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# Development of a Candle Filter Failure Safeguard Device

Keywords: **Filter failure safeguard, Fiber, Barrier, Stop dust leak**

## INTRODUCTION

In IGCC or PFBC processes, gas filtration at elevated temperatures is utilized to separate particulates from a dirty gas stream. The cleaned gas is then used to fire a turbine. The particulates must be almost completely (<0.5 ppmw) removed in order to protect the turbine from erosion, as well as to meet environmental needs. The Siemens Westinghouse Power Corp. (SWPC) hot gas filter (HGF) design utilizes candles made from ceramic or metal alloys capable of withstanding the hot filtration conditions from 400 – 850 C and oxidative or reducing environments. In the event of a filter element (candle) failure, without backup protection, the turbine is exposed to erosion, downstream components are contaminated, and backpulsing plugs the clean side of intact elements. In order to minimize damage from filter element failures and unplanned outages, SWPC has provided a safeguard device (SGD or failsafe), whose objective is to plug with ash or char should an element, or elements, fail, and thus maintain safe operation of the plant. Field testing at the Power Systems Development Facility (PSDF) has shown that the original SWPC design did not always work effectively. Thus with DOE/NETL support we have conducted a 24 month program to develop an improved SGD. The program consists of a conceptual design phase, followed by bench-scale testing, optimization of the design and field-testing. In the program, Siemens Westinghouse developed a passive compact SGD, designed and configured as an independent component, which was located at the outlet of each candle element. This approach is preferred since:

- It provides maximum protection to all downstream components, including other operating, intact candle elements.
- It is maintainable, replaceable, and leads to the lowest cost alternative.

The following two SGD concept approaches were evaluated by initial screening and bench-scale testing:

- A unique, low-cost nested metal fiber design.
- A high-performance, barrier device fabricated as a ceramic or metal cross flow and as an inverted miniature array of metal candles.

Siemens Westinghouse worked with Specific Surface, CeraMem and Mott Corporation to design and supply the barrier SGD concepts.

## OBJECTIVE

The objective of the program was to develop an SGD which would essentially eliminate ash or char leakage. The quantitative target was arrived at based on detailed estimates of gas turbine and combustor performance degradation due to particle erosion and deposition. Table 1 summarizes results of turbine tolerance modeling and shows predicted operating times between water wash frequency needed to remove deposited particulate. An SGD capable of limiting particle leakage to <0.5 ppmw will be needed to achieve highest system availability, commensurate with annual maintenance outage. Our advanced SGD concepts were selected to achieve the goal of >16,000 hours cleaning interval.

Other objectives of the program are summarized in Table 2.

## APPROACH

The SWPC approach was to develop a passive compact SGD, designed and configured as an independent component located at the outlet of each candle filter element. This isolates a damaged or degraded filter element, or an element with leaking seals, from all downstream hardware and from the other properly functioning filter elements. Furthermore, each SGD can be individually cleaned or replaced leading to lower maintenance costs. Figure 1 illustrates the general SGD configuration.

An alternative configuration is to place a backup hot gas filter system in series with the primary hot gas filter system to provide protection for the gas turbine, and other downstream equipment, from primary filter system particulate leaks. Such a backup is not preferred because it will not prevent the internal components within the primary hot gas filter unit from being contaminated by particulate, leading to, for example, blinding of the clean-side of the undamaged filter elements. Occurrence of such “back side” blinding could in fact cause earlier shutdown (loss of availability) and unnecessary costs to replace an even larger number of otherwise undamaged candle elements.

Several other criteria were considered in our approach to the design of the SGD. These are explained below:

**Active vs. Passive SGD:**

Siemens Westinghouse chose a passive SGD approach, limiting the penetration of particulate by inherent phenomena that requires no leak detection or external device activation. A barrier filter SGD is an example of a passive SGD. The SGD could also be an active device, requiring some sort of leak detection, or leak triggering phenomena to automatically activate the SGD particulate penetration control. A valve activated by detecting a sudden increase in gas flow through the SGD is an example of an active SGD. Active devices such as valves will require grouping a relatively large number of candle elements per valve set. When activated, this will result in the removal from service of undamaged candle elements, resulting in higher operating pressure drops, more frequent cleaning, and the need to shut down sooner. Also, undamaged candle elements in the activated grouping will suffer backside blinding and will need to be replaced. The passive SGD is also favored because of greater reliability, expected less complex design and lower cost, and the possibility of active SGD being triggered in error.

**Maximum DP Criterion for SGD Screening:**

If PFBC and IGCC are both considered to be applications of equal interest, and if a single safeguard device design is to be developed for all applications, then the maximum pressure drop across the safeguard device should be based on PFBC applications. This is because PFBC has lower acceptable filter system pressure drop than IGCC applications, and PFBC is expected to operate with a greater gas volumetric flow per safeguard device than for IGCC.

The maximum PFBC filter system pressure drop in PFBC applications is normally specified to be about 35 kPa(5 psi), or lower, which is about 2.5% of the absolute gas inlet pressure to the filter vessel. At this maximum, or “trigger” pressure drop the “average” pressure drop across the filter vessel would be about 28 kPa(4 psi). The filter vessel pressure drop represents a direct efficiency penalty to the PFBC power plant and an increased cost-of-electricity factor, so it is important to keep it at an acceptable level. While arbitrary, a maximum safeguard device pressure drop contribution of 20% of the filter maximum pressure drop would seem to be reasonable. This criterion results in a maximum acceptable safeguard device pressure drop of about 7 kPa(1 psi), which corresponds to about 25% of the average filter vessel pressure drop. This maximum should correspond to the maximum volumetric flow expected through a standard 1.5-m candle in PFBC and, based on a 3 m/ min(10 ft/min) face velocity, the corresponding volumetric flow would be about 30 acfm. This criterion functioned to identify if a safeguard device was in the range of acceptability or if it required design modifications to approach acceptable pressure drop performance.

Vendor tests of the safeguard device and our own initial characterization tests were in air at room temperature and atmospheric pressure. Assuming that the safeguard device pressure drop is controlled by viscous losses, with inertial losses being negligible, the maximum pressure drop should be given by the ratio of the gas viscosity of air at room temperature to that of PFBC combustion gases at 843$^{o}$C (1550$^{o}$F):

DP (max) = 3 kPa(12 iwg) at an airflow of 30 scfm

Additional tests were performed (by the vendor and by STC) over a wide range of gas flows, to check on the inertial losses characteristic of the safeguard device. Inertial losses would result in higher safeguard device pressure drop in the actual, pressurized application than expected by the simple atmospheric pressure testing.

## PROJECT DESCRIPTION

Two principal types of SGDs were designed and evaluated in this program. They consisted of (a) low cost nested fiber impaction SGD and (b) a high performance barrier device fabricated as a ceramic or metal crossflow and as an inverted array of miniature metal candles. These are shown in Figure 2.

Description of the Concepts and Preliminary Screening:

The nested fiber SGD may be termed an impaction device. In impaction-type SGDs, a bed or layer of impact targets, or obstructions – such as a bed of fibers, pellets, or set of screens – having relatively large flow passages are used to initiate the accumulation of particulate primarily by impaction and sticking on these flow obstructions. Particle interception, diffusion, gravity, and back-pulse settling, also contribute to particle removal. The pressure drop across the clean impact-type SGD has both viscous and inertial contributions. While this type of SGD can have a considerably lower gas pressure drop than the barrier filter SGDs, the penetration of particulate may be initially higher, dropping off only as a significant amount of particulate accumulates within the device, increasing collection efficiency. As the flow resistance across the SGD increases with continued particulate accumulation, the gas flow through the SGD will be considerably reduced. Two types of fibers, coarse, 0.57 mm, and fine, 0.10 mm, were investigated. The fibers were packaged within standard SWPC SGD packages so they could be easily tested in the field as well as in the laboratory. The nested fiber SGD is shown in Figure 3.

The cross flow, honeycomb structure was made of porous metal or ceramic that is permeable for gas but impermeable for particulates. Adjacent channels are alternately sealed at opposing ends to create the cross flow path. In the unactivated condition, sufficient surface area and material permeability are required for low pressure drop. In the event of filter element or gasket failure, particulate would plug the upstream channels. Back pulsing may partially dislodge channels, but since it is a barrier device, leakage of particulate to the clean side would not occur. An initial study was made to develop a SGD cross flow design that would project a 7 kPa (1 psi) differential pressure (20 percent of the filter vessel maximum pressure drop) at 843°C (1550°F), 1050kPa(150 psi), and 3m (10 feet) per minute face velocity (30 acfm volumetric flow). Based on permeability testing at the STC site as well as the vendors, a satisfactory design was obtained which could be packaged for testing at the STC high temperature high pressure facility, and could also be retrofit into our hot gas filter (PCD) at the PSDF, for field testing. These were cylindrical units 152 mm(6”) long, 67 mm(2.65”) diameter with 4mm x 4mm channels and 1 mm wall thickness. Such test units from Specific Surface with integral channel plugs, and from CeraMem are shown in Figures 4 and 5, respectively.

A test version of the inverted array metal barrier filter made from 316 stainless steel is shown in Figure 2. After some iterations with the manufacturer an acceptable wall thickness/pore size combination was determined. This would have required a 7” length making it impractical, but not impossible, for retrofitting, so the test article was carried forward to bench scale testing. All ceramic barrier units tested during the bench scale tests were equipped with thermal regenerators, in order to protect them from thermal shock.

Bench Scale Testing Experimental Approach:

The experimental method utilized in this program included “bench scale” testing of safeguard devices (SGDs) utilizing the DOE/NETL three candle array hot gas filter test facility and the Siemens Westinghouse 4 and 15 candle plenum hardware.

In the DOE/NETL three-candle array facility, SGD testing was targeted to:

1. Focus on the catastrophic failure scenario, i.e., 33 percent candle failures. Transient performance (time to activate and close down) of the SGD device is considered critical in such circumstances.
2. Qualify fixturing and gasketing of the SGDs.

Table 3 presents test arrangements, conditions and exposures for tests conducted at NETL. All NETL tests were conducted at 70 psig with a single plenum, three candle arrangement with two intact candles and with the SGD device fitted to the third candle position. This simulated a 33 percent catastrophic failure during dust feeding.

Attempts were made to measure outlet dust concentration using a laser-based sensor. The resultant data was very scattered and often inconclusive. Attempts were made to measure the speed and extent of flow reduction from pluggage using a flow pipe and pressure taps across the SGD. It was hoped to also measure resistance to unplugging during back pulsing in this manner. Absence of flow could be detected but high residual dust levels made trending of flow for SGD performance evaluation impossible.

The Siemens Westinghouse STC hot gas filter facility is a PFBC simulator. Four and 15-candle plenum hardware was used in this test program to test normal failures (from 20% to 7% of elements failing). The scope of STC testing was targeted to take the best advantage of what was learned from the NETL testing. That is:

1. "Normal" operation (no failed candles) testing was not needed because NETL testing had already qualified the fixturing and gasketing of the SGDs.
2. "Catastrophic" operation tests (high percentage of failed candles) were added to the scope of STC tests because demonstration of performance under such conditions was not confirmed at NETL.
3. "Nominal" operation tests (low percentage of failed candles) were retained in the scope of STC tests.

Table 4 presents test arrangements, conditions and exposures conducted at STC.

Outlet dust concentration readings were determined by withdrawing a gas sample, passing it through a filter to collect the dust, measuring the amount of dust gravimetrically (by weight change) and measuring the amount of gas using a dry test meter. Dust concentrations were then reported in parts per million by weight. The speed and extent of flow reduction from plugging was determined using a flow pipe and pressure taps across the SGD. Resistance to unplugging during back pulsing was also assessed in this manner.

## RESULTS

### NETL Testing

A metal honeycomb SGD was the first unit to be exposed to dust laden hot gas at NETL, followed by a SiC honeycomb SGD, both from Specific Surface. Higher than expected pressure drops prior to feeding of fines for the barrier SGDs were attributed to residual ash causing early activation. Trending of decreasing flow was, therefore, not possible. Inspection of gasketing following testing confirmed that gaskets and fixturing were effective in preventing any by-pass leakage of fines. Subsequent testing at STC provided additional evidence that residual fines were the probable cause of early SGD activation (i.e. such early activation did not occur at STC with essentially identically gasketed units). Pressure drop measurements of the units suggested that they plugged completely and effectively prevented the passage of fines. Table 5 shows differential pressure measurements before and after NETL exposures for the two honeycomb units. When removed from their hardware, it was found that both units were fractured, indicating that they were susceptible to thermal fatigue failure, even though they were exposed to a limited number of cycles.

The inverted filter SGD tested at NETL showed high-pressure drop upon exposure to flow and prior to feeding of fines. The unit was cut open and found to have one cracked filter tube. The cracking occurred adjacent to the weld joining the tube to the tubesheet. The unit was ultrasonically cleaned in water. Original permeability was not recovered by the cleaning operation. Metallographic inspection of the tube indicated that the pores were blinded with material on the interior surface of the tube. Detailed inspection of the structure indicated that fines were absent in the media but that considerable oxidation was present. Such premature blinding evidently limits the usefulness of this SGD design. Cracking adjacent to filter tube welds pointed to an additional manufacturing issue. Further testing of this type of SGD was discontinued.

A coarse fiber ( 0.57 mm (0.022")) SGD containing type 310 stainless steel fibers was exposed at NETL. Slight passage of fines was detected but could not be quantified. Flow decreased to a low value over a period of approximately twenty minutes. Backpulsing did not cause significant dislodging of fines from the SGD. An alloy 214 fine fiber ( 0.10 mm (0.004")) SGD was exposed at NETL. A fairly low flow was noted from the start of testing. Upon feeding of fines very low flow was noted. Very few fines could be detected at the outlet throughout the test. The qualitative conclusion from coarse and fine fiber testing at NETL is that the fine fiber SGD demonstrated superior control to limit passage of ash fines.

### STC Testing

The first two tests at STC (Table 4) used a configuration of three intact candles and one broken candle to simulate a 25% “catastrophic” failure. In the first test a 316 stainless steel honeycomb SGD (Specific Surface) was placed above the broken candle. It stopped dust leakage after a brief initial period, but when the unit was removed from test it was found that the unit had burned and melted in its interior, possibly due to a brief collection of combustible material during start-up. In light of the fragile structure of the stainless steel honeycomb unit noted in earlier NETL testing and the susceptibility of the unit to burning noted above, additional testing of stainless honeycomb was discontinued. It is possible that improved manufacturing and alternate material selection may overcome the limitations noted for such units in this test program.

The SiC honeycomb barrier SGD (Specific Surface) was tested next, with a thermal regenerator. It plugged rapidly in less than one pulse cycle. Outlet dust concentration was below our detectable baseline. Flow through the SGD decreased rapidly and was stopped in 15 minutes and the plugging was resistant to accelerated pulsing. Unfortunately, post-test inspection indicated numerous cracks in the SGD. With positive performance in terms of dust control but with evidence of a less than robust structure, this unit was identified for further development. Specific Surface was encouraged to provide more rugged units by recrystallizing SiC and/or by heat treating the sintered SiC to remove silica bonds between grains and to rebond by vapor deposition of SiC.

The next series of tests (Nos. 3,4 and 5) at STC involved testing of various alloy (310, 214 and FeCrAlY) fiber SGDs with a single plenum, fifteen candle arrangement. Each test included fourteen intact candles and with the one fiber SGD fitted to the fifteenth candle position. This simulated a seven percent 'nominal' failure during dust feeding. Flow decreased abruptly and was virtually stopped within several minutes. Furthermore, the pluggage was resistant to accelerated back pulsing. Low flow readings during dust feeding were observed for all fiber tests.

While the activated fiber SGDs stopped flow, outlet dust concentrations were not always insignificant. In particular, the coarse fiber device showed readings in the range of 75 to 185 ppmw. With repeated cycles of dust feeding, the coarse fiber device continued to display ineffective dust control. On the other hand, both fine fiber devices showed dust control to levels of the order of 6 to 15 ppmw. Nonetheless the dust control was far superior to the first generation SWPC SGD which used screens and Raschig rings to capture dust and plug after a filter break. This is shown in Figure 6 for a fine fiber SGD.

Therefore we concluded that while fiber devices quickly and effectively block flow, dust continues to permeate through the coarse fiber bed. Fine fiber beds, on the other hand, control dust to relatively low levels. Fiber of 0.10 mm (0.004") diameter is effective in preventing dust passage while fiber of 0.57 mm (0.022") is ineffective. Since the fiber devices are low cost, have low operating pressure drops and show effective flow control, ten units were fabricated and sent to the PSDF for field testing.

A variety of materials were exposed in gasification and oxidation conditions to assess the long-term durability of different fiber alloys for SGD application. Gasification exposure at the PSDF totaled 1000 hours at temperatures up to 593C (1100F). Oxidation exposure in an STC furnace totaled 6500 hours at 843C (1550F).

Metallographic examinations of cross sections of exposed and unexposed fibers provided quantitative evaluation of the depth of corrosive attack. Both alloys 160 (UNS No. N12160) and 310 (UNS No. S31008) showed excellent resistance to attack in gasification conditions with no measurable attack. For oxidation exposure, alloys 310 (UNS No. S31008) and 230 (UNS No.

N06230) showed relatively large attack (20 and 25 microns respectively) while alloys 214 (UNS No. N07214) and FeCrAlY showed little attack (3 and 2 microns respectively).

Specific Surface developed two new structures for improved thermal shock resistance. The first was essentially a new material structure incorporating non-oxide bonds between particles. The second enhanced thermal conductivity from recrystallizing the silicon carbide at $2450^0$C ($4440^0$F). The Specific Surface units do not require cement for plugging the alternate channels but are fabricated with plugs integral to their body, as shown in Figure 4. Ceramem Corporation developed their own silicon carbide honeycomb utillizing two different cements for plugging alternate channels. Units that they provided for testing are shown in Figure 5.

In STC Test 6 two units from Specific Surface Corporation (Specific Surface New Material and Specific Surface Fully Recrystallized) were installed over intact candle filters. Two units from CeraMem were installed - one over an intact candle filter and one over a missing candle filter. Nine additional filter positions were candled with conventional failsafes to simulate an approximate 8% failure scenario. All honeycomb units were outfitted with Raschig Ring heat exchangers (regenerators). After approximately 31 hours of exposure to dust and backpulsing the units were removed from their hardware. All honeycomb units (both from Specific Surface Corporation and from CeraMem Corporation) showed resilience to backpulsing - that is, no damage was noted. Periodic dust sampling of five-minute duration showed that the unit from CeraMem (BF4) that was activated (positioned over a missing candle filter) plugged rapidly and completely upon feeding of ash dust. Differential pressure readings over a flow tube leading to the unit, Figure 7, showed that the unit terminated flow within a few minutes of dust feed and did not unplug during backpulsing at any time during the testing. Final permeability testing of this unit showed that this honeycomb device remained totally plugged after all testing was complete.

The longer-term durability of the silicon carbide units was assessed in STC Test 7 by accelerated pulsing at $650^0$C ($1200^0$F). This temperature was selected after discussion with DOE-COR and consideration that most near-term applications would be in gasification conditions where temperatures would be limited to 370 - - $480^0$C (700 - $900^0$F). Two units from Specific Surface Corporation were installed over intact candle filters. One unit from CeraMem was installed over an intact candle filter. One additional filter position was candled with a conventional failsafe. After exposure to 1024 accelerated pulses, the units were disassembled and examined. All three units sustained the exposure without any evidence of damage. Honeycomb barrier safe guard devices made of silicon carbide from CeraMem and from Specific Surface (fully recrystallized or new material) are durable, provide excellent dust control and therefore will be field tested at the PSDF.

## CONCLUSIONS

Testing at NETL included inverted metal barrier filter, honeycomb barrier and fiber devices and provided the following conclusions:

1. Gaskets and fixturing for all SGDs were effective in preventing any by-pass leakage of fines.
2. The inverted metal barrier filter SGD blinded prematurely and permeability could not be recovered.
3. Honeycomb SGDs plugged completely upon exposure to fines.
4. Cracking of metal and ceramic honeycomb SGDs was attributed to manufacturing defects and fragile construction respectively.

5.The fine fiber SGD activated more quickly than the coarse fiber SGD upon exposure to fines.

Testing at STC included “catastrophic” and “nominal” filter failure conditions of both honeycomb and fiber SGDs and provided the following conclusions:
1. The metal honeycomb SGD was damaged in service – probably as a result of fuel burning.
2. The ceramic honeycomb SGD plugged effectively upon exposure to fines but damage in service confirmed fragile construction as noted in (4) above.
3. Fine fiber of 0.10mm diameter is effective in preventing dust passage in a SGD while coarse fiber of 0.57mm diameter is ineffective.
4. Testing of improved ceramic honeycomb SGDs included silicon carbide units from two manufacturers and provided the following conclusions:
    a. The units are durable up to service temperatures of 650$^o$C
    b. The units plug rapidly upon exposure to fines and do not unplug upon backpulsing.

Material exposure tests at the PSDF and at STC provided the following conclusions for selection of fibers for the fiber failsafes:
1. Alloys 160 and 310 are resistant to gasification attack.
2. Alloys 214 and FeCrAlY are superior in oxidation resistance to alloys 310 and 230.

## FUTURE ACTIVITIES

Eight of the CeraMem SGDs and two of the Specific Surface recrystallized SGDs were packaged for retrofit into PCD 301 at the PSDF for field testing. Currently one of each type is being exposed to gasification and has had 300 hours of exposure. In the next test run they will be tested for dust blockage. The other units will be installed above good candles for gas exposure.

## ACKNOWLEDGEMENT

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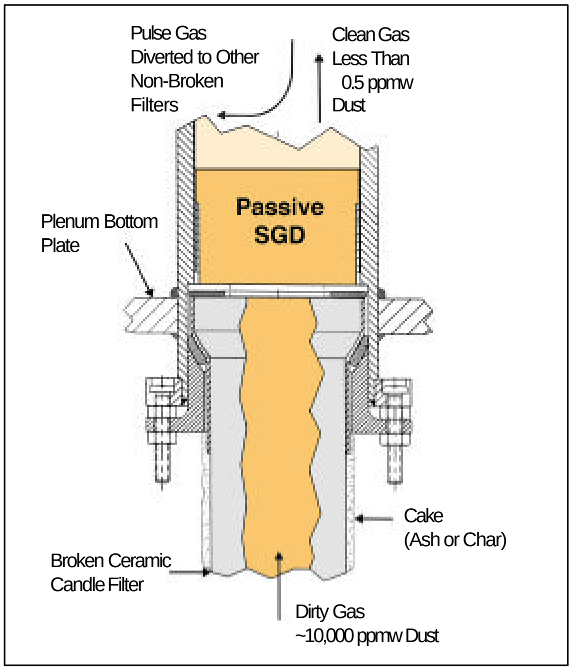

**Figure 1 – Representation of Siemens Westinghouse SGD**

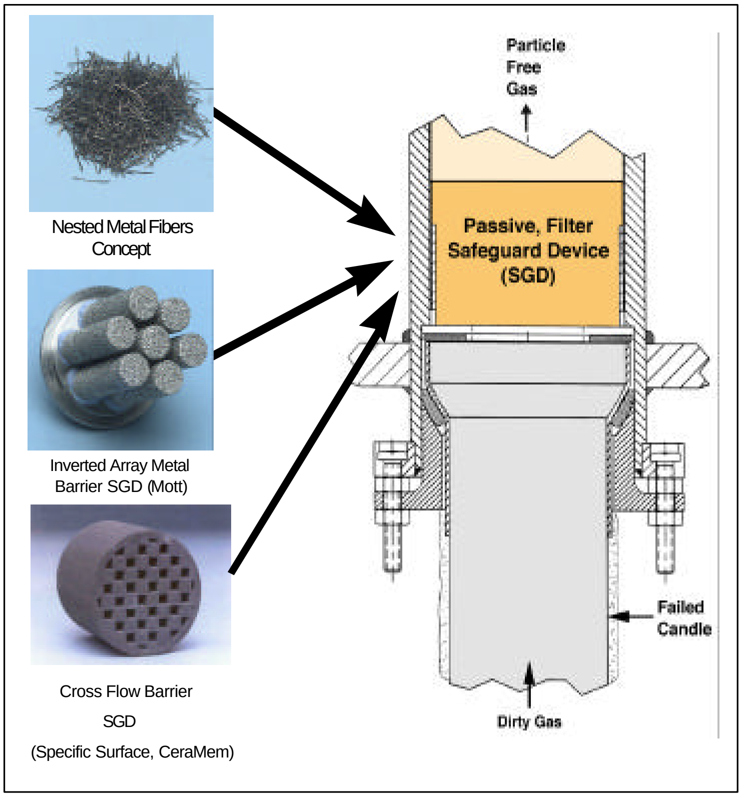

**Figure 2: Types of SGDs investigated in the program**

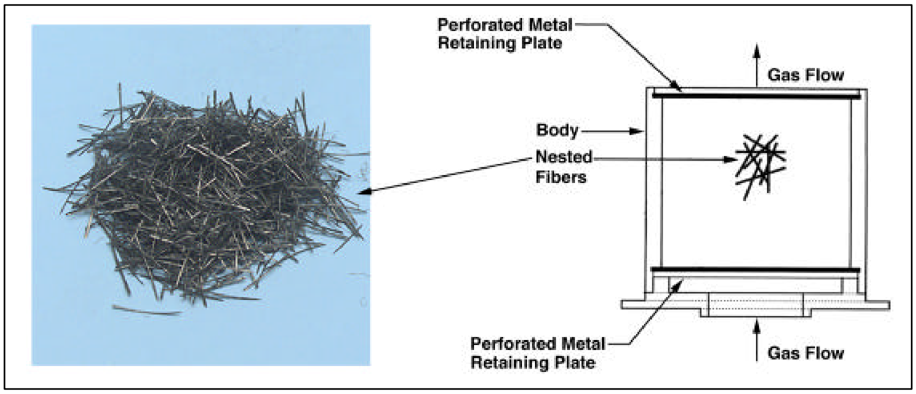

**Figure 3: Nested Fiber SGD as packaged within a standard SWPC SGD configuration**

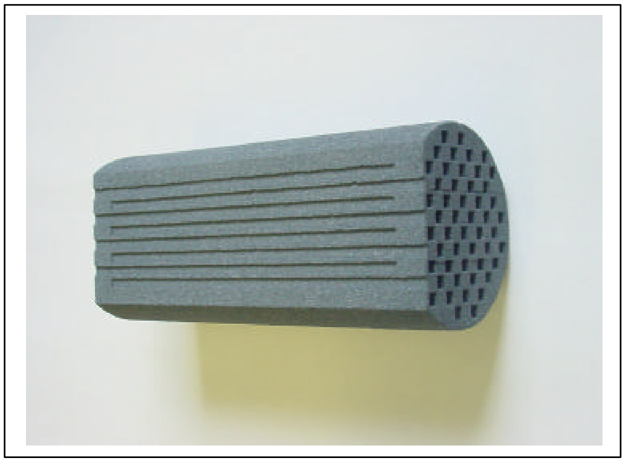

**Figure 4 – Cross Section of Specific Surface SGD Showing Integral Channel Plugs**

**Figure 5 – CeraMem Silicon Carbide Honeycomb SGDs for Optimization Testing**

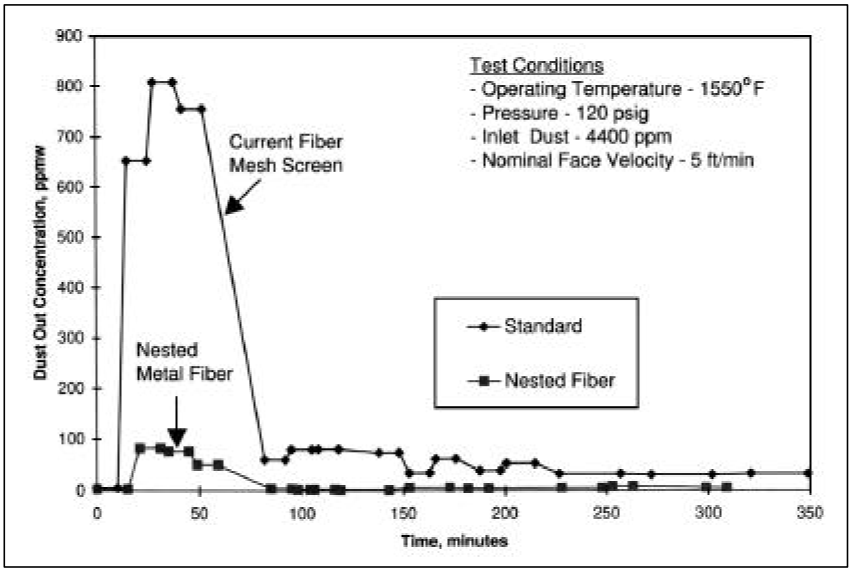

Figure 6 – Comparison of Standard Fine Mesh and Nested Fiber SGD

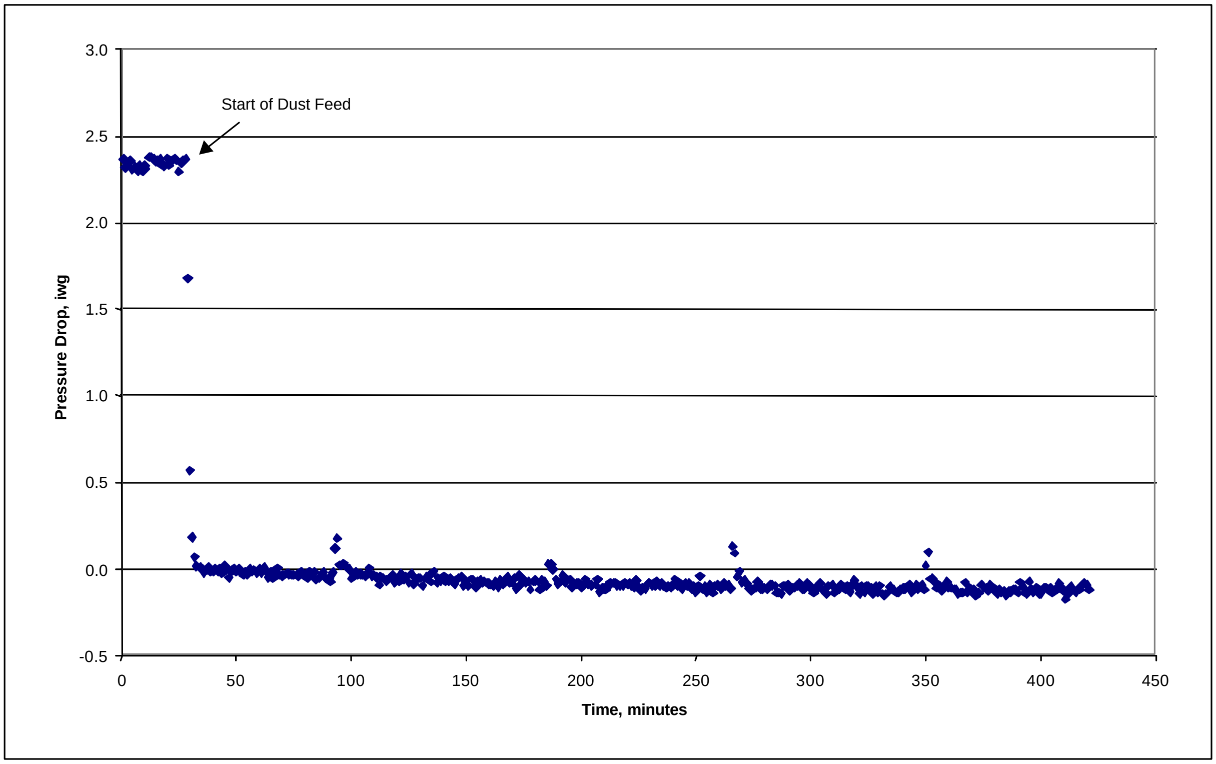

Figure 7 – Flowtube DP during Test of SiC Honeycomb SGD

### Table 1 – Summary of Turbine Tolerance to Particle Deposition

| Hot Gas Filter Leak | IGCC | PFBC | APCFB | SGD Technology |
|---|---|---|---|---|
| 1000 ppmw | 80 hours | 200 hours | 80 hours | No SGD |
| 5 ppmw | 1600 hours | 2300 hours | 1600 hours | Today’s SGD |
| 0.5 ppmw | >16,000 hours | >16,000 hours | >16,000 hours | Future SGD |

### Table 2 – SGD Technical and Application Requirements

| Technical and Application Requirements | Selected Approach or Parameter Values | How Addressed in SGD Program |
|---|---|---|
| Device Configuration | Per Candle as Preferred Solution | Not Varied, See Below |
| Active vs. Passive | Passive as Preferred Solution | Not Varied, See Below |
| Pressure Drop and Gas Flow Capacity | 20% of HGF Maximum DP<br>10 to 100 acfm | Bench-Scale Testing |
| Particle Removal and Response Time (Maintained Over Repeated Cleaning Cycles) | <0.5 ppmw leak | Bench-Scale Testing |
| Fixturing and Gaskets | Reliable, Stable and No Leaks | Bench-Scale Testing and Pilot Plant Exposure |
| Effective Operating Life and Gas Environment | >3 years<br>Reducing 650$^{o}$C (IGCC)<br>Oxidizing, 870$^{o}$C (APCFB) | Material Exposure in Operating Pilot Plants (PSDF) and laboratory furnace |
| Change-Out | Quick, No Extension of Maintenance Period | Pilot Plant Experience |
| Retrofit/New Installations (Reusable) | Meet Physical Constraints<br>76 mm(3”) long and 67mm(2.65”) OD (Retrofit)<br><304mm(12”) long and 67mm(2.65”) OD (New) | Design Phase, Demonstrated in Pilot Plant Testing |

**Table 3 – NETL Test Arrangements, Conditions and Exposures**

| Test No. | SGD Device | Plenums / Candle Pos. | Temp. $^0$C ($^0$F) |
|---|---|---|---|
| 1 | 316 SS Honeycomb | 1/3 | 816 (1500) |
| 2 | Inverted Metal Filter | 1/3 | 816 (1500) |
| 3 | SiC Honeycomb | 1/3 | 816 (1500) |
| 4 | Coarse 310 Fiber | 1/3 | 816 (1500) |
| 5 | Fine 214 Fiber | 1/3 | 816 (1500) |

**Table 4 – STC Test Arrangements, Conditions and Exposures**

| Test No. | SGD Device | Plenums / Candle Pos. | Temp. $^0$C ($^0$F) | Pressure psig | Dust Feed Cycles | Dust Feed Time (hrs) | No. Accelerate Pulses |
|---|---|---|---|---|---|---|---|
| 1 | 316 SS Honeycomb | 2/4 | 816 (1500) | 150 | 15 | 10.6 | 110 |
| 2 | SiC Honeycomb | 2/4 | 816 (1500) | 150 | 21 | 10.9 | 221 |
| 3 | Coarse 310 Fiber | 1/15 | 816 (1500) | 88 | 5 | 6.4 | 690 |
| 4 | Fine 214 Fiber | 1/15 | 816 (1500) | 88 | 9 | 15.3 | 741 |
| 5 | Fine FeCrAlY Fiber | 1/15 | 816 (1500) | 88 | 11 | 13.6 | 817 |
| 6 | 4 Ceramic Honeycomb | 1/13 | 816 (1500) | 98 | 21 | 31.4 | 0 |
| 7 | 3 Ceramic Honeycomb | 2/4 | 649 (1200) | 132 | 0 | 0 | 1024 |

**Table 5 – 316 SS and SiC SGDs Exposed at NETL**

| Unit / Condition | Differential Pressure (iwg @ X scfm) |
|---|---|
| 316 SS / Before Exposure | 9.8 @ 24.6 |
| 316 SS After Exposure | 194 @ 27.9 |
| SiC / Before Exposure | 8 @ 31 |
| SiC / After Exposure | 62.4 @ 15 |