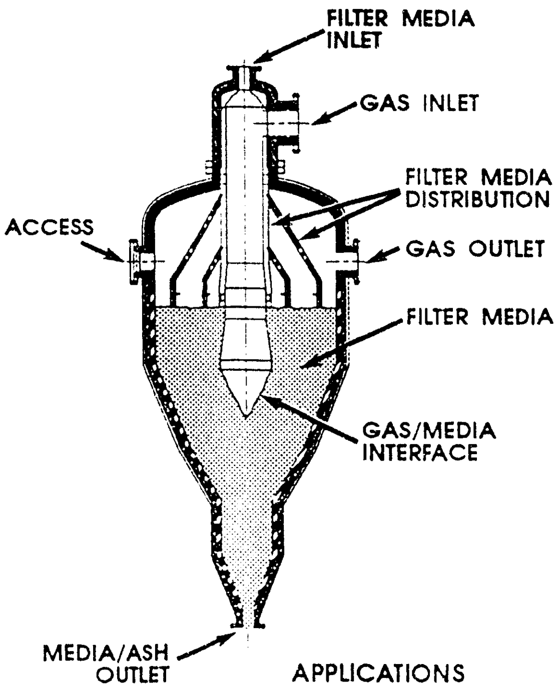


Figure 2. KRW Air Blown Gasifier Plant

RESULTS

For these plants, granular bed filters are proposed as shown in Figure 3. Hot gas enters each filter, through central ducting, and flows downward into a zone of active media movement. It is perceived that most of the particulate will be removed near this inlet gas/media interface. The movement of media and ash in this zone is expected to prevent ash agglomeration if this is a tendency. Gas turns to flow upward through progressively cleaner media and emerges into the cavity in the upper quarter of the vessel. Filter media is 6 mm, spherical, dense alumina; much like the 3 mm media successfully used at NYU. This configuration was chosen from a number of options based on a preliminary design and cost estimate. It is basically a larger version of the filter tested at NYU. To size the filters, and predict performance, computational fluid dynamics (CFD) analysis was used to model gas flow through the filter. This analysis predicts gas velocities, flow patterns, and pressure drop through the filter.

Included with each granular bed filter (GBF) is a media circulation and ash removal system as shown in Figure 4 for a single filter installation. The particle-laden media from the filter is withdrawn at the bottom and transported pneumatically, by process gas, in a lift pipe to a de-entrainment vessel where the filter media and the ash particles are separated. The clean media flows by gravity back to the filter vessel. The media is distributed in the filter vessel through distribution pipes and an annulus around the central inlet pipe. The lift gas and particles leaving the de-entrainment vessel are cooled to 500°F in a regenerative heat exchanger. Ash is removed from the cooled lift gas in a pressurized baghouse and depressurized through a lock-hopper system. The lift pipe transport gas is further cooled to 250°F in a water-cooled heat exchanger, boosted in pressure 10-15 psi with a blower, reheated in the regenerative heat exchanger, and reused to convey particle-laden media up the lift pipe. For the CPFBC filter, all four filter vessels are serviced by the same lift pipe.



APPLICATIONS

	CPFBC	CARBON-IZER	KRW GASIFIER
CAPACITY, MWe	450	450	100
QUANITY	8	2	1
HEIGHT, FT	56	45	45
ID, FT	20	14	14

Figure 3. Granular Bed Filter Configuration

Currently, the ceramic candle filter appears to have the most promise for successful development. For this reason, it was chosen for comparison against the granular bed filter. Ceramic candle filter elements are commercially available from several sources. These filter elements are rigid tubes, closed at the bottom and flanged at the top. They are formed by bonding ceramic fibers and/or grains with an aluminosilicate binder. Lengths are typically 1 to 1.5 m and outside diameters are 60 mm with a wall thickness of 10 to 15 mm. For the Foster Wheeler second generation PFB combustion plant, there are four candle filter vessels for each CPFBC and one candle filter vessel for each carbonizer; the same as for the granular bed filters. The ceramic candle filter for each application is shown in Figure 5. The candle filter configuration is based on utilizing the largest tubesheet possible. This was shown feasible by stress analysis on a unique tubesheet and tubesheet support design. All filter elements are attached to the tubesheet to simplify the filter element layout and the pulse gas piping. In this configuration, filter elements can be inspected and maintained from inside the filter vessel.

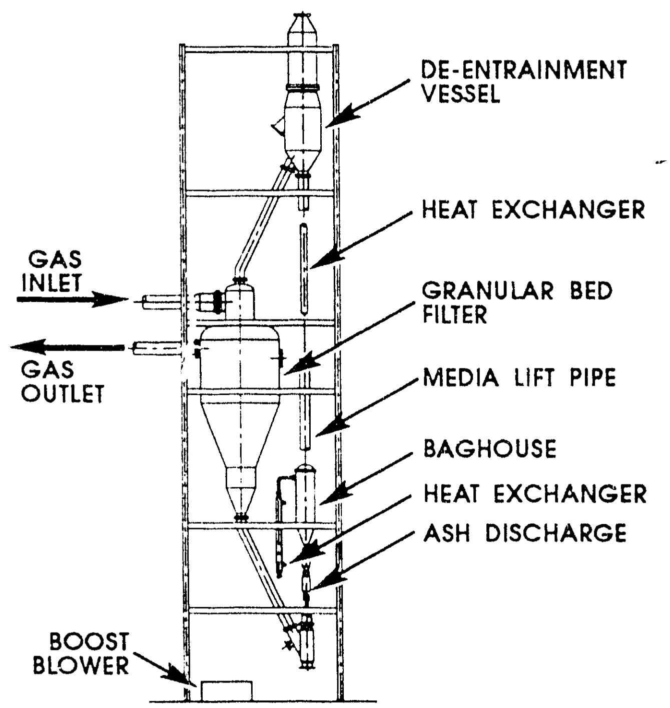
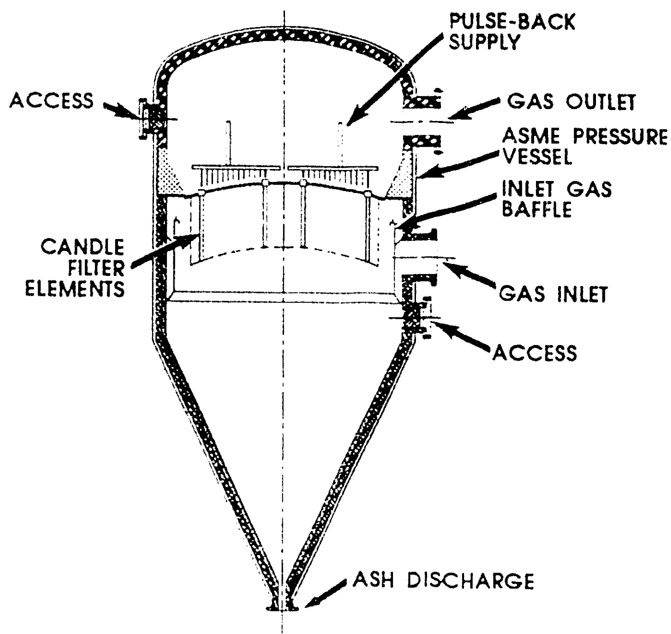


Figure 4. Granular Bed Filter System

Hot, particulate ladened gas enters below a tubesheet, and is distributed by a baffle around the upper portions of the filter elements. The gas passes through the filter elements, collects above the tubesheet, and exits through a single port. Ash is dislodged from the filter elements by high pressure, pulse gas. In combustion systems, high pressure air is used to clean the filter elements. In gasifiers, nitrogen or process gas is used. Ash is collected in the hopper below the tubesheet and discharged into ash cooling and depressurization equipment.



APPLICATIONS

	CPFBC	CARBON-IZER	KRW GASIFIER
CAPACITY, MWe	450	450	100
QUANITY	8	2	1
HEIGHT, FT	51	46	45
I.D., FT	20.5	18	16.5

Figure 5. Candle Filter Configuration

The face velocity is 10 ft/min for the CPFBC filter and 5 ft/min for the carbonizer and gasifier filters. Pulse gas volume is 0.40 ft3 per pulse per element. This was chosen as a compromise between the wide variation in values reported in the literature, at least between .2 ft^3 and 1.29 ft^3 per pulse per element[5,6]. Data available in open literature was used to define the characteristics of the filter cakes generated in combustion and gasification processes. These data plus a calculation methodology provided in a METC publication[7] produced filter pressure drop values and pulse cycle times for the candle filters.

Heat loss and pressure drop across each filter is accounted for in the calculation for the cost of electricity. Filter pressure drop represents a loss in power generation. Heat losses show up as temperature drop across the filter and can be accounted for by burning or gasifying more coal. These values are shown in Table 1. The candle filter pressure drop was predicted using filter

Table 1. Filter Losses

Parameter	Candle Filter	GBF
CPFBC Filter		
Pressure Drop, psi	2.7	3.0
Temperature Drop, °F	12	20
Carbonizer Filter		
Pressure Drop, psi	2.0	1.3
Temperature Drop, °F	27	34
Gasifier Filter		
Pressure Drop, psi	2.0	1.3
Temperature Drop, °F	31	35

cake resistivity measurements made by METC[7] researchers, and the GBF pressure drop was established by finite element (CFD) analysis as described above. Heat loss for the candle filters includes radiation and convection losses from the filter vessels and heat loss from cooling process gas used as pulse gas. Since pulse air for the CPFBC candle filter is not cooled prior to usage, it does not represent a heat loss. For the granular bed filter, heat loss includes radiation and convection losses from the filter vessel and the media circulation system components, and heat loss from cooling filter media circulation gases. This heat could be used to heat boiler feedwater.

The major items included in the filter cost comparison are shown in Table 2.

Table 2. Filter Cost Items

Candle Filter	GBF System
Capital Costs	
Filter Vessel	Filter Vessel
Filter Elements	Filter Media
Pulse System	Media Circ.
Compressors	Boost Blower
Gas Treating	De-Entrainment
Piping/Valves	Transport Pipes
Ash Handling	Baghouse
Ash Cooler	Regen. Hx
Pres. let-down	Pres. let-down
Annual Costs	
Maintenance	
Heat Loss Influence	
Pressure drop Influence	

Costs, in December, 1991 dollars, for the commercial size granular-bed and ceramic candle filter plants are presented in Table 3 for comparison. *Bare erected costs* include capital and installation costs for equipment. The granular-bed filter system includes: filter media circulation and cleaning, ash cooling, and ash discharge equipment. The candle filter system includes: pulse gas supply, ash cooling, and ash discharge equipment.

Table 3. Filter Cost Comparisons

Parameter	Candle Filter	GBF
CPFBC Filter (450 MWe)		
Bare Erected Cost, k$	38,187	27,339
Maintenance Cost, k$/yr	2,522	1,040
Electrical Load, kVa	349	318
Carbonizer Filter (450 MWe)		
Bare Erected Cost, k$	6,795	5,851
Maintenance Cost, k$/yr	619	286
Electrical Load, kVa	123	59
Gasifier Filter		
Bare Erected Cost, k$	4,458	3,775
Maintenance Cost, k$/yr	300	156
Electrical Load, kVa	22	84

For the granular-bed filter, the media circulation system separates ash from the filtration media, serving a similar function as the candle filter pulse cleaning system. For the granular-bed filter, the regenerative heat exchanger cools the ash; the candle filter uses a water-cooled ash screw (except for the carbonizer filter which feeds ash directly to the PFBC).

Annual maintenance costs are determined as a percentage of the *bare erected cost* of the filter system plus the cost of replacing systems expected to have a short life. The Electric Power Research Institute (EPRI) Technical Assessment Guide (TAG™) recommends maintenance costs ranging from 3% to 6% of the *bare erected cost* for processes handling solids at high temperature and pressure. Four percent is used in this study since the maintenance cost of major pieces of equipment needing periodic replacement are added to this base maintenance cost.

For the granular bed filter, three areas are identified that will require periodic replacement. The bags in the pressurized baghouse are recommended for replacement on a yearly basis by the vendor. The lift pipe liner is assumed to need replacement every three years, based on the limited data from testing at NYU, and the filter internals for the carbonizer and gasifier are assumed to need replacement every five years, based on corrosion rates for metals in high temperature, reducing atmospheres.

For the ceramic candle filters, four areas are identified that will require periodic replacement. It is assumed that filter elements will need replacement every three years. Solenoid pulse valve and isolating ball valve replacement is at 10% and 5% per year based on the high number of cycles. The filter internals for the carbonizer and gasifier are assumed to need replacement every five years, based on corrosion rates for metals in high temperature, reducing atmospheres.

Electrical requirements for the granular-bed filters include power for the boost blowers and for cooling water supply to the water-cooled heat exchanger. Most of the power is for the boost blowers. For the candle filter, power is required for pulse air/gas compressors and dryers, ash coolers, and miscellaneous cooling water needs. Most of the power is for the pulse air/gas compressors and dryers.

The economic study shows that the granular bed filter compares favorably with the ceramic candle filter from an economic standpoint. For the granular bed filters, the capital costs are less, the projected maintenance costs are less, the costs of electricity (COE) are less. The summary COE's are presented in Table 4.

Table 4. Cost of Electricity Values

Plant/COE Basis	Plant W/ Candle Filter	Plant With GBF
450 MWe PFB Combustion Plant		
Current $, mills/kWh	76.5	74.1
Constant $, mills/kWh	54.5	52.8
100 MWe KRW Gasifier Plant		
Current $, mills/kWh	134.0	133.2
Constant $, mills/kWh	92.4	91.8

The Cost of Electricity is calculated for the entire power plant and is based on methodology described in the Technical Assessment Guide, published by the Electric Power Research Institute, Volume 1, EPRI-

4463-SR, December 1986. These guidelines are summarized in a "Lotus Cost of Electricity (COE) - Users Manual" available from METC. The cost of electricity is stated in terms of 10^{th} year levelized dollars. Current-dollar analysis includes expected effects of inflation on capital carrying charges and operating costs. It is used by most utilities in evaluating their business investments. Constant-dollar analysis does not incorporate inflation effects in capital carrying charges and operating costs. It is generally preferred by economic analysts; it makes levelized values appear close to today's values.

FUTURE WORK

Determination of capital and operation costs for commercial size granular bed and ceramic candle filters, and comparison of the resultant COE's, is the first task of a program that has three other options. These options will be funded by the Department of Energy at its discretion.

Option I. Component Testing provides the opportunity to test and evaluate different granular bed filter designs and critical sub-systems determined from the base study described above.

Option II. Moving granular bed filter proof tests will be performed at a Gasification and PFBC Test Facility. Currently this is scheduled to be built by Southern Company Services in Wilsonville, Alabama.

OPTION III. This option, partially funded by the government, recognized that successful development of the granular bed filter for multi-contaminant control will make this equipment unique Besides removing particulate, a granular-bed filter has the potential of removing other pollutants in the gas stream. The filter is an excellent gas/solids contactor; in that, it has gas residence times in the order of several seconds, solids residence times in the order of several hours, uniform gas flow across the media, and the gas and filter media flow in opposite directions for the maximum driving potential.

The contaminants of major concern, besides particulate in coal utilization processes, are sulfur compounds, nitrogen compounds, alkali compounds, halogenated compounds, tars, and trace contaminants such as cadmium and mercury[8]. A granular-bed filter which is able to capture particulate and one or more of these additional contaminants would have significant benefits over just a particulate removal system.

Many processes that are under development are able to meet current New Source Performance Standards, but may have trouble meeting more stringent requirements which could be promulgated in the future. As an example, pressurized fluidized bed combustors are able to meet New Source Performance Standards of 90% sulfur removal but probably will have difficulty obtaining 95-98% sulfur removal. A granular-bed filter with an SO_2 absorbing media may be able to increase the overall sulfur removal efficiency from 90% to 98% in a PFBC system while maintaining a cost effective calcium to sulfur ratio.

Having determined possible processes for multi-contaminant control, proof of concept testing will be required to establish feasibility of the proposed processes. In order to conduct the proof of concept testing, test plans and conceptual designs of the test equipment will be prepared. Actual testing will occur in the next phase of the program after approval of the test plans by DOE.

References

1. Guillory, J.L. 1980. *High-Temperature Particulate Removal By Moving Bed Granular Filtration.* TR 80-3. Menlo Park, CA: Combustion Power Company.

2. Wilson, K.B. March 1989. Performance Evaluation of a Screenless (Counter-Current) Granular Bed Filter on a Subpilot-Scale PFBC. In *Proceedings of the Sixth Annual Coal-Fueled Heat Engines and Gas Stream Cleanup Systems Contractors Review Meeting*, ed. R.C. Bedick, T.P. Dorchak, N.F. Rekos, H.A. Webb, 293-303. DOE/METC-89/6101 (DE89000952). Morgantown, WV: Morgantown Energy Technology Center.

3. A. Robertson, et al. September 1989. *Second-Generation Pressurized Fluidized Bed Combustion Plant Conceptual Design and Optimization of a Second-Generation PFB Combustion Plant, Phase 1, Task 1.* Report DOE/MC/21023-2825, Vol.1. Prepared by Foster Wheeler Development Corporation, Livingston, New Jersey under contract No. DE-AC21-86MC21023.

4. D. F. Ciliberti, T. E. Lippert. 1986. *Performance Evaluation of a Ceramic Cross-Flow Filter on a Bench-Scale Coal Gasifier.* Westinghouse Eighth Quarterly Report and Monthly Project Status Report for September 1, 1986 - September 30, 1986, DOE/METC Contract No. DE-AC21-84-MC21338.

5. M. Durst, Schumacker. March 11-13, 1992. J.C. Haas notes from *Second EPRI Workshop on Filtration of Dust from Coal-Derived Reducing and Combustion Gases at High Temperature.* San Francisco.

6. G.P. Reed, G.K. Burnard, O.J. Tassicker and A.J. Leitch. 1987. A Large Ceramic Candle Filter Module on a Pressurized Bed Combustion Plant - Description and Preliminary Data. *Advanced Coal Power Plant Technology and Hot Gas Cleaning Conference.* Duesseldorf, Germany.

7. R.A. Dennis. August, 1990. *Evaluation of Dust Cake filtration at High Temperature With Effluence from an Atmospheric Fluidized-Bed Combustor.* Technical note DOE/METC-91/4105.

8. Bossart, S.J., D.C. Cicero, C.M. Zeh, and R.C. Bedick. August, 1990. *Gas Stream Cleanup-Technology Status Report.* DOE/METC-91/0273.

DATE FILMED

11/22/93