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WESTINGHOUSE STANDLEG MOVING GRANULAR BED FILTER DEVELOPMENT PROGRAM

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5.7 Westinghouse Standleg Moving Granular Bed Filter Development Progam

CONTRACT INFORMATION

Contract Number	DE-AC21-91MC27259
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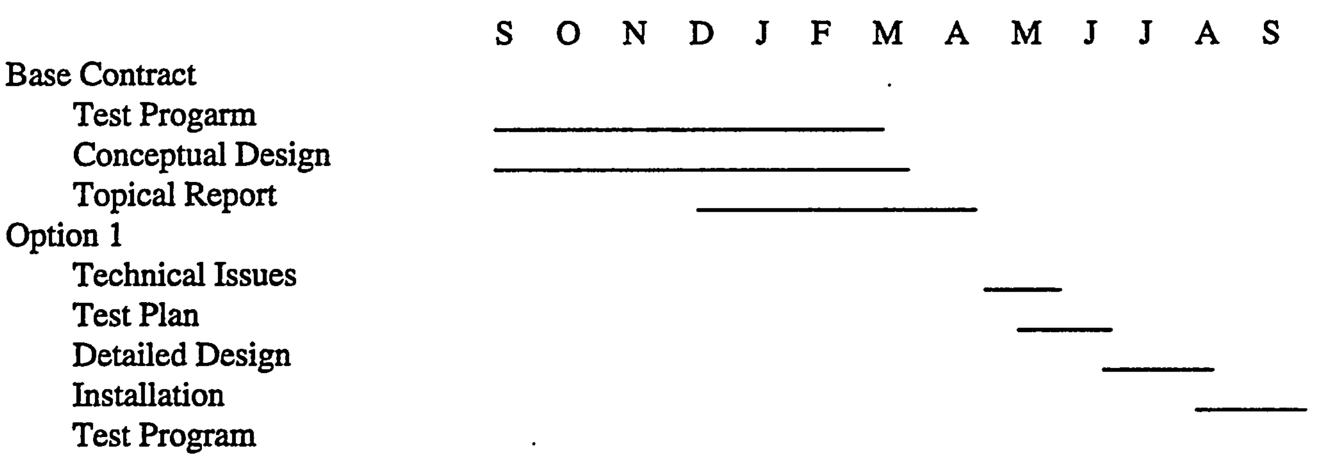
Period of Performance	May 13, 1991 to December 15, 1994

Schedule and Milestones

FY94 Program Schedule



OBJECTIVES

The overall goal of the Standleg Moving Granular Bed Filter (SMGBF) development program is to establish a moving granular bed filter system that meets all of the performance requirements and design constraints imposed by advanced power generation applications, and is economically competitive with ceramic barrier filter systems. In the recently completed, Base Contract period, it was the objective of the program to identify barrier technical issues for the SMGBF technology and to perform critical testing and evaluation to resolve those key issues. This paper summarizes the activities and conclusions from the Base Contract period.

BACKGROUND INFORMATION

Advanced, coal-based, power plants, such as IGCC and Advanced-PFBC, are currently nearing commercial demonstration. These power plant technologies require hot gas filtration as part of their gas cleaning trains. Ceramic barrier filters are the major filter candidates being developed for these hot gas cleaning applications. While ceramic barrier filters achieve high levels of particle removal, there are concerns for their reliability and operability.

An alternative hot gas filtration technology is the moving granular bed filter. These systems are at a lower state of development than ceramic barrier filters, and their effectiveness as filters is still in question. Their apparent attributes, relative to ceramic barrier filter systems, result from their much less severe mechanical design and materials constraints, and the potential for more reliable, failure-free particle removal operation.

The Westinghouse Science & Technology Center has proposed a novel moving granular-bed filter concept, the Standleg Moving Granular-Bed Filter (SMGBF) system, that may overcome the deficiencies of the current state-of-the-art moving granular-bed filter technology. The SMGBF is a compact unit that uses cocurrent gas-pellet contacting in an arrangement that greatly simplifies and enhances the distribution of dirty, process gas to the moving bed and allows effective disengagement of clean gas from the moving bed.

The SMGBF vessel concept is elucidated in Figure 1. Dirty process gas is introduced into the top chamber of the filter vessel through a tangential entry. The moving bed media is introduced into the same chamber through a single, vertical dipleg pipe, where it spills from the base of the dipleg pipe to form a free surface having the normal media angle of repose. The dirty process gas enters the moving bed media through this free surface. Cocurrent flow of gas and bed media through the short, vertical standleg promotes intimate contact between the flowing gas stream and the moving bed media, resulting in excellent separation of fly ash particles. The cocurrent gas/solids operation also prevents fluidization at the bottom of the standleg and permits high flow throughput (3 to 6 ft/s through the standleg), with relatively small ratios of bed media-to-fly ash (mass ratio of about 10). The cleaned gas is then allowed to flow out through the free surface of the bed formed naturally below the standleg. Special design features are built into the region at the base of the standleg to permit disengagement of the cleaned gas from the moving bed media without significant fly ash re-entrainment. The bed media and captured fly ash withdrawal from the filter vessel is controlled by a water-cooled, rotary valve or screw conveyor located below the vessel. The SMGBF vessel design is relatively simple, and it employs well-known standpipe design technology, making it cost effective, reliable, and easy to scaleup.

Two approaches for handling the bed media can be applied to the SMGBF: "Once-Through" media operation, and "Recycle" media operation. Once-Through media operation applies pelletization technology to generate filter pellets from the power plant solid waste materials, and uses these pellets as a "once-through" filtering media to eliminate the need for costly, complex, and large filter media recycling equipment. This pelletizing step also generates a more environmentally acceptable solid waste product

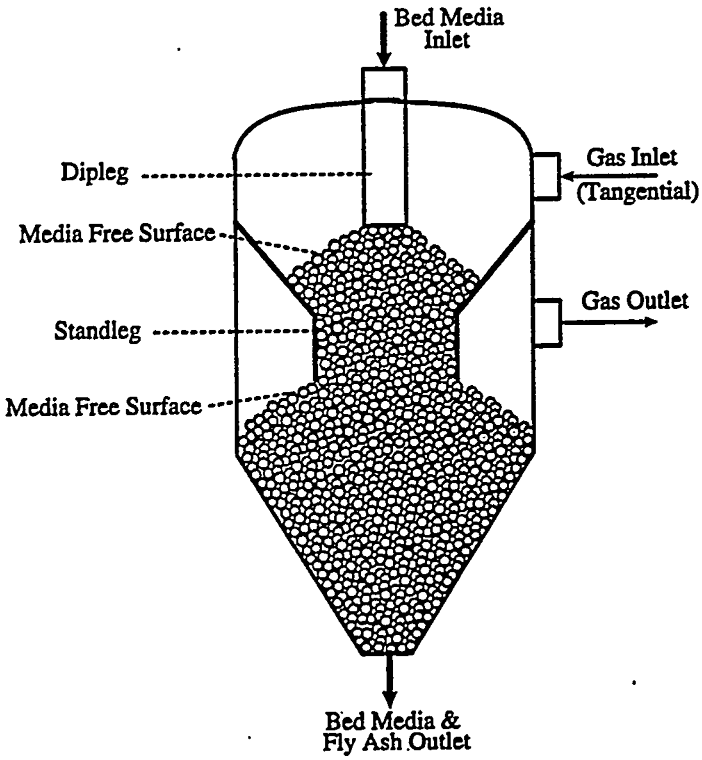


Figure 1. SMGBF Configuration Concept

and provides the potential to incorporate gas-phase contaminant sorbents into the filtering media. Recycle media operation recirculates granules from the SMGBF bottom withdrawal point to a top feed point, much as in the traditional moving granular bed filter approach. The SMGBF system performs this media circulation function by applying standleg, dense-phase flow and pneumatic transport that uses the dirty process gas to carry the granules. The granules are purchased bed media selected for its attrition resistance and it performance as a filtering media.

A general schematic diagram of the Once-Through SMGBF system in PFBC and IGCC applications is shown in Figure 2. The Once-Through SMGBF system is closely integrated with the power plant because of its need to utilize the power plant solid waste as the moving bed filter media while maintaining high power plant performance and economics. The major system components are:

- The SMGBF modules and their connecting piping
- The plant solid waste handling system (solids cooling and heat recovery, depressurization, transport)
- The pelletization system
- The pellet handling system (pressurization, transport, feeding and distribution)
- The pellet/dust cake handling system (cooling and heat recovery, depressurization, transport)

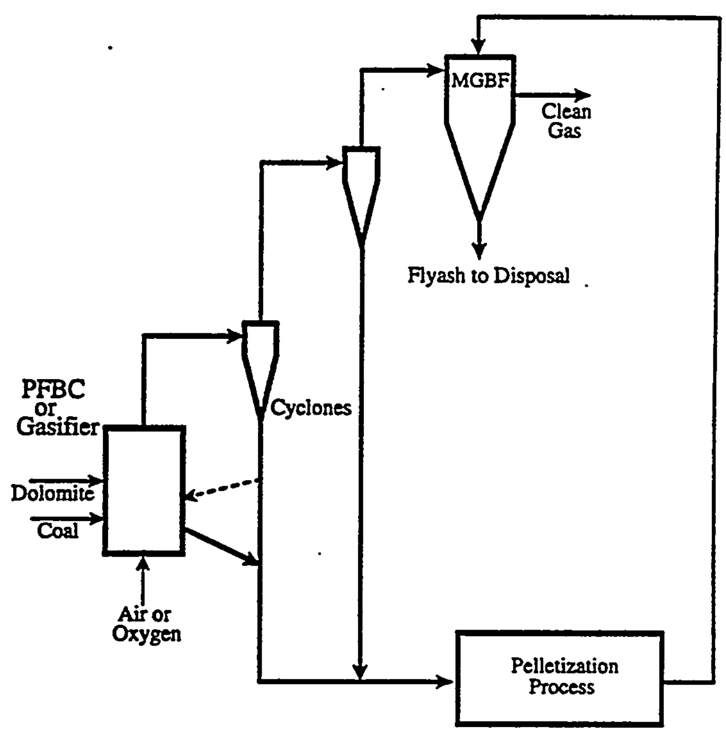


Figure 2. Once-Through SMGBF System Concept

There are several equipment options for each of these system components. The solids handling systems and pelletization system are generally commercially available components, but their selection is highly dependent on the nature of the solid waste streams, and they may need to be adapted to environments (eg., high pressure) where they have not been previously demonstrated. The pelletization system is a key system, and many pelletization techniques are available. The pelletization system must be integrated into the power plant to minimize complexity and to maximize energy efficiency, as well as being selected to produce sufficiently durable pellets for the SMGBF system.

The Recycle SMGBF system is Conceptually illustrated in Figure 3. Granules and captured fly ash are drained from the SMGBF and ash-granule separation is performed to remove a large portion of the captured fly ash.

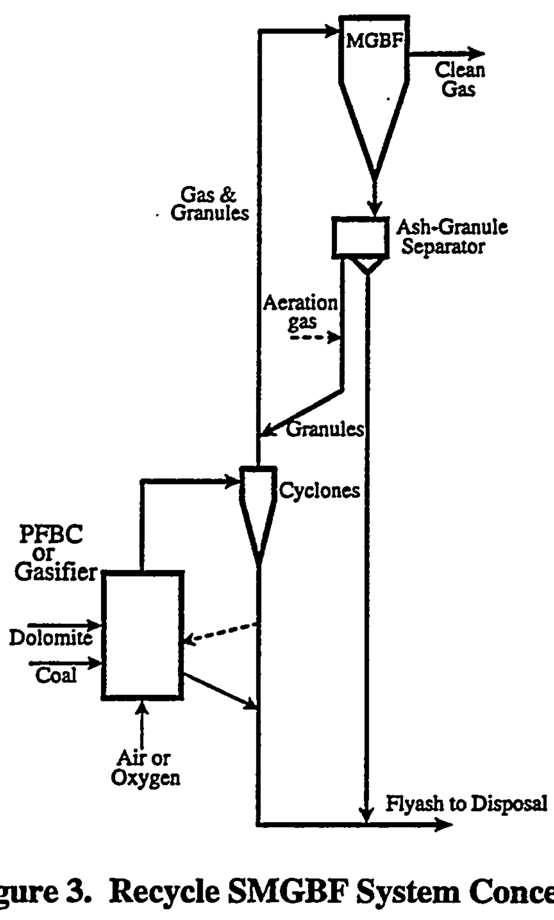


Figure 3. Recycle SMGBF System Concept

the SMGBF. The SMGBF configuration allows the transport to be accomplished by the dirty, process gas, and fly ash not separated from the granules in the ash-granule separator are reintroduced to the SMGBF.

PROJECT DESCRIPTION

The Standleg Moving Granular Bed Filter (SMGBF) development program is a four-phase program, a Base Contract and 3 Optional phases. The program has successfully completed the initial, Base Contract period, identifying and resolving barrier technical issues, and demonstrating conceptual feasibility. The Option 1 program has been initiated, confronting the major technical issues remaining for the SMGBF by conducting key component tests to optimize the SMGBF performance. Option 3 will demonstrate the SMGBF at an advanced, coal-fired power plant, pilot facility to be selected. Option 4 is devoted to development of multi-contaminant control features for the SMGBF, incorporating gas-phase contaminant sorbents into the moving bed media.

RESULTS

The SMGBF development program has completed the initial, Base Contract period. The barrier technical issues identified were:

- The ability to achieve sufficient levels of fly ash removal to meet environmental standards and turbine protection criteria,
- The ability to generate sufficiently durable pellets from plant solid wastes, using commercial, economical pelletization techniques integrated with advanced power plants.

The technical approach applied to achieve the Base Contract objective was to conduct commercial plant conceptual design evaluation, in combination with laboratory and bench-scale testing that focused directly on the barrier issues. These activities were performed in parallel to ensure that each had the appropriate perspective to provide significant results.

Two major test efforts were undertaken to establish the conceptual feasibility of the SMGBF with respect to its ability to achieve sufficient fly ash removal, a cold flow model test program, and a high-temperature, high-pressure (HTHP) test program. The cold flow model test program was conducted first to investigate several design and operating features of the SMGBF in a facility where performance phenomena within the SMGBF unit could be visualized, where detailed probing could be easily performed, and where equipment changes could be easily made. The HTHP testing was then conducted to show that the cold model trends were reproducible at HTHP conditions, and to demonstrate the SMGBF performance at small-scale, prototypic conditions. In parallel to the cold model test program, an effort to identify viable solid waste pelletization techniques, and to test pellet durability was conducted.

A new, cold flow model facility was designed and constructed, as shown in Figure 4. The model was constructed primarily of Plexiglas, with a vessel OD of 36", and a 36" long standleg having 12" OD. The test unit was designed to be highly sectionalized so that internal modifications could easily be performed, and was of a size that represented a reasonable scaling to commercial dimensions. Support facilities for the cold model test included a large bed media feed hopper located above the SMGBF vessel, a screw feeder and weight scale located below the SMGBF vessel to control and record the flow rate of bed media, a fly ash feed system

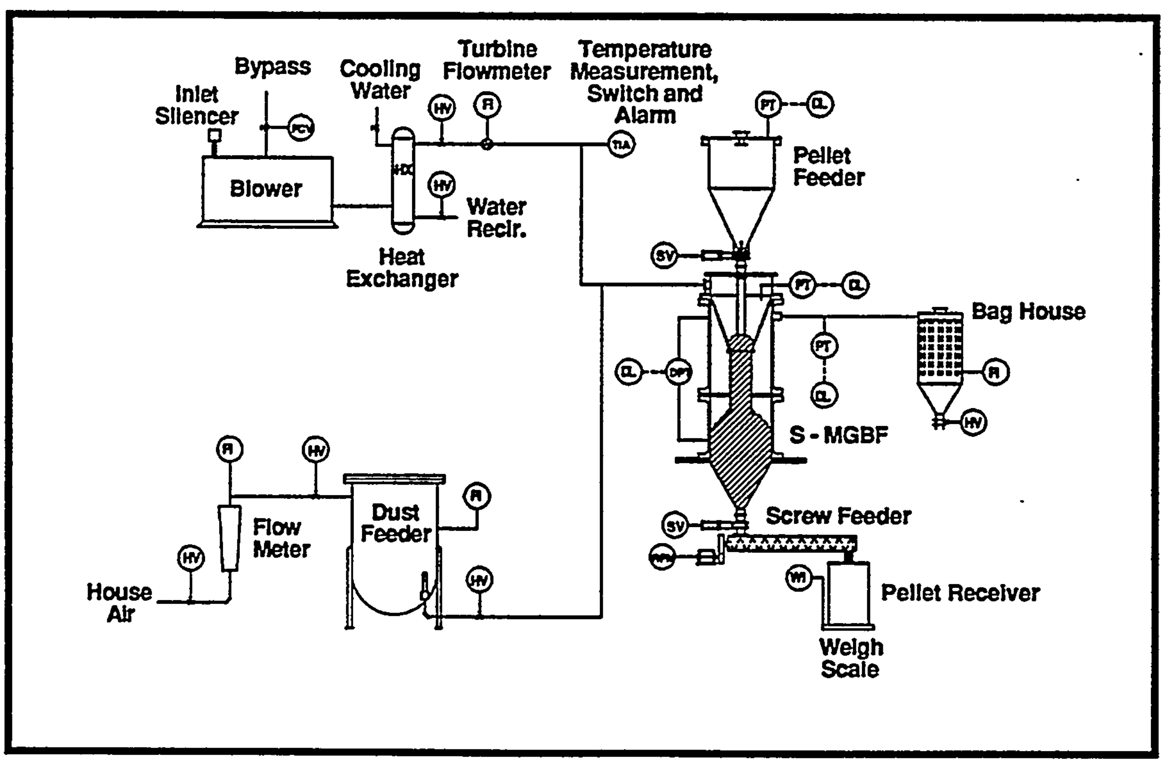


Figure 4. SMGBF Cold Model Facility

(K-Tron, loss-in-weight screw feeder) to inject fly ash into the inlet gas, a fabric filter to capture the fly ash in the SMGBF outlet gas so that its particle removal performance could be monitored, and instrumentation to measure the pressure drop profile within the SMGBF unit.

The cold flow model testing was performed with crushed acrylic particles, having an average diameter of about 3800 μm, as the bed media. The acrylic was selected because it had a density low enough to provide proper scaling to the actual, high-pressure SMGBF environment. A series of cold flow model tests were performed to characterize the gas flow and bed pressure drop characteristics, and the bed media flow characteristics, without fly ash feed. No visible fluidization of the bed media could be detected at standleg velocities up to 6 ft/s, exceeding the bed media minimum fluidization velocity of 5 ft/s. The clean bed pressure drop was consistent with existing packed bed pressure drop correlations. Fly ash injection testing was performed with fly ash from a PFBC pilot plant. Three SMGBF configurations were tested: the simple standleg configuration, a skirt section added at the base of the standleg, and a secondary, or topping bed added to surround the standleg skirt. Operating with a standleg gas velocity of about 3 ft/s, a bed media to fly ash mass feed ratio of about 10, and an inlet fly ash loading of about 6400 ppmw, total unit pressure drop was acceptable at less than 40 in-wg, and the particle removal performance achieved was:

- >97% removal with the simple standleg configuration,
- >99% removal with the added skirt section,
- >99.95% with the added topping bed.

Test durations were extended to relatively long periods of time to ensure that steady levels of performance were achieved. The cold flow model testing identified the key phenomena controlling the SMGBF performance, established the design features needed to achieve high levels of performance, and demonstrated the potential performance capabilities of the SMGBF. The cold flow model testing was representative of both the Once-Through and Recyle SMGBF performance capabilities.

Pelletization studies were performed by collecting representative solid waste samples from various advanced, coal-fired power plant units, and having commercial vendors prepare pellets from these wastes by several commercial techniques. Solid waste samples from both IGCC plants and PFBC plants were collected, as well as from some AFBC plants. All of these were successfully pelletized by several vendors. The generated pellets were then tested for durability by simple furnace heating tests, as well as a standard, rotary pellet attrition test rig that was adapted to high-temperature conditions. The attrition test subjected the pellets to much more severe attrition conditions than they would see in the SMGBF application. The results indicated that sufficiently durable pellets can be produced with advanced power plant solid wastes using conventional pelletization methods, but more evaluation is required to develop optimum techniques for solid waste sizing, water and binder content, mixing, and curing.

An existing HTHP test facility previously used to test ceramic barrier filter elements was adapted to test the SMGBF, as illustrated in Figure 5. The pressure vessel used had an OD of 40" and a total vessel height of about 10 feet. A new vessel head was constructed with a tangential gas inlet nozzle, and the natural gas-fired combustion system was moved to the head gas inlet location. The standleg internals inserted in

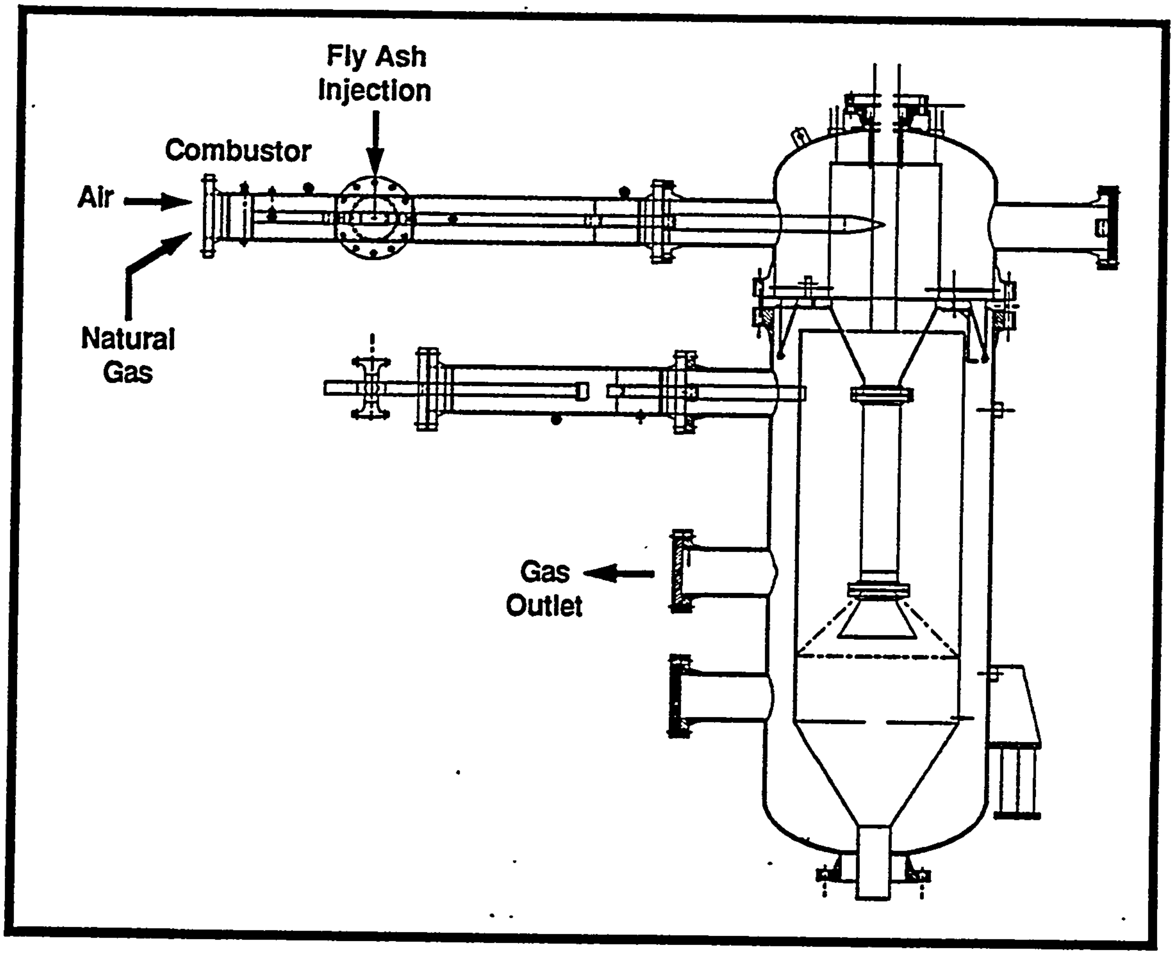


Figure 5. SMGBF HTHP Facility

the vessel had a 6" diameter, and were operated at a standleg velocity of about 3 ft/s in most of the testing. The standleg was constructed with a skirt section attached at its base, with its design based on the cold flow model results. A pressurized, water-cooled screw conveyor was added to the facility to control the flow of bed media through the unit. A batch feed hopper for bed media was located over the SMGBF vessel. The tests were performed under conditions simulating a PFBC application:

- Temperature of 1500 to 1600°F,
- Pressure of 100 psig,
- Injected PFBC fly ash at inlet loadings of 1000 to 7000 ppmw.

A total of 18, high-temperature test runs were completed. The tests were arranged in three major series:

1. On-off bed media flow with pelletized fly ash,
2. Continuous bed media flow with alumina beads,
3. Continuous bed media flow with pelletized fly ash.

The pelletized fly ash used in the tests was Aardelite, a commercial, pelletized conventional pulverized coal (PC) power plant fly ash product. The on-off bed media flow testing showed very high levels of particle removal performance, with outlet loadings of 2 to 20 ppmw, but operational problems would not permit representative, steady operation to be achieved. Subsequent, continuous bed media flow testing with alumina beads, a mixture of 1/4" and 3/8" diameter beads, was performed without operational problems, but the higher density, more uniform sized and shaped alumina beads resulted in poorer particle removal performance, with outlet loadings of 6 to 250 ppmw. The final series of continuous bed media flow, pelletized fly ash tests achieved good performance, with acceptable unit pressure drop and outlet loadings of 8 to 14 ppmw. The HTHP testing showed a clear trend for higher particle removal performance as the mass ratio of bed media to fly ash flow was increased, and demonstrated a particle removal performance acceptable for commercial applications. Mass ratios of bed media to fly ash were in the range of 10 to 20 for acceptable performance.

Conceptual design evaluations were conducted for IGCC and Advanced-PFBC applications of the SMGBF technology, and comparisons were made with ceramic barrier filter technology by applying Reference Studies conducted previously for ceramic barrier filter applications (Ciliberti, et al, 1986; Foster Wheeler Development Corp., 1989). Process flow diagrams and material & energy balances were developed for the IGCC and Advanced-PFBC applications using SMGBF hot gas cleaning. Both Once-Through and Recycle SMGBF were evaluated. The SMGBF system equipment was sized and specified to the extent needed to develop equipment delivered and installed cost estimates and to produce rough plant equipment layouts. The impact of the SMGBF system on the power plant thermal efficiency was estimated based on estimated heat losses, SMGBF system gas pressure drop, and auxiliary power consumption. Finally, total power plant capital requirements, annual operating costs and cost-of-electricity (COE) estimates were made, updating the Reference Studies to the current plant economic premises.

The evaluation results show that the SMGBF system is economically competitive with ceramic barrier filters for IGCC and Advanced-PFBC applications. The installed equipment costs of the SMGBF system are comparable to those of the ceramic barrier filter systems, although the pelletization system adds a significant equipment cost to the Once-Through SMGBF system:

- Installed equipment cost for IGCC application
  - Once-Through SMGBF: 32 - 41 $/kW
  - Recycle SMGBF: 17 - 22 $/kW
  - Ceramic barrier filter:, 11 - 19 $/kW

- Installed equipment cost for Advanced-PFBC application
  - Once-Through SMGBF: 31 $/kW
  - Recycle SMGBF: 18 $/kW
  - Ceramic barrier filter: 17 $/kW

The Once-Through SMGBF system has a higher total power plant capital cost, annual operating cost, and COE than the ceramic barrier filter system for IGCC and Advanced-PFBC, but these cost increases are small, about 1% for IGCC, and about 3-5% for Advanced-PFBC. The waste material issued from the plants using Once-Through SMGBF potentially has a superior environmental character, or even byproduct possibilities. The Recycle SMGBF system total power plant capital cost, annual operating cost and COE is nearly identical with that of the ceramic barrier filter system.

The Base Contract conclusions reached are:

- Design features have been identified in the cold flow model testing that optimize the SMGBF particle removal performance.

- Cold flow model and HTHP testing trends are consistent.

- Particle penetration levels of 6 to 14 ppmw are representative performance levels based on the HTHP testing, with the cold flow model testing indicating that even higher performance levels can be achieved.

- Particle removal performance increases and the unit pressure drop decreases as the mass feed ratio of bed media to fly ash increases. Ratios of 10 to 20 are required for acceptable performance.

- Sufficiently durable pellets can be generated from advanced power plant solid waste using conventional pelletization techniques, but further evaluation of optimum solid waste sizing, water and binder content, mixing, and curing procedures is needed.

- The pelletized solid waste may provide particle removal performance superior to more regular shaped and uniformed sized purchased granules.

- The Once-Through SMGBF total power plant capital requirement and COE are only marginally higher (1 to 5%) than that for ceramic barrier filter systems in both IGCC and Advanced-PFBC applications.

- The Recycle SMGBF system is comparable in capital cost and COE to the ceramic barrier filter system for both IGCC and Advanced-PFBC applications.

REFERENCES

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