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Moving Granular Bed Filter Development Program

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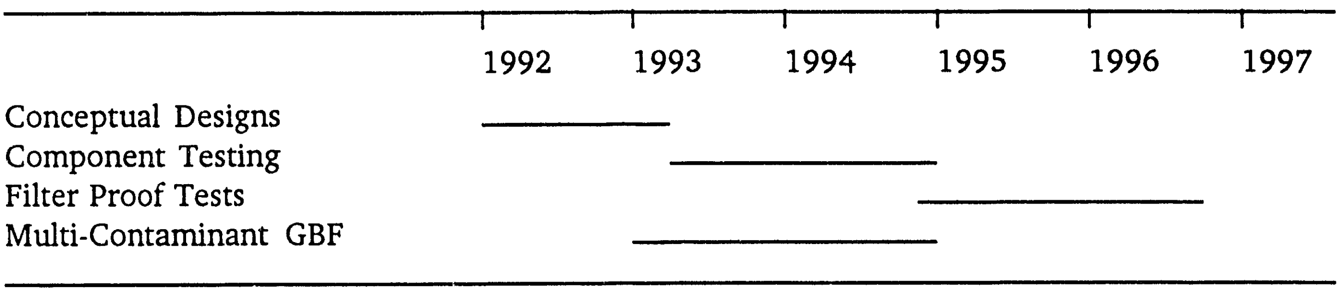
Moving Granular Bed Filter Development Program

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	Sept. 28, 1990 to Oct. 27, 1992

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 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 to be 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].

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 present program by utilizing the information gained from the filter development up through the NYU test program to reassess the commercial approach.

PROJECT DESCRIPTION

Two studies were chosen for developing conceptual designs and cost estimates of the commercial sized filters. One is the economic study of the 250 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, air-blown KRW 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 cost of electricity (COE) is compared.

Foster Wheeler Development Corporation is developing a second-generation fluidized bed combustion plant. In this 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. Carbonizer fuel gas combines with CPFBC offgas at a gas turbine. Steam generated in a heat recovery steam generator 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 capacity. Hot gas filters for each CPFBC module handle 2,644,000 lb/hr oxidizing gas at 190 psia and 1600°F (175,800 acfm). Hot gas filters for each carbonizer module handle 244,650 lb/hr reducing gas at 208 psia and 1500°F (15,800 acfm).

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, shown in Figure 1, coal is gasified in an entrained flow 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. 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. In the schematic shown in Figure 1, ceramic cross-flow filters are shown as the HGCU device. As in the Foster Wheeler study, the ceramic cross-flow filters are replaced with a moving granular-bed and with a ceramic candle filter for cost comparison purposes.

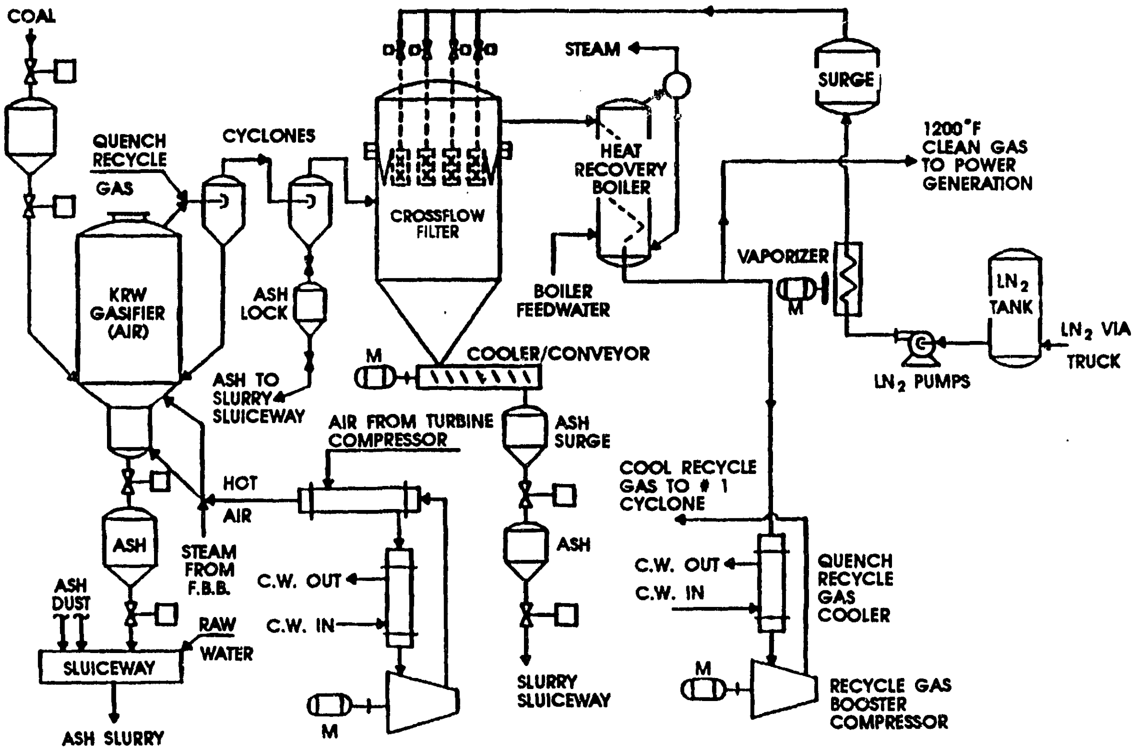


Figure 1. KRW (Air) Gasifier Plant

Table 1. HGCU Filter Requirements for IGCC Plant

Operating Parameter	Expected Value
Gas State:	Reducing
Gas Flow Rate (acfm):	12,600
Gas Temperature (°F):	1600
Gas Inlet Pressure (psia):	385
Gas Flow Rate (lb/hr)	312,800
Gas Composition (% volume)	
CO_2	17.1
H_2O	4.3
N_2	44.1
O_2	0.0
CO	9.2
H_2	24.5
CH_4	0.8
H_2S	700. PPM
Particulate Load (lbs/hr):	2660
Mean Particulate Size (micron)	2.1

RESULTS

For the 100 MWe, KRW (Air) gasifier, a single granular bed filter vessel is proposed and is shown in Figure 2. Hot gas enters the 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 preliminary designs and cost estimates. It is basically a larger version of the filter tested at NYU. To size the filter, and predict performance, computational fluid dynamics (CFD) analysis was used to model the flow through the filter. This analysis predicts gas velocities, flow patterns, and pressure drop through the filter. It is based on matching coefficients from the Ergun equation to a general purpose finite element based CFD program with explicit formulation for porous media. The filter inside diameter is 14 ft, and the filter bed depth is nominally 5 ft.

Sizing is dictated by ash loading in this case; since, the ash concentration in the inlet stream is fairly high at 8,500 ppm. Main filter vessel height is about 38 ft, with an additional height of 7 ft for the inlet cap. Pressure drop, based on CFD analysis, is 36 IWC.

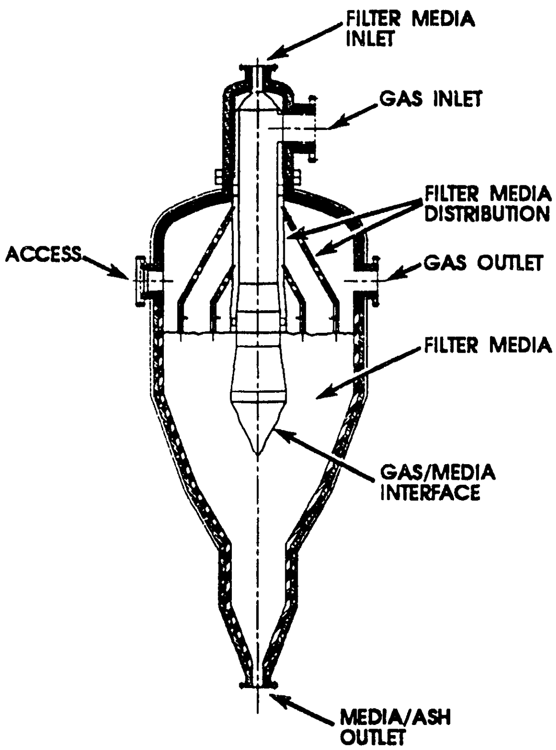


Figure 2. Granular Bed Filter for 100 MWe KRW (Air) Gasifier

Included with the moving granular bed filter (GBF) is a media circulation and ash removal system as shown in Figure 3. The particle-laden media from the filter is withdrawn at the bottom and transported pneumatically 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 with a blower, reheated in the regenerative heat exchanger, and reused to convey particle-laden media up the lift pipe.

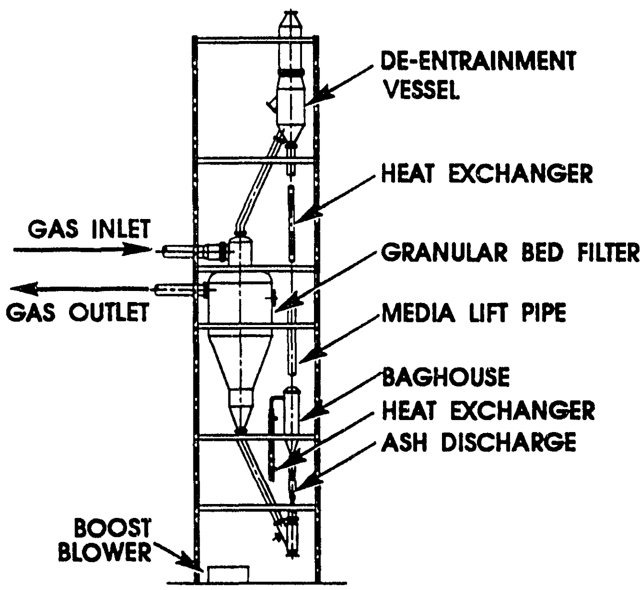


Figure 3. GBF System

The ceramic candle filter for the gasifier is also a single vessel and is shown in Figure 4. 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-back gas. Ash is collected in the hopper below the tubesheet, discharged into a water-cooled screw, depressurized through lock-hoppers, and fed to an ash disposal system.

The filter vessel is 18' diameter, inside refractory, and about 42' high. Filter elements are 1.5 meters long, 60 mm outside diameter and made with two layer construction to minimize the possibility for ash to penetrate into the ceramic matrix.

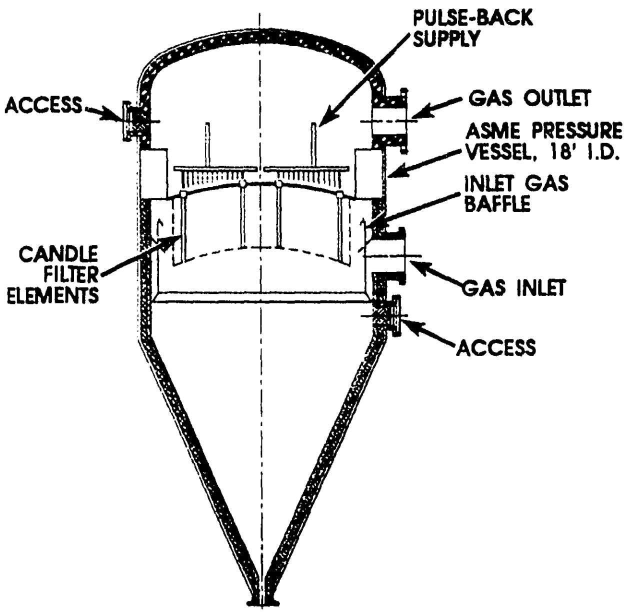


Figure 4. Candle Filter for KRW (Air) Gasifier

The face velocity is 5 ft/min requiring 900 filter elements for a total of 2,520 sq ft of filter area. Pulse-back gas is reported in the literature to vary widely, between .2 ft^3 and 1.29 ft^3 per pulse per element[5,6]. Combustion Power used 0.40 ft^3 per pulse as a design value. Very little data is available on properties of filter cakes generated in a gasification environment. Texaco reports[7] that their filter cakes had a high cake resistance, low cohesivity and low density. Typical cleaning times for filter cakes from both the Texaco and the Shell Processes were about 5 minutes. Testing by Ahlstrom showed that filter cakes from gasification processes have a permeability 1/3 of cakes formed in a combustion process[8]. These considerations plus a calculation procedure provided in a METC publication[9] produced a filter pressure drop of 2.0 psi for a 6 minute cycle time. Pulse gas is furnished from cooled, pressurized process gas at 685 psia and 7150 lb/hr, which includes a 32% margin on the theoretical flow requirement.

Filter elements are grouped in sets of 15 for each pulse manifold. A quick acting pulse valve is supplied for each three manifolds which are isolated by ball valves. Therefore there are 60 ball valves and 20 pulse valves, plus isolation valves needed for maintenance.

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. Items that influence the cost of electricity (COE) are capital cost and operating cost. Capital cost of equipment includes installation, with allowances made for plant facilities, engineering, contingency, construction interest and inflation, start-up costs, spares, and other items. Annual operating costs include fuel, consumable, ash disposal, plant labor, maintenance, insurance, taxes, royalties, with credit for sulfur production. The COE is stated in terms of 10th year levelized dollars and includes a current dollar and a constant dollar analysis. The major items that will influence the COE comparison of the KRW (Air) gasifier based power plant are listed in Table 2. Cost estimates at publication time were not complete.

Table 2. Filter Cost Items

GBF System	Candle Filter
Capital Costs	
Filter Vessel	Filter Vessel
Media Circ.	Filter Elements
Media	Pulse Back
Transport Pipes	Compressors
Boost Blower	Gas treating
De-Entrainment	N_2 Backup
Regen. Hx	Ash Handling
Water-Cooled Hx	Ash cooler
Baghouse	Pres. let-down
Annual Costs	
Maintenance	
Heat Loss Influence	
Pressure drop Influence	

Heat loss and pressure drop across each filter will be accounted for in the calculation for the COE. Filter pressure drop represents a loss in power generation. Heat losses for the gasifier show up as temperature drop across the filter and can be accounted for by gasifying more coal. These values are shown in Table 3. The candle filter pressure drop was substantiated by a METC calculation procedure, and the GBF pressure drop was established by finite element (CFD) analysis as described above. Heat loss for the candle filter includes radiation and convection losses from the filter vessel and heat loss from cooling process gas for use as pulse-back gas. Since a boiler is proposed for cooling pulse-back gas, some of this heat is recovered. 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 circulation gases. This heat could be used to heat boiler feedwater, but this is not proposed.

Table 3. Filter Losses

Parameter	Candle Filter	GBF
Pres. Drop, psi	2.0	1.3
Temp. Drop, °F	31	35

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

Successful development of the granular bed filter for multi-contaminant control will make this equipment unique. The filter may be modified to remove particles, and other coal-derived contaminants containing sulfur, nitrogen, alkali, halogens, tars, and heavy metals. The government has partially funded this option.

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