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Moving Granular-Bed Filter Development Program Option I -- Component Test Facilities Technical Tradeoffs and Issues

Topical Report

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June 1994

Work Performed Under Contract No.: DE-AC21-91MC27259

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

By
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

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1. INTRODUCTION

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 in these applications.

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 the current, moving granular-bed filter technologies are relatively large, complex, and costly systems in terms of their capital investment, their operating and maintenance cost, and their impact on the power plant efficiency. In addition, 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 inherent 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

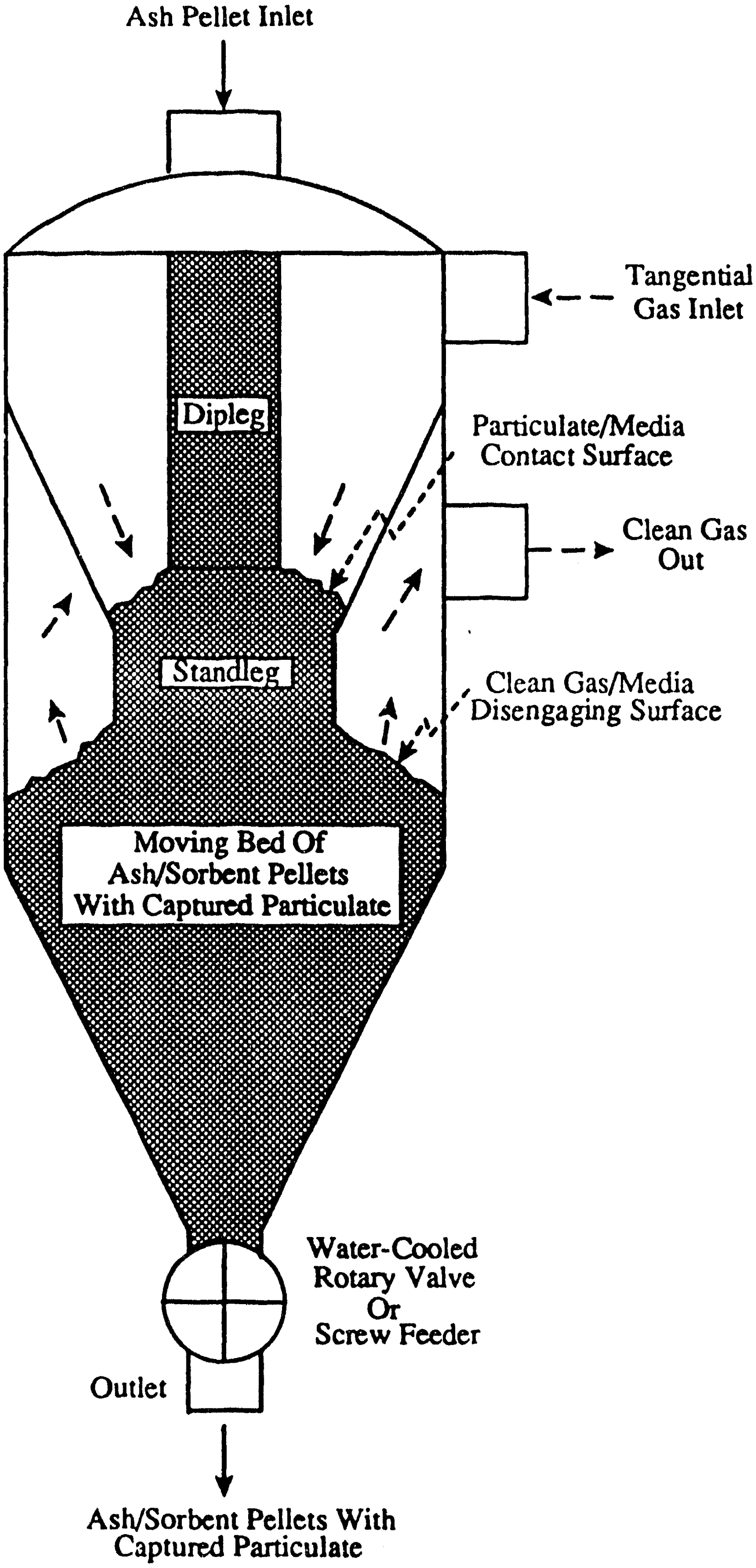

Figure 1 - SMGBF Module Schematic

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 design technology, making it cost effective, reliable, and easy to scaleup.

Two approaches for bed media flow can be used, "continuous" flow or "on-off" flow. In the continuous flow approach, the media conveyor operates continuously and the filter bed reaches and remains at a relatively steady condition with the filter bed having a constant pressure drop. In the on-off flow mode, the media conveyor remains off until the filter bed pressure drop reaches a "trigger" value. At the trigger pressure drop, the media conveyor is activated and media flows through the SMGBF at a relatively high rate until the bed pressure drop is reduced to a baseline value. While the net media use rate is about the same for the two techniques, there may be particle removal efficiency advantages with the on-off technique compared to the continuous flow technique. Experimental comparison is required to establish such an advantage.

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 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 its 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 (size reduction, pelletization)
- The pellet handling system (pressurization, transport, feeding and distribution)
- The pellet/dust cake handling system (cooling and heat recovery, depressurization, transport)

There are several equipment options for each of these system components, and some of them replace system components that would exist in the power plant when using ceramic barrier filters for particulate control. 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 (e.g., high pressure) where they have not been previously demonstrated.

The pelletization system is a key system, and many pelletization techniques are available, applying principles of

- Granulation
- Pressure compaction
- Extrusion compaction

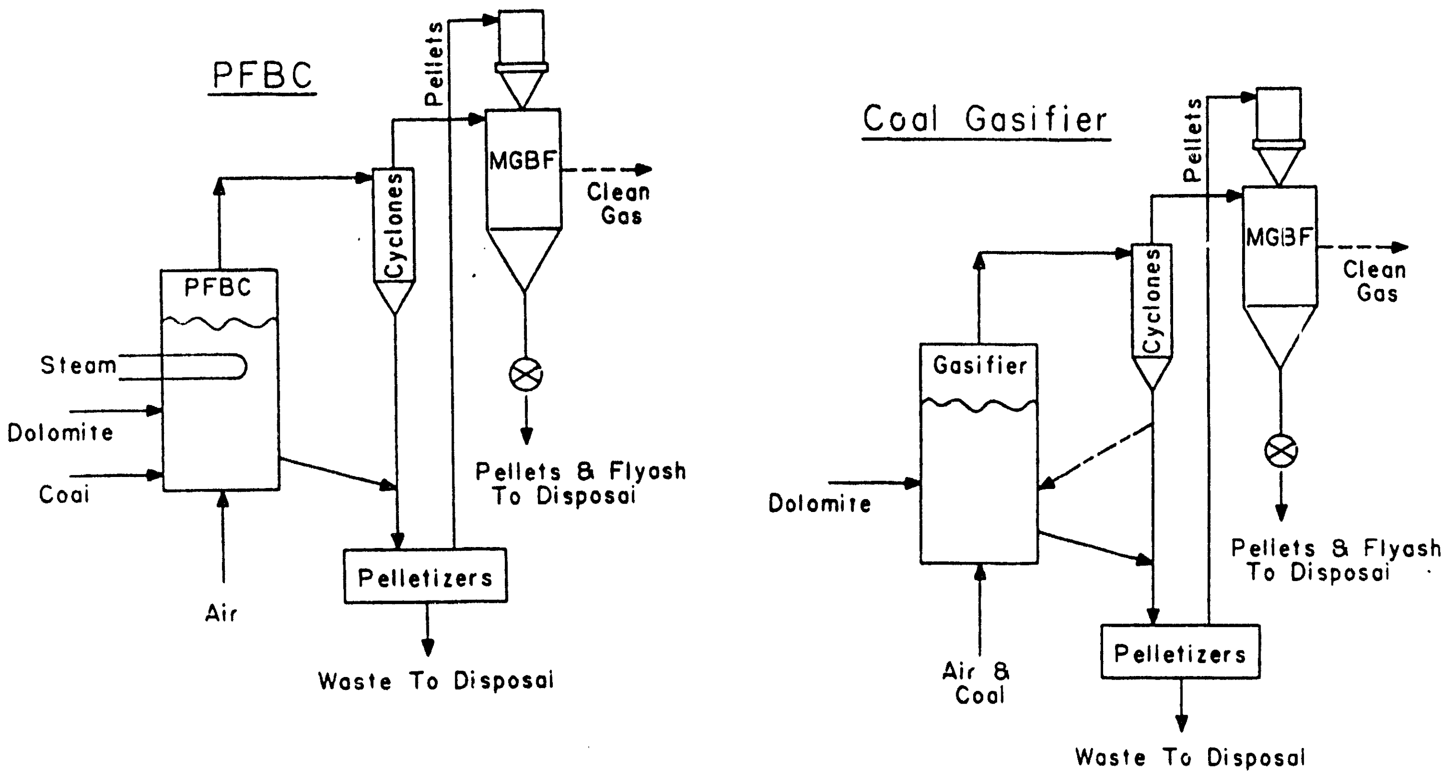

Figure 2 - Once-Through SMGBF System Schematic

- Agglomeration (with or without binders)
- Globulation (for slags, such as those in some entrained gasifiers and some DCFT)
- Heat bonding

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. The granules are then aerated in a standleg pipe to increase their pressure so that they may be pneumatically transported back to the entrance of 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.

The SMGBF concept has apparent advantages over conventional granular bed filter technologies, as well as potential advantages over ceramic barrier filter technologies. Relative to conventional granular bed filter technology, the SMGBF is potentially

- More compact, with fewer modules;
- Simpler in design and layout, with no media recycle, or has simplified media recycle;
- Lower in power consumption, with small media feed rate;
- More easily scaled up to commercial size;
- Capable of dealing with plant solid waste issues;
- Higher in performance.

These potential advantages can only be confirmed through experimental testing and conceptual design comparisons.

A meaningful comparison of the SMGBF system and ceramic barrier filters can be made in terms of their design features, cost factors, and technical issues and

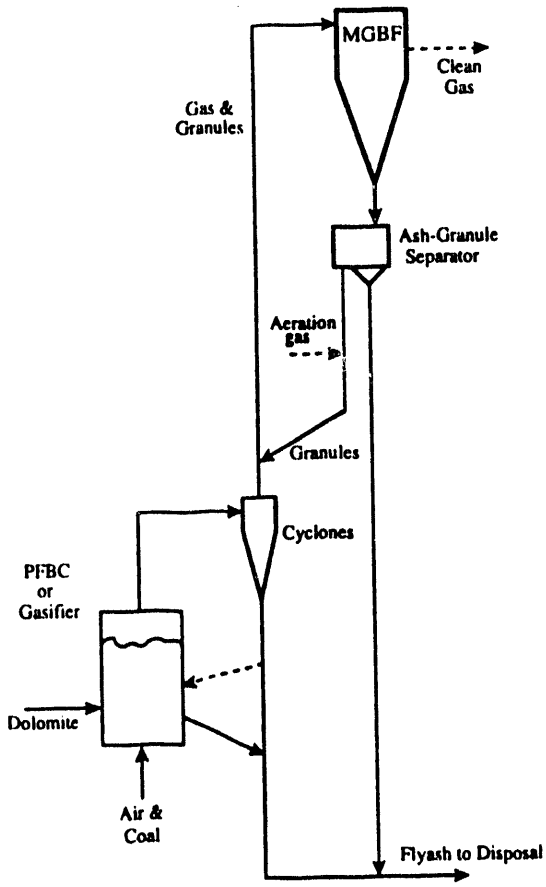

Figure 3 - Recycle SMGBF System Schematic

capabilities. The SMGBF has the following potential advantages over ceramic barrier filters:

- Simpler in design and scaleup;
- Comparable gas throughput;
- Easier operation and maintenance;
- Ability to handle difficult fly ash particles (e.g., sticky particles) and gases (e. g., coking);
- Can operate at very high temperatures without water-cooled internals;
- Can operate with higher reliability, having no high-risk internals;
- More tolerant to process thermal and flow transients and upset conditions.

The objective of this report is to identify and prioritize the technical tradeoffs and issues relating to the SMGBF technology. These are the tradeoffs and issues that will be addressed in the Option 1, Component Test Facilities program, and this report provides the basis for developing the Test Plan for this phase of the program. The SMGBF system tradeoffs and issues are largely process oriented, as well as relating to the optimization of the basic performance of the SMGBF module and system. Ceramic barrier filter issues are largely materials and mechanical design oriented, relating to both short-term and long-term component life. Overall, the key issues for the two technologies are the same: the reliability, operability, and availability of the particle removal system under conditions that meet all application performance requirements and constraints.

2. SUMMARY

The SMGBF Base Contract development program has been successfully completed, and Option 1 of the development program has been initiated. This report identifies and prioritizes the SMGBF technical issues and represents the results of the first task of the Option 1 program. The highest priority development and optimization issues for the SMGBF system are, in priority order:

Once-Through SMGBF:

- Scaleup of the SMGBF module to large capacities,
- Optimized pellet fabrication durability (size reduction, binder use, water use, curing)
- Optimized particle removal performance (special design features, pellet shape and size distribution, optimum pellet/ash ratio),
- Determination of pellet solid waste environmental performance.

Recycle SMGBF:

- Scaleup of the SMGBF module to large capacities,
- Flow distribution of pneumatically circulated granules to the SMGBF top bed,
- Operability of the granule circulation system,
- Development of an effective ash-granule separation system,
- Optimized particle removal performance (special design features, granule shape and size distribution, optimum granule/ash ratio).

The resolution of these issues will require a combination of engineering evaluation activities, modeling activities, and testing activities. The testing activities will need to be performed in cold flow facilities, HTHP facilities, laboratory facilities, as well as using prototypic vendor pelletization equipment. The prioritized issues and the alternatives to resolve them that are identified in this report form the basis for Task 2 or the Option 1 program, the development of a Test Plan.

3. STATUS OF SMGBF DEVELOPMENT

The SMGBF development program has completed the initial, Base Contract period of the four-phase program. The objective of the Base Contract period was to identify and resolve the "barrier" technical issues, demonstrating conceptual feasibility. 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.

The SMGBF Base Contract program has addressed two barrier technical issues that were identified early in the program:

- The ability to achieve sufficient levels of fly ash removal with the SMGBF to meet environmental standards and turbine protection needs,
- the ability to generate sufficiently durable pellets by practical, economical pelletization methods that can be closely integrated into the advanced power plant.

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. 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 (factor of 4 to 10). 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 (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 (the Exxon Miniplant). 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 greater than:

- 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 Recycle 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 pellet attrition test rig that was adapted by Westinghouse 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. The pressure vessel used in the program 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 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 in the Base Contract test program. 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, using pelletized fly ash as bed media, 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.

The overall goal of the SMGBF development program is to realize 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. A conceptual, economic design evaluation was performed to assess this comparison. 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. Process flow diagrams and material & energy balances were developed for the IGCC and Advanced-PFBC applications using SMGBF hot gas cleaning. Only the continuous bed media flow technique was considered in the evaluation. 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 showed 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 have a superior environmental character, or even by-product 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 in the test program were:

- Design features have been identified in the cold flow model testing that improve the SMGBF particle removal performance – the standleg skirt and the secondary, topping bed are major examples.

- 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 Base Contract conceptual design evaluation has resulted in the following conclusions:

- The Once-Through SMGBF system is more expensive than ceramic barrier filter systems for both IGCC and Advanced-PFBC applications, but total power plant capital requirements and COE are only marginally higher (1 to 5%).

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

4. REVIEW OF TECHNICAL TRADEOFFS AND ISSUES

The SMGBF technology is grouped into two categories, system component technology, and SMGBF module technology. Table 1 lists the major system component technologies, their potential technical tradeoffs, and the nature of their selection resolution. Separate listings are shown for the Once-Through SMGBF and the Recycle SMGBF systems. Many of the potential technical tradeoffs are of limited concern, or have been partially resolved based on the evaluations performed during the Base Contract. Others are major tradeoff issues requiring engineering evaluation, and/or modeling, and/or testing evaluations.

The SMGBF module itself consists of the following major components:

- Media feed hopper
- Media feed dipleg
- Dirty gas inlet nozzle
- Cone and standleg section
- Gas-media disengaging section
- Media/fly ash discharge cone and nozzle
- Clean gas outlet nozzle

Each of these vessel components is designed by the application of engineering techniques in the areas of gas and particle flow and handling. In general, the flow of pellets through hoppers, diplegs, standlegs, and nozzles is a relatively well developed technology for which reliable engineering design criteria have been developed. The less easily quantified aspects of the module design and performance estimates relate to the dust flow and accumulation within the moving bed of media, the media-dust particle interactions (cohesion, attrition of agglomerates, etc.), and especially the dust removal efficiency and losses in the vicinity of the gas-media disengaging section. Engineering materials issues and mechanical design are relatively easy to assess and reliable selections can be made.

Table 1 - SMGBF System Component Technologies and Tradeoffs

Once-Through SMGBF

TECHNOLOGY	TRADEOFFS	SELECTION RESOLUTION
Media transport	• Mechanical or pneumatic technique selection	• Mechanical favored for pellet durability
Media pressurizing	• Alternatives to lock hopper systems	• Lock hoppers acceptable from process evaluation
Media feeding and distribution	• Ability to control • Uniformity of distribution	• Limited concern • Limited concern
Media flow control	• High temperature valve and conveyor reliability	• Limited concern using water-cooled valves and conveyors
Media cooling and heat recovery	• Commercial techniques vs. developmental concepts	• Commercial acceptable from process evaluation
Media/ash depressurization	• Developmental techniques (e.g., RPDS) vs. lock hopper techniques	• Lock hoppers acceptable from process evaluation
Solids size reduction	• High temperature techniques (e.g., air-jet) vs. low-temperature commercial	• Commercial acceptable from process evaluation
Pelletization	• Adapt commercial techniques to high pressure • Apply high temperature techniques • Sensitivity to solids properties and size, binder and water content, and curing technique	• Requires significant development effort • Requires significant development effort • Testing required
System integration	• Sufficient pellet/fly ash ratio • Minimize process gas cooling • Effective arrangement of multiple modules	• Pellet recycle and process evaluation • Process evaluation of options • Engineering evaluation of options

Table 1 - SMGBF System Component Technologies and Tradeoffs(Continued)

Recycle SMGBF

TECHNOLOGY	TRADEOFFS	SELECTION RESOLUTION
Media transport	• Mechanical or pneumatic technique • Granule attrition	• Pneumatic favored • Limited concern with specified granules
Makeup media pressurization	• Alternatives to lock hopper systems	• Lock hoppers acceptable
Media feeding and distribution	• Ability to control • Uniformity of distribution	• Requires engineering evaluation and testing • Testing required
Media flow control	• Dense-phase aeration reliability	• Nonmechanical valves favored • Testing required
Granule-ash separation	• Adapt commercial to high pressure and temperature	• Requires engineering evaluation and testing
Ash depressurization	• Developmental techniques (e.g., RPDS) vs. lock hopper techniques	• Lock hoppers acceptable from process evaluation
System integration	• Effective arrangement of multiple modules	• Engineering evaluation of options.

Table 2 lists the design aspects involved in the characterization of the SMGBF module, the key tradeoffs, issues and uncertainties, and the nature of their resolution. They apply equally to both Once-through and Recycle SMGBF. Special design features have been identified in the Base Contract program to modify the gas-media disengaging section for optimum particle removal performance:

- Addition of a skirt, or screen section at the standleg base,
- Addition of a secondary, or topping bed surrounding the standleg base,
- Installation of low resistance fiber filter (e.g., Battelle ceramic fiber filter) above the disengaging section.

and these are potentially key considerations for the Option 1 program.

Table 2 - SMGBF Module Design Technologies and Tradeoffs and Issues

DESIGN ASPECT	TRADEOFFS ISSUES/UNCERTAINTIES	RESOLUTION
Media flow: - Standleg - Hopper - Nozzle	• Impact of dust accumulation and agglomeration • Flow distribution to top of vessel	• Design criteria limited to clean systems • Major issue for Recycle SMGBF
Gas flow	• Local fluidization in disengager • Flow uniformity through standleg • Pressure drop estimation • Tangential or radial inlet flow	• All require modeling and testing
Dust flow	• Dust accumulation patterns and plugging • Dust re-entrainment at disengaging zone	• All require modeling and testing
Media-dust interaction	• Dust agglomeration/adhesion on pellets • Dust agglomerate formation • Pellet cohesion/clinkers	• All require modeling and testing
Media operating mode	• Continuous media flow vs. On-Off flow	• Requires modeling and testing
Materials Selection	• Refractory vs. high-alloy internals	• Engineering evaluation of options
Mechanical design	• Options to support internals	• Engineering evaluation of options
Particle removal performance	• Special features to minimize dust penetration • Standleg length/velocity • Outlet zone velocity • Media/dust feed ratio • Media size and shape	• All require modeling and testing

5. PRIORITIZED TRADEOFFS AND ISSUES

Table 3 lists the technical tradeoffs and issues identified and ranks them according to priority, with 1 being the highest priority, and 5 being the lowest. They are listed both as SMGBF module issues and SMGBF system issues, and they are ranked separately for each of these categories. The tradeoffs and issues listed in Tables 1 and 2 are identified as key if it potentially can lead to improved performance or economics, but not if it is just an academic exploration. The tradeoff or issue must also be of major importance at this point in the SMGBF development -- that is, for example, not all engineering design tradeoffs and issues that can be resolved by standard engineering evaluations are considered to be of high priority at this time. The tradeoffs and issues ranked as 1, 2 or 3 in Table 3 should be considered in the Option 1 Test Plan.

The key technical tradeoffs and issues are seen to be those related to module scaleup, optimization of the Once-Through pelletization process, the Recycle SMGBF system ash-granule separation and granule transport components, and the optimization of the particle removal performance of the SMGBF. Alternatives for resolving the tradeoffs and issues are also listed in Table 3, and are the basis for the development of the Option 1 Test Plan. Included are mathematical modeling, engineering evaluation, cold flow model testing, HTHP testing, laboratory testing and vendor testing. In many cases, multiple resolution options will need to be applied, and an appropriate balance of options, acceptable within the economic resources of the program, must be selected.

Table 3 - Prioritized List of Tradeoffs and Issues and Approaches to Resolve

Once-Through SMGBF

TRADEOFF/ISSUE	RANKING	RESOLUTION
Module Design		
• Scaleup to large capacity	1	• Mathematical modeling, • Cold flow unit probing.
• Improved particle removal features (skirt design, baffles, topping bed, fiber filter)	3	• Cold flow unit testing, • Engineering evaluation.
• Optimized pellet shape and size distribution.	3	• Mathematical modeling, • Cold flow unit testing, • HTHP testing.
System Design		
• System integration (layout, multiple modules, power plant integration)	5	• Engineering evaluation.
• Optimized pellet fabrication durability (size reduction, water and binder content, mixing, curing)	2	• Vendor tests, • Laboratory tests,
• Optimum pellet/ash ratio,	3	• Cold flow testing, • HTHP testing, • Mathematical modeling.
• Pellet environmental performance	3	• Laboratory testing, • Engineering evaluation.
• Pellet by-product use	5	• Laboratory testing, • Engineering evaluation.
• On Off pellet feed vs continuous	5	• Cold flow testing, • HTHP unit testing.

Table 3 - Prioritized List of Tradeoffs and Issues and Approaches to Resolve (Continued)

<u>Recycle SMGBF</u>

TRADEOFF/ISSUE	RANKING	RESOLUTION
<u>Module Design</u>		
• Scaleup (gas flow, pellet flow distribution)	1	• Mathematical modeling, • Cold flow unit probing.
• Improved particle removal features (skirt design, baffles, topping bed, fiber filter)	3	• Cold flow unit testing, • Engineering evaluation.
• Optimized granule shape and size distribution.	3	• Mathematical modeling, • Cold flow unit testing, • HTHP testing.
• Pneumatic transport feed of granules to SMGBF top bed	2	• Cold flow unit testing, • HTHP testing.
<u>System Design</u>		
• System integration (layout, multiple modules, power plant integration)	5	• Engineering evaluation.
• Ash-granule separation	2	• Engineering evaluation, • Cold flow test.
• Optimum granule/ash ratio	3	• Cold flow testing, • HTHP testing, • Mathematical modeling.
• Media circulation and flow flow control	3	• Cold flow testing, • Mathematical modeling.
• On-Off granule feed vs continuous	5	• Cold flow testing, • HTHP unit testing.

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