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Moving Bed, Granular Bed Filter Development Program
Option 1: Component Test Facility
Task 2: Identification of Technical Issues

Topical Report

J. C. Haas
K. B. Wilson

March 1994

Work Performed Under Contract No.: DE-AC21-90MC27423

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Combustion Power Company
Menlo Park
Oakland, California

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Abstract

Combustion Power, under the auspices of the US Department of Energy, is developing a moving granular-bed filter for the control of particulate in gasification and pressurized fluidized bed environments. In Task 2, technical issues are identified which need to be resolved for the granular-bed filter to be commercially viable. The technical issues are ranked in relative importance.

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1.0 INTRODUCTION

1.1 Objective

The purpose of Task 2 is to identify technical issues associated with the development of Granular-Bed Filter (GBF) for the control of particulate in gasification and pressurized fluidized bed combustion (PFBC) environments. Some of the technical issues identified are due to problems encountered during testing of a GBF at New York University. Other issues are a result of the redesign of the GBF to make it more competitive. The issues are discussed in terms of a priority based on the seriousness of the issue and the difficulty in resolving it. With each issue is a discussion of the approach which will be taken to resolve it. Some issues are amenable to being solved in a component test facility while others will have to be dealt with in the Department of Energy's Power Systems Development Facility (PSDF) located at a Southern Company Services' facility in Wilsonville, Alabama.

1.2 Background

Combustion Power Co. developed a low temperature commercial GBF in the 1970's for the removal of particulate from atmospheric flue gas streams at temperatures below 700°F. Recognizing the needs of advanced power cycles, work began on the development of a GBF for cleaning high temperature, high pressure (HTHP) gas in 1977. The initial development program demonstrated the successful cperation of a GBF operating on 1500°F to 1600°F gases produced from an atmospheric pressure coal-fired fluidized bed combustor (Guillory, 1983). Overall collection efficiencies above 99% and sub-micron collection efficiencies above 96% were consistently demonstrated in over 1500 hours of high temperature testing. Following this initial development effort, HTHP test were conducted at New York University (NYU) in 1988 (Wilson, 1989).

In the New York University tests, 2 mm and 3 mm spherical alumina balls were used as the filter medium. Ash-laden medium was continuously removed from the filter, cleaned and returned by a pneumatic process. The flue gas and ash were generated by a coal-fired 30" I.D. fluidized bed combustor operating up to 10 atmospheres at 1500-1600°F with 20-30% excess air. The test using 2 mm balls as the filter medium had inlet concentrations of 70-6400 ppmw, outlet concentrations of 1-20 ppmw, particulate efficiency of greater than 99% and a steady pressure drop of less than 1 psi. Tests using 3 mm balls had inlet particulate concentrations of 160-1570 ppmw, outlet concentrations of 1-11 ppmw, collection efficiency greater than 99% and a steady pressure drop of less than 1 psi.

Based on the filter design tested at NYU, a commercial design was proposed for American Electric Power's Philip Sporn PFBC Repowering Project. The proposed approach was to use 80 filter modules housed in four pressure vessels. This approach is complicated and potentially mcre expensive than a candle filter approach. Recognizing these limitations, the Department of Energy sponsored a new program for the development of a GBF which would be smaller, less complicated and cost competitive with candle filters. Under this program, Combustion Power reviewed the design of granular-bed filters and came to the conclusion that the most effective method of packaging a GBF is to have large filters up to 20 ft in diameter (Wilson, 1993). The filter geometry tested at NYU was scaled to large sized filters to maximize the chances of having a successful filter configuration. Other modifications to the NYU design were that the size of the balls used as filter medium was increased to 6 mm and the gas inlet pipe configuration was optimized to reduce the pressure drop through the filter. The cost of the large scale GBF was compared to that of candle filters for a 2nd generation PFBC application and for a KRW gasifier. The cost of electricity using a GBF was less than that of the candle filter for these two applications.

1.3 Description of Technology

Figure 1 shows the granular-bed filter and Figure 2 is a process flow diagram of the GBF and the filter medium circulation system. Particle laden gas enters the filter through a centrally located duct submerged in filter medium (stream 1 in Figure 2). The filter medium moves continuously downward toward the cone section of the filter. Particles are removed by the filter medium by impaction and interception as the gas turns and flows upward through the filter. The particle-laden medium from the filter is withdrawn at the bottom of the filter element, stream 3, and transported pneumatically in a lift pipe, stream 6, to a de-entrainment vessel where the filter medium and the ash particles are separated. The clean medium flows by gravity back to filter vessel, stream 9. The medium is distributed in the filter vessel through multiple distribution pipes and an annulus around the central gas inlet pipe. The lift gas and particles leaving the DEV, stream 10, are cooled to 500°F in a recuperative heat exchanger. Ash is removed from the circulation gas in a pressurized bag house and then further cooled in an water cooled heat exchanger to 250°F. The lift pipe transport gas is then boosted in pressure with a blower, reheated in the recuperative heat exchanger and reused to convey particle-laden medium up the lift pipe. The recuperative heat exchanger serves two function: it reduces the temperature of the gas entering the baghouse and it reheats the gas exiting the boost blower. The gas from the boost blower needs some degree of reheat to insure that any condensed liquids which may have formed during the gas compression in the boost blower are vaporized. Furthermore, the reheating the transport gases minimizes the heat loss from the filter system.

The baghouse is designed to operate at a temperature of up to 500°F with standard fiberglass felt bags. For the gasification and carbonizer applications, the baghouse uses nitrogen as the pulse gas. Ash from the baghouse discharges to a pressurized collection system.

The medium used in the filter is composed of 6 mm, manufactured ceramic balls. Bulk density is 106 lb/ft^3. A new supplier will be used for the 6 mm balls and as such the balls will require more extensive evaluation than if the 3 mm balls from the NYU tests were used.

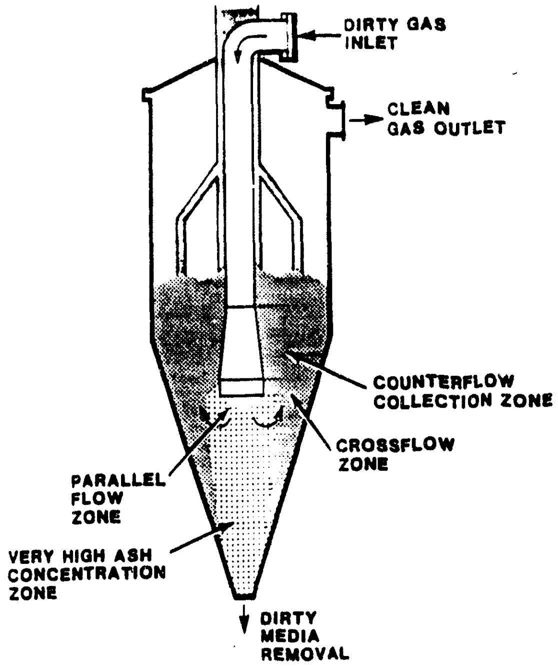

Figure 1 Granular-Bed Filter

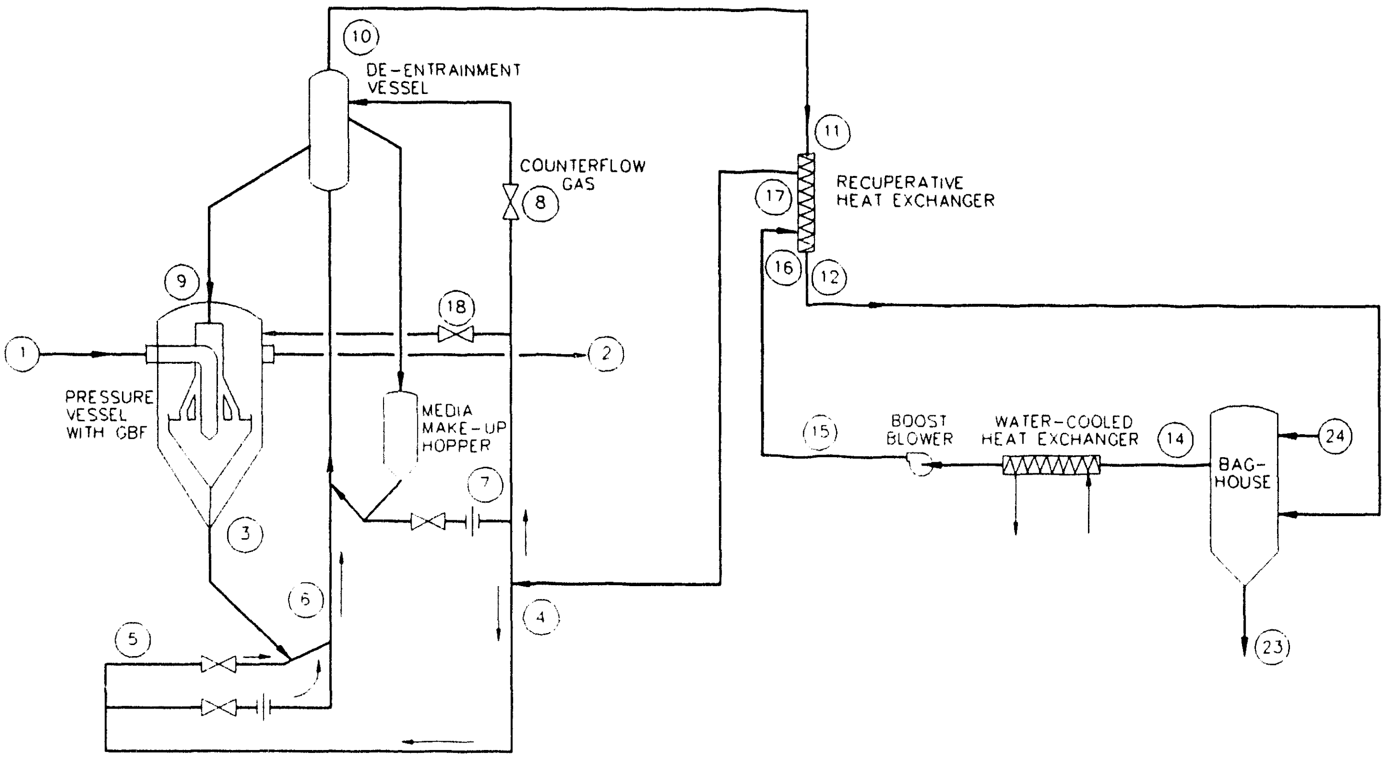

Figure 2 Process Flow Sheet

2.0 GRANULAR-BED FILTER DEVELOPMENT ISSUES

The following technical issues relate to the development of the granular-bed filter for any application. No issue other than performance is identified which is directly related to the particular applications of gasification or pressurized fluidized bed combustion. The issues are listed in order based on the their relative importance.

2.1 GBF Scale Up

Combustion Power's approach to commercialization of the GBF is to use filters up to twenty feet in diameter. This presents the challenge of how to scale the results from the 5 ft diameter filter tested at NYU and the 3.5 ft diameter filter to be tested at the PSDF to large scale commercial filters. There is also the challenge of scaling the 5 ft diameter filter tested at NYU to the 3.5 ft diameter filter to be tested at the PSDF. We feel that the more difficult challenge will be to properly scale the filter down in size rather than increasing its size. In scaling down the filter we have reduced the crossflow component of filtration. The space between the gas inlet duct and the outer wall of the filter will have fewer collectors. There are several reasons why this has occurred. The size of the balls used as filter medium was doubled so that there are half as many collectors if no other geometry changes occurred. In scaling down to the 3.5 ft diameter filter, there is simply less distance between the gas inlet duct and the outside wall of the filter. Computational fluid dynamics analysis showed that an increase in the ratio of the gas inlet duct diameter to filter diameter as compared to the ratio used at NYU would reduce the pressure drop through the filter due to the lower velocity of the gas entering the filter medium. The increased inlet duct diameter has been incorporated in the GBF design. The loss in crossflow filtration in the 3.5 ft diameter filter will be taken up by counterflow filtration. This means that the bed height of a smaller diameter filter may have to be higher than that of a larger filter which has a more extensive crossflow filtration zone. Future commercial units will be built with the capability of operating with the bed height established in testing with the 3.5 ft diameter filter. Their performance should improve due to the additional crossflow filtration which will occur in the larger units.

Based on the above line of reasoning, scaling the GBF to larger diameters should not be a problem once good performance has been established in a smaller unit. There are other tools available to help insure that the GBF is properly scaled to larger sizes. We know that, for a GBF to be properly scaled, similarity must be maintained with the flow pattern of the medium between the large and small filters and that the flow pattern of gas in the counterflow region of the filter must be similar. The gas flow pattern for different sized filters can be checked with the use of computational fluid dynamics which is able to model flow through a porous medium. The gas and medium flow pattern can also be checked on different sized filters in a component test facility. Test plans will propose the measurement of flow patterns in a cold flow 3.5 ft diameter filter and in a 6.0 ft diameter filter. The establishment of similar flow patterns between the two filters will demonstrate that the filter flow patterns scale if geometric similarity is maintained. We believe that the combined approach of computational fluid dynamic modeling along with cold flow modeling will enable us to successfully scale the GBF to commercial sizes.

2.2 Ash Concentration in the Filter Medium

The ratio of ash to medium in the filter has a significant impact on the size of the medium circulation system, the temperature drop through the filter and filter efficiency. It is desirable to operate the filter with the highest concentration of ash in the medium at which the filter is able to meet its performance objectives. For a given ash inlet loading, a high ash to medium concentration corresponds to low medium circulation rates. Low medium circulation rates are desirable in that they correspond to smaller medium circulation systems which are less costly. More importantly, a large percentage of the temperature drop through the filter is due to cooling which occurs in the medium circulation system. Operating at high ash concentrations will reduce the temperature drop in the filter compared to operating with low ash concentration in the medium.

The maximum concentration of ash in medium is a function of ash type and filter operating parameters and as such has not been quantified. The tests at NYU had an ash concentration in the medium of 1% or less . The reason for the low concentration of ash in the medium was the relatively low concentration of dust in the gas to be filtered. The filter to be tested at the PSDF is designed with a dust concentration of 2%. Tests at Combustion Power Co. demonstrated that medium flow can be controlled with an ash concentration of more than 5% but the effect of ash concentration on filter performance has not been quantified.

We believe tests have to be conducted in a system that generates realistic ash and as such can not be done in a component test facility using simulated ash. The issue of the maximum concentration of ash in the medium will be resolved at the testing planned for the PSDF. Ash concentrations during the tests will be varied between 1 and 10%. The tests planned for the PSDF will determine the maximum ash concentration in the medium as a function of operating conditions, ash type and filtration velocity. This information will allow for the optimization of future commercial designs, minimizing the effect of medium circulation on filter temperature drop.

2.3 Effect of Filter Cone Angle and Sidewall Materials on Medium Flow and Ash Segregation

The medium in the upper section of the filter should move in plug flow. If there is relative motion in the filter medium in the top section of the filter, ash will be dislodged and the filter efficiency will be reduced. The flow pattern of medium in the upper section of the filter is controlled by the shape and surface finish of the lower conical section. Ideally the conical section of the filter should have a smooth polished surface and a long cone length. For economic considerations, the cone length should be as short as possible.

For high temperature applications, the filter vessel surface will not be polished metal but fire brick. The cone angle needs to be such that plug flow will occur in the upper section of the brick-lined filter.

A cold flow test will be proposed to insure that the selected cone geometry, with a refractory brick lining, establishes plug flow in the upper section of the filter. Initial tests will be proposed with a model which has a vertical glass partition on its centerline such that the flow pattern of the medium can be observed. After the geometry is verified, the medium flow pattern will be checked in a cold flow bricked lined filter vessel.

The presence of ash in the medium could effect the flow pattern of medium in the filter vessel. Cold flow tests will also be proposed with a mixture of ash and medium. The flow pattern will be checked to insure that the presence of ash has not changed the medium flow pattern.

2.4 Maximum Gas Filtration Rate

The maximum filtration rate of the GBF will depend on filter geometry, ash content of the gas and the properties of the ash to be filtered. The current design is for the filter to operate at about 40% of the velocity which will cause the filter medium to fluidize. The fluidization velocity as well as the velocity which would cause spouting of medium in the GBF can be determined in a component test facility. This data will establish the theoretical maximum operating velocity and will be used to verify the design assumptions used for the filter. Establishment of the maximum operating velocity, which is a function of ash type and concentration, will be part of the test program at the PSDF.

The PSDF filter will have the capability of operating at different gas velocities. The filter will have two layers of removal refractory linings which will allow the cross sectional area of the filter to be changed. With both linings in place, the filter will be able to operate at a maximum of 50% of the medium fluidization velocity. With both layers of refractory removed, the filter can operate at 21% of the minimum fluidization velocity of 6 mm balls; although, the purpose of the second removable layer is to allow a back-up operation point on a higher capacity PSDF unit.

2.5 Filtration Efficiency

Test at NYU with filter medium composed of 3 mm balls had an efficiency ranging from 98.0% to 99.3%. The lower efficiency corresponded to low dust inlet concentrations and had corresponding low outlet concentrations. Filter efficiency and how it is effected by operating variables will be part of the test program at the PSDF. No measurements of filter efficiency will be proposed as part of the component test facility since it will not be possible to generate a representative ash in such a facility. It is expected that filtration efficiency will be related to ash characteristics and dust concentration in the gas.

2.6 Lift pipe wear

During the GBF test at NYU, sections of the lift pipe experienced unacceptable wear. We believe that the cause of the high wear was due to improper curing of the refractory used in the sections of the lift pipe which experienced high wear. The lift pipe to be used at the PSDF will use wear resistant liners such as silicon carbide to eliminate the potential of high wear. The lift pipe will be composed of at least one different liner materials so that data can be collected on candidate materials for commercial applications. A wear test is proposed on candidate lift pipe liner materials as part of Task 6 test program.

2.7 Heat Exchanger Fouling

During testing at NYU, the only piece of equipment which had operational problems was the heat exchanger located before the baghouse. Over time, the exchanger would become fouled so that the temperature entering the baghouse would increase. The problem was overcome by rapping on the heat exchanger, knocking off ash deposits.

The issue of heat exchanger design and performance will be addressed at the PSDF. We do not believe that significant testing can be accomplished on the heat exchanger in a component test facility. The fouling characteristics of the ash will depend on the fuel characteristics and the process conditions under which it is generated.

The heat exchanger, whose performance will be evaluated at the PSDF, will be a recuperative heat exchanger which uses the hot dusty gas from the lift pipe to reheat the cooled cleaned gas from the boost blower. The heat exchanger will be designed to minimize fouling. The design will include a generous fouling factor to account for the presence of an ash layer on the heat transfer surfaces. The heat exchanger will be instrumented so that the fouling factor can be measured and subsequently used in commercial designs. Because the fouling characteristics are unknown, the recuperative heat exchanger at the PSDF will be followed by an air cooled heat exchanger. The air cooled heat exchanger will be used to compensate for any temperature rise in the recuperative heat exchanger due to fouling. The heat exchangers will also be designed with pads for attachment of rappers. Rappers would be added to the heat exchangers should fouling interfere with heat exchanger performance. The use of rappers was effective in removing deposits from the heat exchanger used in the GBF test at NYU. We believe that this arrangement will insure proper operation of the PSDF recuperative heat exchanger and provide data for the design of the heat exchanger for a commercial unit.

2.8 GBF Media Issues

There are several issues associated with the filter medium used in the GBF. The supplier of the medium used for the test work at NYU can not supply balls larger than 3 mm. Having changed from 3 mm balls to 6 mm balls would also required a re-evaluation. The 6 mm balls should be evaluated for the following properties which affect their suitability for use in a GBF.

- Spalling (de-lamination)
- Attrition resistance
- Fluidization characteristics
- Medium flow characteristics

Resolution of possible spalling: During the development of the GBF, tests were run with 4 mm balls which broke by the spalling off of layers. These balls were produced on a disk pelletizer which builds up particles in layers making them susceptible to spalling.

The 6 mm balls proposed for the GBF is a commercial product used as catalyst bed support by the petrochemical industry. For this application, resistance to de-lamination (spalling), attrition resistance, and crush strength are established properties which have been proven through years of use. The catalyst support is produced by an extrusion process and then rounded into spheres so that the spheres are not formed in layers. This material can withstand the thermal shock of being dropped into a water bath after having been heated to a temperature of 1500°F.

Attrition Resistance: As indicated above, commercial catalyst bed support spheres have high attrition resistance. The attrition resistance of the 6 mm balls can be compared to that of the 3 mm balls used at NYU using ASTM test procedure D4058-92. The balls prior to the attrition tests would be thermally cycled by being placed in a 1700 °F oven for 0.5 hours and removed to ambient conditions for 0.5 hours for a total of 6 cycles. Both the 6 mm and 3 mm balls are expected to show very low attrition using this procedure. A significant difference in attrition resistance as revealed by this test procedure would indicate a need for a different medium. The thermal cycling and the attrition test may also expose any potential problem with spalling.

Part of the proposed program to develop medium for multi-contaminant control (MCC), Option III, is a lift pipe/moving bed attrition tester. The 6 mm balls can be run in this apparatus for comparison with medium developed for MCC. Any serious problems with attrition could be spotted in these tests. Long term attrition characteristics should be determined during the testing at the PSDF.

Fluidization Characteristics: The minimum fluidization velocity is a design parameter used in sizing a filter for a given application. The size and density of the 6 mm balls proposed for the PSDF GBF are different from those used in the NYU tests. The fluidization velocity and flow versus pressure drop characteristics of the filter medium using 6 mm balls can be determined in a component test facility. For these tests, a fluidized bed distributor can be used so that the effects of the GBF gas inlet configuration can be separately evaluated. Standard correlations can be used to relate low pressure, low temperature data to the operating conditions of commercial hot gas clean up systems.

Medium and Ash Flow Characteristics: The flow characteristics of a medium using 6 mm balls is not expected to be significantly different than one using 3 mm balls. The medium composed of larger balls may have some advantage in its flow properties when mixed with ash as compared to one using smaller balls. The flow characteristics can be checked during the development of the bottom cone configuration in a component test facility.

2.9 Pressure Transients

Pressure transients can cause operational problems for a GBF. The test at NYU showed that the filter had no operational problems if pressure transients were less than 2 psi per minute. Problems occurred with transients greater than 4 psi per minute in that they caused a temporary imbalance in pressure between the filter and the medium circulation system. This problem was corrected with the design of an automated pressure balancing system that maintains the proper pressure balance between the GBF and the medium circulation system by bleeding gas into or out of the circulation system. The principle behind the control system was demonstrated by operator intervention which in the future will be performed by an automatic control system.

Large pressure transients can also cause large increases in flow which can cause the bed to fluidize and in extreme cases to be carried out of the filter. The new filter design will mitigate the problem of fluidization and transport of medium out of the filter. The 6 mm medium used in the new design has a lower pressure drop than 3 mm medium for a given flow rate of gas so that it will require nearly 50% more flow to fluidize the 6 mm medium. Similarly th terminal velocity of the 6 mm medium is 42% higher than the 3 mm medium. Corresponding to the 6 mm medium the bed height is increased from 2.5 ft to 5.0 ft. Doubling the bed height increased the mass of bed material which makes the bed less susceptible to spouting or fluidizing. Another design change made to reduce the possibility of medium fluidization is the gas distributor was redesigned for a lower pressure drop which will reduce the total pressure drop through the filter reducing the possibility of fluidization. A fourth design change is that baffles will be added to freeboard region of the GBF to knock down any entrained medium. These changes improve the GBF's compatibility with the flow and pressure transients that other components of the power system can tolerate. Tests at the PSDF will determine the size of the pressure transients that the new GBF design can tolerate.

2.10 Mechanical Design of the Gas Inlet Duct

The gas inlet duct is supported at the top of the filter vessel. Downward flowing filter medium can exert significant force on the duct. If there is an unequal distribution of force around the periphery of the duct, a significant bending moment can also be generated. In high temperature applications, these forces and moments could generate stresses comparable to the allowable stress. In order to help resolve and understand this issue, tests could be conducted in a component test facility. The gas inlet duct of a cold flow GBF model would be instrumented with strain gages to measure to loads and bending moments at the attachment of the inlet duct to the filter vessel. The data would be used to confirm theoretical calculations and to insure the integrity of the commercial designs.

2.11 Optimizing the Size of Balls Used as Filter Medium

Test at NYU used both 2 and 3 mm balls as a filter medium. In these tests, the 3 mm balls were more effective in that operation was more stable and as a result collection efficiencies were higher. The improved filter design will use 6 mm balls as the filter medium Cold flow tests and other evaluation techniques will be proposed using 6 mm balls as the filtration medium in a component test facility. Filter performance will be determined using 6 mm balls as the filter medium in the GBF to be tested at the PSDF. Should the medium composed of 6 mm balls not meet performance expectations, test can be performed with 3 mm balls at the PSDF by removing the inner lining of the filter to increase the filter cross sectional area and lowering the filtration velocity which will allow the use of the smaller size balls. This approach will allow the testing of media composed various ball sizes under realistic operating conditions so that the relative merits of a given medium can be evaluated.

2.12 Filter Pressure Drop

Filter pressure drop is an important operating parameter in that it can have a considerable effect on plant heat rate. It is anticipated that filter pressure drop will be in the neighborhood of 2 to 3 psi which is comparable to that of barrier filters. The filter pressure drop is a function of gas velocity and bed depth. Currently a computational fluid dynamic (CFD) model of the filter is used to predict filter pressure drop for new configurations. Gas flow tests with a cold flow GBF can be used to check the predictive accuracy of the CFD model. It will remain for tests at the PSDF to determine the bed depth needed to obtain the desired performance and to determine the effect of ash concentration in the filter medium on filter pressure drop. It is anticipated that the filter pressure drop will be less than 5 psi for any operating condition.

2.13 Instrumentation and Control

The GBF tested at NYU was controlled manually, and as such, required operator intervention. The GBF to be tested the PSDF will use automatic controls for the operation of the filter. The control strategy used at NYU has been incorporated into the automatic control system for the filter. The control system will control the flow rate of filter medium in response to the filter outlet dust concentration and the filter pressure drop. The control system will also maintain the pressure balance between the filter and the circulation system during steady operation and at time of pressure transients.

The pressure balance between the filter and the circulation is an extremely important operating parameter. The pressure balance across the bottom seal leg must be such that gas from the filter leaks into the lift pipe. If the pressure balance is such that gas leaks from the lift pipe into the bottom of the filter, fine ash particles would be stripped from the filter medium and would collect in the lower cone region of the filter. Should this happen, it would result in the separation of the ash from the filter medium and probably the eventual pluggage of the filter. The control system is designed to prevent such an occurrence.

In applications in which the filtration capacity can be handled with a single filter, the flow rate of the filter medium can be correlated with the pressure drop in the lift pipe. In larger applications which require several filters using a common lift pipe, the filter medium flow rate through each filter can not be so easily determined. Although not essential, it would be desirable to have a means of determining the medium flow rate through each individual filter. We have not found commercial solids flow monitoring equipment which can function at the temperature and pressure at which a GBF operates. Until commercial instrumentation becomes available for monitoring solids flow at high temperature and pressure, we will try to develop correlations using the temperature and pressure drops in the GBF seal legs to determine the flow rate of solids in the seal leg. Such correlations will be developed during testing at the PSDF. We believe that we can at least establish a flow or no flow condition by monitoring temperatures in the seal leg. We may be able to refine the technique to determine flow rates.

2.14 Compatibility of the GBF with Gasification and Combustion Processes

Test at NYU have demonstrated that the GBF is compatible with a combustion environment. This will be reconfirmed during tests at the PSDF. The GBF has not been evaluated in a gasification environment. The initial testing of the GBF with a gasification process will be at the PSDF. At this time we see no reason why the GBF will not be compatible with either gasification or combustion processes.

Concerns have been raised that the GBF may not be compatible with gasification or combustion processes because of the size and weight of the GBF. Combustion Power Co.'s report "Granular-Bed and Ceramic Filters in a Commercial Plants - A Comparison" showed that there are not significant differences in the size of the two types of filters. The following table composed from data in that report shows a comparison between a GBF and a candle filter as applied to Foster Wheeler's 2nd generation fluidized bed combustor at a 226 MW capacity. The number and size of filters are nearly the same for this application. The cost of the filters are nearly the same with the GBF having a cost of 3% less than that of the candle filter. The weight of the GBF is about 50% greater than that of the candle filter. The majority of the additional weight of the GBF is due mainly to the weight of the filter medium which is added to the filter after the filter is installed. We do not consider the additional weight to be significant in that it only affects the foundations and the size of the supporting members. The additional cost for these items were factored in the Cost of Electricity which showed the GBF to be less than that of the candle filter.

TABLE 1
Comparison of GBF and Candle Filter

	GRANULAR-BED FILTER		**CANDLE FILTER**	
	PFBC	CARBONIZER	PFBC	CARBONIZER
Number of Filter vessels	4	1	4	1
Filter Vessel Dia. ft	21.5	15.6	22.0	19.6
Filet Vessel Height ft	56	45	51	46
Total weight tons	2960		1882	
Cost of Electricity constant $/KWh	52.8		54.5	

2.15 Response to Load Change

A change in power production is associated with changes in gas flow rate, temperature and pressure. A filtration system has to be able to accommodate these changes within the time period of the load change. Usually load changes do not occur at a rate of more than 5% per minute which corresponds to a 50% load change in 13.5 minutes. Foster Wheeler in their report on the 2nd generation PFBC gives the steady state flow values for 100% maximum continuous rating (MCR) and 50% MCR. Assuming that the load change occurs at a rate of 5% per minute, the last column of Table 2 gives the average rate of change of the gas properties for the Combustor and the Carbonizer.

Table 2
Filter Inlet Conditions for the 2nd Generation PFBC

	100% MCR	50% MCR	delta	% change	delta per min
PFBC					
power (MW)	453	222	231.2	51.1%	17.12
pressure (psi)	186	146	40.5	21.8%	3.00
temperature (F)	1596	1546	50.0	3.1%	3.70
gas flow (million lb/hr)	5.3	5.1	0.1	2.6%	0.01
CARBONIZER					
pressure (psi)	206	160	46.0	22.3%	3.41
temperature (F)	1487	1403	84.0	5.6%	6.22
gas flow (klb/hr)	489	160	329.3	67.3%	24.39

The rate of change of pressure for both filter applications is between 3 and 3.5 psi per minute. The tests at New York University demonstrated that the filter can operate with pressure changes of this magnitude. Temperature changes are 4 to 6 °F per minute which are not an operating problem for the GBF. An unknown associated with load change is the change in dust concentration and the possibility of transient increases in dust. At this time, we have no data on the rate of temperature and pressure changes for various gasification system. One would expect that they are of a similar magnitude as for the PFBC system. Part of the test program at the PSDF should include the simulation of load changes from both PFBC systems and gasification systems. Such tests will demonstrate the capability of the GBF to respond to load changes.

2.16 Temperature Drop Across the Filter

The temperature drop across the filter is a result of heat loss to the environment and the cooling of the gas in the filter medium circulation loop. The heat loss to the environment would be similar to that of a candle filter used for the same application. The size of a commercial GBF filter vessel is the same order of magnitude as that of a candle filter vessel. As a result, the heat loss to the environment will be similar for the two types of filter. The GBF has an additional heat loss associated with the filter medium circulation loop. The circulation gas from the lift pipe is first cooled in the recuperative heat exchanger. The recuperative heat exchanger recycles the heat removed back into the cleaned recirculation gas. Additional heat is removed from the circulation gas after the recuperative heat exchanger. This additional heat removed is not able to be returned to the filter medium circulation system and is the cause of the additional temperature drop in the filter. The amount of heat removed in the medium circulation loop is proportional to the design medium circulation rate. The filter medium circulation rate depends on the maximum dust concentration in the medium. Our commercial design is based on a maximum dust concentration of 2.5% dust in the medium. Tests at the PSDF will determine the maximum dust concentration at which the filter can operate which will determine the amount of heat rejected by the medium circulation system. The projected GBF temperature drop for a 2nd generation PFBC system is 20°F for the combustor filters and 35°F for the carbonizer filter. For the KRW gasification system, the projected filter temperature drop is 35°F.

2.17 Filter Pluggage

The possibility exist that ash and filter medium could combine into a non flowing coherent mass in the filter preventing the flow of gas through the filter and the movement of the filter medium. This would only be the case with an extremely sticky ash or with rapid coke formation from a carbonizer gas. The stickiness of a particular ash will dependent on its inherent characteristics and the presence of alkali condensate due to cooling in the filter. It is conceivable that there may be some types of coal ash which could cause operating problems for a GBF. It is likely that such an ash would have also caused operating problems for other types of equipment such as steam generators. If an ash is suspected to have extreme cohesive qualities, it should be tested in a GBF at a facility such as the PSDF before a commercial filter is implemented. Generally a cohesive ash is handled by maintaining a high circulation rate of filter medium to prevent the joining together of the balls used as the filter medium.

2.18 Flow Splitting of Gas and Filter Medium

In the de-entrainment vessel, filter medium is separated from the circulation gas used to convey the filter medium and collected ash up the lift pipe. The circulation gas and ash go to the pressurized bag house for separation and the ash free filter medium returns to the filter. In normal filter operation, it is not a problem separating the filter medium from the conveying gas. Hundreds of thousands of hours have been logged on Combustion Powers low temperature granular-bed filters. These filters as well as the one tested at NYU do not experience a problem separating the filter medium from the conveying gas.

2.19 Filter Medium Caught in Expansion Joints

During tests at NYU, 2 mm balls became trapped in expansion bellows. The new filter design does not have any expansion bellows in an equivalent area thus eliminating any such problems.

3.0 REFERENCES

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4.0 LIST OF ACRONYMS

FBC: Fluidized-Bed Combustor

GBF: Granular-Bed Filter

HTHP: High Temperature and High Pressure

KRW: Kellogg-Rust-Westinghouse

NYU: New York University

PFBC: Pressurized Fluidized-Bed Combustion

PSDF: Power Systems Development Facility

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